3RD EDITION

THE BOOK OF PF

A NO-NONSENSE GUIDE TO THE OPENBSD FIREWALL

PETER N.M. HANSTEEN

no starch press

PRAISE FOR *THE BOOK OF PF*

"The definitive hardcopy guide to deployment and configuration of PF firewalls, written in clear, exacting style. Its coverage is outstanding."
—Chad Perrin, Tech Republic

"This book is for everyone who uses PF. Regardless of operating system and skill level, this book will teach you something new and interesting."
—BSD Magazine

"With Mr. Hansteen paying close attention to important topics like state inspection, SPAM, black/grey listing, and many others, this must-have reference for BSD users can go a long way to helping you fine-tune the who/what/where/when/how of access control on your BSD box."
—InfoWorld

"A must-have resource for anyone who deals with firewall configurations. If you've heard good things about PF and have been thinking of giving it a go, this book is definitely for you. Start at the beginning and before you know it you'll be through the book and quite the PF guru. Even if you're already a PF guru, this is still a good book to keep on the shelf to refer to in thorny situations or to lend to colleagues."
—Dru Lavigne, author of *BSD Hacks* and *The Definitive Guide to PC-BSD*

"The book is a great resource and has me eager to rewrite my aging rulesets."
—;login:

"This book is a super easy read. I loved it! This book easily makes my Top 5 Books list."
—Daemon News

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A No-Nonsense Guide to the OpenBSD Firewall

by Peter N.M. Hansteen

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To Gene Scharmann,
who all those years ago nudged me
in the direction of free software

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FOREWORD
from the first edition

OpenBSD's PF packet filter has enjoyed a lot of success and attention since it was first released in OpenBSD 3.0 in late 2001. While you'll find out more about PF's history in this book, in a nutshell, PF happened because it was needed by the developers and users of OpenBSD. Since the original release, PF has evolved greatly and has become the most powerful free tool available for firewalling, load balancing, and traffic managing. When PF is combined with CARP and pfsync, PF lets system administrators not only protect their services from attack, but it makes those services more reliable by allowing for redundancy, and it makes them faster by scaling them using pools of servers managed through PF and relayd.

While I have been involved with PF's development, I am first and foremost a large-scale user of PF. I use PF for security, to manage threats both internal and external, and to help me run large pieces of critical infrastructure in a redundant and scalable manner. This saves my employer

(the University of Alberta, where I wear the head sysadmin hat by day) money, both in terms of downtime and in terms of hardware and software. You can use PF to do the same.

With these features comes the necessary evil of complexity. For someone well versed in TCP/IP and OpenBSD, PF's system documentation is quite extensive and usable all on its own. But in spite of extensive examples in the system documentation, it is never quite possible to put all the things you can do with PF and its related set of tools front and center without making the system documentation so large that it ceases to be useful for those experienced people who need to use it as a reference.

This book bridges the gap. If you are a relative newcomer, it can get you up to speed on OpenBSD and PF. If you are a more experienced user, this book can show you some examples of the more complex applications that help people with problems beyond the scope of the typical. For several years, Peter N.M. Hansteen has been an excellent resource for people learning how to apply PF in more than just the "How do I make a firewall?" sense, and this book extends his tradition of sharing that knowledge with others. Firewalls are now ubiquitous enough that most people have one, or several. But this book is not simply about building a firewall, it is about learning techniques for manipulating your network traffic and understanding those techniques enough to make your life as a system and network administrator a lot easier. A simple firewall is easy to build or buy off the shelf, but a firewall you can live with and manage yourself is somewhat more complex. This book goes a long way toward flattening out the learning curve and getting you thinking not only about how to build a firewall, but how PF works and where its strengths can help you. This book is an investment to save you time. It will get you up and running the right way—faster, with fewer false starts and less time experimenting.

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Director, The OpenBSD Foundation
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Edmonton, Alberta, Canada

ACKNOWLEDGMENTS

This manuscript started out as a user group lecture, first presented at the January 27, 2005 meeting of the Bergen [BSD and] Linux User Group (BLUG). After I had translated the manuscript into English and expanded it slightly, Greg Lehey suggested that I should stretch it a little further and present it as a half day tutorial for the AUUG 2005 conference. After a series of tutorial revisions, I finally started working on what was to become the book version in early 2007.

The next two paragraphs are salvaged from the tutorial manuscript and still apply to this book:

> This manuscript is a slightly further developed version of a manuscript prepared for a lecture which was announced as (translated from Norwegian):
>
> "This lecture is about firewalls and related functions, with examples from real life with the OpenBSD project's PF (Packet Filter). PF offers firewalling, NAT, traffic control, and bandwidth management in a single, flexible, and sysadmin-friendly system. Peter hopes that the lecture will give you some ideas about how

to control your network traffic the way you want—keeping some things outside your network, directing traffic to specified hosts or services, and of course, giving spammers a hard time."

Some portions of content from the tutorial (and certainly all the really useful topics) made it into this book in some form. People who have offered significant and useful input regarding early versions of this manuscript include Eystein Roll Aarseth, David Snyder, Peter Postma, Henrik Kramshøj, Vegard Engen, Greg Lehey, Ian Darwin, Daniel Hartmeier, Mark Uemura, Hallvor Engen, and probably a few who will remain lost in my mail archive until I can `grep` them out of there.

I would like to thank the following organizations for their kind support: the NUUG Foundation for a travel grant, which partly financed my AUUG 2005 appearance; the AUUG, UKUUG, SANE, BSDCan, AsiaBSDCon, NUUG, BLUG and BSD-DK organizations for inviting me to speak at their events; and the FreeBSD Foundation for sponsoring my trips to BSDCan 2006 and EuroBSDCon 2006.

Much like the first, the second edition was written mainly at night and on weekends, as well as during other stolen moments at odd hours. I would like to thank my former colleagues at FreeCode for easing the load for a while by allowing me some chunks of time to work on the second edition in between other projects during the early months of 2010. I would also like to thank several customers, who have asked that their names not be published, for their interesting and challenging projects, which inspired some of the configurations offered here. You know who you are.

The reason this third edition exists is that OpenBSD 5.5 introduced a new traffic shaping system that replaced ALTQ. Fortunately Bill Pollock and his team at No Starch Press agreed that this new functionality combined with several other improvements since the second edition were adequate reason to start work on the third edition during the second half of 2013.

Finally, during the process of turning the manuscript into a book, several people did amazing things that helped this book become a lot better. I am indebted to Bill Pollock and Adam Wright for excellent developmental editing; I would like to thank Henning Brauer for excellent technical review; heartfelt thanks go to Eystein Roll Aarseth, Jakob Breivik Grimstveit, Hallvor Engen, Christer Solskogen, Ian Darwin, Jeff Martin, and Lars Noodén for valuable input on various parts of the manuscript; and, finally, warm thanks to Megan Dunchak and Linda Recktenwald for their efforts in getting the first edition of the book into its final shape and to Serena Yang for guiding the second and third editions to completion. Special thanks are due to Dru Lavigne for making the introductions which led to this book getting written in the first place, instead of just hanging around as an online tutorial and occasional conference material.

Last but not least, I would like to thank my dear wife, Birthe, and my daughter, Nora, for all their love and support, before and during the book writing process as well as throughout the rather intense work periods that yielded the second and edition. This would not have been possible without you.

INTRODUCTION

This is a book about building the network you need. We'll dip into the topics of firewalls and related functions, starting from a little theory. You'll see plenty of examples of filtering and other ways to direct network traffic. I'll assume that you have a basic to intermediate command of TCP/IP networking concepts and Unix administration.

All the information in this book comes with a warning: As in many endeavors, the solutions we discuss can be done in more than one way. And, of course, the software world is always changing and the best way to do things may have changed since this book was printed. This book was tested with OpenBSD version 5.6, FreeBSD 10.0, and NetBSD 6.1, and any patches available in late July 2014.

This Is Not a HOWTO

The book is a direct descendant of my popular PF tutorial, and the third edition of the manuscript in book form. With all the work that's gone into making this book a useful one over the years, I am fairly confident you will find it useful, and I hope you will find it an enjoyable read, too. But please keep in mind that this document is not intended as a precooked recipe for cutting and pasting.

Just to hammer this in, repeat after me:

```
//The Pledge of the Network Admin//

This is my network.

It is mine,
or technically, my employer's.
It is my responsibility,
and I care for it with all my heart.

There are many other networks a lot like mine,

but none are just like it.

I solemnly swear

that I will not mindlessly paste from HOWTOs.
```

The point is that while I have tested all of the configurations in this book, they're almost certainly at least a little wrong for your network as written. Please keep in mind that this book is intended to show you a few useful techniques and inspire you to achieve good things.

Strive to understand your network and what you need to do to make it better and please do not paste blindly from this document or any other.

What This Book Covers

The book is intended to be a stand-alone document to enable you to work on your machines with only short forays into man pages and occasional reference to the online and printed resources listed in Appendix A.

Your system probably comes with a prewritten *pf.conf* file containing some commented-out suggestions for useful configurations, as well as a few examples in the documentation directories such as */usr/share/pf/*. These examples are useful as a reference, but we won't use them directly in this book. Instead, you'll learn how to construct a *pf.conf* from scratch, step by step.

Here is a brief rundown of what you will find in this book:

- Chapter 1, "Building the Network You Need," walks through basic networking concepts, gives a short overview of PF's history, and provides

some pointers on how to adjust to the BSD way if you are new to this family of operating systems. Read this chapter first to get a sense of how to work with BSD systems.

- Chapter 2, "PF Configuration Basics," shows how to enable PF on your system and covers a very basic rule set for a single machine. This chapter is fairly crucial, since all the later configurations are based on the one we build here.
- Chapter 3, "Into the Real World," builds on the single-machine configuration in Chapter 2 and leads you through the basics of setting up a gateway to serve as a point of contact between separate networks. By the end of Chapter 3, you will have built a configuration that is fairly typical for a home or small office network, and have some tricks up your sleeve to make network management easier. You'll also get an early taste of how to handle services with odd requirements such as FTP, as well as some tips on how to make your network troubleshooting-friendly by catering to some of the frequently less understood Internet protocols and services.
- Chapter 4, "Wireless Networks Made Easy," walks you through adding wireless networking to your setup. The wireless environment presents some security challenges, and by the end of this chapter, you may find yourself with a wireless network with access control and authentication via `authpf`. Some of the information is likely to be useful in wired environments, too.
- Chapter 5, "Bigger or Trickier Networks," tackles the situation where you introduce servers and services that need to be accessible from outside your own network. By the end of this chapter, you may have a network with one or several separate subnets and DMZs, and you will have tried your hand at a couple of different load-balancing schemes via redirections and `relayd` in order to improve service quality for your users.
- Chapter 6, "Turning the Tables for Proactive Defense," introduces some of the tools in the PF tool chest for dealing with attempts at undesirable activity, and shows how to use them productively. We deal with brute-force password-guessing attempts and other network flooding, as well as the antispam tool `spamd`, the OpenBSD spam deferral daemon. This chapter should make your network a more pleasant one for legitimate users and less welcoming to those with less than good intentions.
- Chapter 7, "Traffic Shaping with Queues," introduces traffic shaping via the priorities and queues systems introduced in OpenBSD 5.5. This chapter also contains tips on how to convert earlier ALTQ-based setups to the new system, as well as information on setting up and maintaining ALTQ on operating systems where the newer queueing system is not available. This chapter should leave you with better resource utilization by adapting traffic shaping to your network needs.

- Chapter 8, “Redundancy and Resource Availability,” shows how to create redundant configurations, with CARP configurations for both failover and load balancing. This chapter should give you insight into how to create and maintain a highly available, redundant, CARP-based configuration.
- Chapter 9, “Logging, Monitoring, and Statistics,” explains PF logs. You’ll learn how to extract and process log and statistics data from your PF configuration with tools in the base system as well as optional packages. We’ll also discuss NetFlow and SNMP-based tools.
- Chapter 10, “Getting Your Setup Just Right,” walks through various options that will help you tune your setup. It ties together the knowledge you have gained from the previous chapters with a rule set debugging tutorial.
- Appendix A, “Resources,” is an annotated list of print and online literature and other resources you may find useful as you expand your knowledge of PF and networking topics.
- Appendix B, “A Note on Hardware Support,” gives an overview of some of the issues involved in creating a first-rate tool as free software.

Each chapter in this book builds on the previous one. While as a free being you can certainly skip around, it may be useful to read through chapters in sequence.

For a number of reasons, OpenBSD is my favorite operating system. My main environment for writing this book is dominated by OpenBSD systems running either recent snapshots, the odd -stable system and every now and then a locally built -current. This means that the main perspective in the book is the world as seen from the command line in OpenBSD 5.6. However, I keep enough of the other BSDs around that this book should be useful even if your choice of platform is FreeBSD, NetBSD or DragonFly BSD. There are areas of network configuration and PF setup where those systems are noticeably different from the OpenBSD baseline, and in those cases you will find notes on the differences as well as platform-specific advice on how to build a useful configuration for your environment.

1

BUILDING THE NETWORK YOU NEED

PF, the OpenBSD *Packet Filter subsystem*, is in my opinion the finest tool available for taking control of your network. Before diving into the specifics of how to make your network the fine-tuned machinery of your dreams, please read this chapter. It introduces basic networking terminology and concepts, provides some PF history, and gives you an overview of what you can expect to find in this book.

Your Network: High Performance, Low Maintenance, and Secure

If this heading accurately describes your network, you're most likely reading this book for pure entertainment, and I hope you'll enjoy the rest of it.

If, on the other hand, you're still learning how to build networks or you're not quite confident of your skills yet, a short recap of basic network security concepts can be useful.

Information technology (IT) security is a large, complex, and sometimes confusing subject. Even if we limit ourselves to thinking only in terms of network security, it may seem that we haven't narrowed down the field much or eliminated enough of the inherently confusing terminology. Matters became significantly worse some years ago when personal computers started joining the networked world, equipped with system software and applications that clearly weren't designed for a networked environment.

The result was predictable. Even before the small computers became networked, they'd become home to malicious software, such as *viruses* (semiautonomous software that is able to "infect" other files in order to deliver its payload and make further copies of itself) and *trojans* (originally *trojan horses*, software or documents with code embedded that, if activated, would cause the victim's computer to perform actions the user didn't intend). When the small computers became networked, they were introduced to yet another kind of malicious software called a *worm*, a class of software that uses the network to propagate its payload.[1] Along the way, the networked versions of various kinds of frauds made it onto the network security horizon as well, and today a significant part of computer security activity (possibly the largest segment of the industry) centers on threat management, with emphasis on fighting and cataloging malicious software, or *malware*.

The futility of enumerating badness has been argued convincingly elsewhere (see Appendix A for references, such as Marcus Ranum's excellent essay "The Six Dumbest Ideas in Computer Security"). The OpenBSD approach is to design and code properly in the first place. However, even smart people make mistakes every now and then, producing bugs, so make sure to design the system to allow any such failure to have the least possible impact security-wise. Then, if you later discover mistakes and the bugs turn out to be exploitable, fix those bugs wherever similar code turns up in the tree, even if it could mean a radical overhaul of the design and, at worst, a loss of backward compatibility.[2]

In PF, and by extension in this book, the focus is narrower, concentrated on network traffic at the network level. The introduction of divert(4) sockets in OpenBSD 4.7 made it incrementally easier to set up a system where PF contributes to *deep packet inspection*, much like some fiercely marketed products. However, the interface is not yet widely used in free software for that purpose, although exceptions exist. Therefore, we'll instead

1. The famous worms before the Windows era were the IBM Christmas Tree EXEC worm (1987) and the first Internet worm, the Morris worm (1988). A wealth of information about both is within easy reach of your favorite search engine. The Windows era of networked worms is considered to have started with the ILOVEYOU worm in May 2000.

2. Several presentations on OpenBSD's approach to security can be found via the collection at *http://www.openbsd.org/papers/*. Some of my favorites are Theo de Raadt's "Exploit Mitigation Techniques" (as well as the 2013 follow-up, "Security Mitigation Techniques: An Update After 10 Years"), Damien Miller's "Security Measures in OpenSSH," and Henning Brauer and Sven Dehmlow's "Puffy at Work—Getting Code Right and Secure, the OpenBSD Way."

focus on some techniques based on pure network-level behavior, which are most evident in the example configurations in Chapter 6. These techniques will help ease the load on content-inspecting products if you have them in place. As you'll see in the following chapters, the network level offers a lot of fun and excitement, in addition to the blocking or passing packets.

Where the Packet Filter Fits In

The packet filter's main function is, as the name suggests, to filter network packets by matching the properties of individual packets and the network connections built from those packets against the filtering criteria defined in its configuration files. The packet filter is responsible for deciding what to do with those packets. This could mean passing them through or rejecting them, or it could mean triggering events that other parts of the operating system or external applications are set up to handle.

PF lets you write custom filtering criteria to control network traffic based on essentially any packet or connection property, including address family, source and destination address, interface, protocol, port, and direction. Based on these criteria, the packet filter performs the action you specify. One of the simplest and most common actions is to block traffic.

A packet filter can keep unwanted traffic out of your network. It can also help contain network traffic inside your own network. Both these functions are important to the *firewall* concept, but blocking is far from the only useful or interesting feature of a functional packet filter. As you'll see in this book, you can use filtering criteria to direct certain kinds of network traffic to specific hosts, assign classes of traffic to queues, perform traffic shaping, and even hand off selected kinds of traffic to other software for special treatment.

All this processing happens at the network level, based on packet and connection properties. PF is part of the network stack, firmly embedded in the operating system kernel. While there have been examples of packet filtering implemented in user space, in most operating systems, the filtering functions are performed in the kernel because it's faster to do so.

The Rise of PF

If you have a taste for history, you probably already know that OpenBSD and the other BSDs[3] are direct descendants of the BSD system (sometimes referred to as *BSD Unix*), the operating system that contained the original reference implementation of the TCP/IP Internet protocols in the early 1980s.

3. If *BSD* doesn't sound familiar, here is a short explanation: The acronym expands to *Berkeley Software Distribution* and originally referred to a collection of useful software developed for the Unix operating system by staff and students at the University of California, Berkeley. Over time, the collection expanded into a complete operating system, which in turn became the forerunner of a family of systems, including OpenBSD, FreeBSD, NetBSD, DragonFly BSD, and, by some definitions, even Apple's Mac OS X. For a very readable explanation of what BSD is, see Greg Lehey's "Explaining BSD" at *http://www.freebsd.org/doc/en/articles/explaining-bsd/* (and, of course, the projects' websites).

As the research project behind BSD development started winding down in the early 1990s, the code was liberated for further development by small groups of enthusiasts around the world. Some of these enthusiasts were responsible for keeping vital parts of the emerging Internet's infrastructure running reliably, and BSD development continued along parallel lines in several groups. The OpenBSD group became known as the most security-oriented of the BSDs. For its packet-filtering needs, it used a subsystem called *IPFilter*, written mainly by Darren Reed. During these early years, OpenBSD quickly earned a positive reputation as "THE firewall OS," and it's still quite common for people to believe that OpenBSD was developed specifically for that purpose.

It shocked the OpenBSD community when Reed announced in early 2001 that IPFilter, which at that point was intimately integrated with OpenBSD, wasn't covered under the BSD license. Instead, it used almost a word-for-word copy of the license, omitting only the right to make changes to the code and distribute the result. The problem was that the OpenBSD version of IPFilter contained several changes and customizations that, as it turned out, were not allowed under the license. As a result, IPFilter was deleted from the OpenBSD source tree on May 29, 2001, and for a few weeks, the development version of OpenBSD (-current) didn't include any packet filter software.

Fortunately, at this time, in Switzerland, Daniel Hartmeier had been performing some limited experiments involving kernel hacking in the networking code. He began by hooking a small function of his own into the networking stack and then making packets pass through it. Then, he began thinking about filtering. When the license crisis happened, PF was already under development on a small scale. The first commit of the PF code was on Sunday, June 24, 2001, at 19:48:58 UTC. A few months of intense activity by many developers followed, and the resulting version of PF was launched as a default part of the OpenBSD 3.0 base system in December of 2001.[4] This version contained an implementation of packet filtering, including network address translation, with a configuration language that was similar enough to IPFilter's that migrating to the new OpenBSD version did not pose major problems.[5]

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4. The IPFilter copyright episode spurred the OpenBSD team to perform a license audit of the entire source tree in order to avoid similar situations in the future. Several potential problems were resolved over the months that followed, resulting in the removal of a number of potential license pitfalls for everyone involved in free software development. Theo de Raadt summed up the effort in a message to the *openbsd-misc* mailing list on February 20, 2003. The initial drama of the license crisis had blown over, and the net gain was a new packet-filtering system under a free license, with the best code quality available, as well as better free licenses for a large body of code in OpenBSD itself and in other widely used free software.

5. Compatibility with IPFilter configurations was an early design goal for the PF developers, but it stopped being a priority once it could be safely assumed that all OpenBSD users had moved to PF (around the time OpenBSD 3.2 was released, if not earlier). You shouldn't assume that an existing IPFilter configuration will work without changes with any version of PF. With the syntax changes introduced in OpenBSD 4.7, even upgrades from earlier PF versions will involve some conversion work.

PF proved to be well-developed software. In 2002, Hartmeier presented a USENIX paper with performance tests showing that the OpenBSD 3.1 PF performed equally well or better under stress than either IPFilter on OpenBSD 3.1 or iptables on Linux. In addition, tests run on the original PF from OpenBSD 3.0 showed mainly that the code had gained in efficiency from version 3.0 to version 3.1.[6]

The OpenBSD PF code, with a fresh packet-filtering engine written by experienced and security-oriented developers, naturally generated interest in the sister BSDs as well. The FreeBSD project gradually adopted PF, first as a package and then, from version 5.3 on, in the base system as one of three packet-filtering systems. PF has also been included in NetBSD and DragonFly BSD.[7]

This book focuses on the PF version available in OpenBSD 5.5. I'll note significant differences between that version and the ones integrated in other systems as appropriate.

If you're ready to dive into PF configuration, you can jump to Chapter 2 to get started. If you want to spend a little more time getting your bearings in unfamiliar BSD territory, continue reading this chapter.

NEWER PF RELEASES PERFORM BETTER

Like the rest of the computing world, OpenBSD and PF have been affected by rapid changes in hardware and network conditions. I haven't seen tests comparable to the ones in Daniel Hartmeier's USENIX paper performed recently, but PF users have found that the filtering overhead is modest.

As an example (mainly to illustrate that even unexciting hardware configurations can be useful), the machine that gateways between one small office network in my care and the world is a Pentium III 450MHz with 384MB of RAM. When I've remembered to check, I've never seen the machine at less than 96 percent idle according to the output from the `top(1)` command.

It's also worth noting that the current PF developers, mainly Henning Brauer and Ryan McBride, with contributions from several others, rewrote large portions of OpenBSD's PF code with improved performance as a stated main goal during recent releases, making each release from 4.4 through 5.6 perform noticeably better than its predecessors.

6. The article that provides the details of these tests is available from Daniel Hartmeier's website. See *http://www.benzedrine.cx/pf-paper.html*.

7. At one point, there even existed a personal firewall product running on Microsoft Windows, named *Core Force*, that was based on a port of PF. By early 2010, Core Security, the company that developed Core Force (*http://force.coresecurity.com/*), seemed to have shifted focus to other security areas, such as penetration testing, but the product was still available for download.

If You Came from Elsewhere

If you're reading this because you're considering moving your setup to PF from some other system, this section is for you.

If you want to use PF, you need to install and run a BSD system, such as OpenBSD, FreeBSD, NetBSD, or DragonFly BSD. These are all fine operating systems, but my personal favorite is OpenBSD, mainly because that's the operating system where essentially all PF development happens. I also find the no-nonsense approach of the developers and the system refreshing.

Occasionally, minor changes and bug fixes trickle back to the main PF code base from the PF implementations on other systems, but the newest, most up-to-date PF code is always to be found on OpenBSD. Some of the features described in this book are available only in the most recent versions of OpenBSD. The other BSDs have tended to port the latest released PF version from OpenBSD to their code bases in time for their next release, but synchronized updates are far from guaranteed, and the lag is sometimes considerable.

If you're planning to run PF on FreeBSD, NetBSD, DragonFly BSD, or another system, you should check your system's release notes and other documentation for information about which version of PF is included.

Pointers for Linux Users

The differences and similarities between Linux and BSD are potentially a large topic if you probe deeply, but if you have a reasonable command of the basics, it shouldn't take too long for you to feel right at home with the BSD way of doing things. In the rest of this book, I'll assume you can find your way around the basics of BSD network configuration. So, if you're more familiar with configuring Linux or other systems than you are with BSD, it's worth noting a few points about BSD configuration:

- Linux and BSD use different conventions for naming network interfaces. The Linux convention is to label all the network interfaces on a given machine in the sequence `eth0`, `eth1`, and so on (although with some Linux versions and driver combinations, you also see `wlan0`, `wlan1`, and so on for wireless interfaces).

  On the BSDs, interfaces are assigned names that equal the driver name plus a sequence number. For example, older 3Com cards using the ep driver appear as `ep0`, `ep1`, and so on; Intel Gigabit cards are likely to end up as `em0`, `em1`, and so on. Some SMC cards are listed as `sn0`, `sn1`, and so on. This system is quite logical and makes it easier to find the documentation for the specifics of that interface. If your kernel reports (at boot time or in `ifconfig` output) that you have an interface called `em0`, you need only type `man em` at a shell command-line prompt to find out what speeds it supports—whether there are any eccentricities to be aware of, whether any firmware download is needed, and so on.

- You should be aware that in BSDs, the configuration is */etc/rc.conf*-centric. In general, the BSDs are organized to read the configuration from the file */etc/rc.conf*, which is read by the */etc/rc* script at startup. OpenBSD recommends using */etc/rc.conf.local* for local customizations because *rc.conf* contains the default values. FreeBSD uses */etc/defaults/rc.conf* to store the default settings, making */etc/rc.conf* the correct place to make changes. In addition, OpenBSD uses per-interface configuration files called *hostname.<if>*, where *<if>* is replaced with the interface name.
- For the purpose of learning PF, you'll need to concentrate on an */etc/pf.conf* file, which will be largely your own creation.

If you need a broader and more thorough introduction to your BSD of choice, look up the operating system's documentation, including FAQs and guides, at the project's website. You can also find some suggestions for further reading in Appendix A.

Frequently Answered Questions About PF

This section is based on questions I've been asked via email or at meetings and conferences as well as some that have popped up in mailing lists and other discussion forums. Some of the more common questions are covered here in a FAQ-style[8] format.

Can I run PF on my Linux machine?

In a word, no. Over the years, announcements have appeared on the PF mailing list from someone claiming to have started a Linux port of PF, but at the time of this writing, no one has yet claimed to have completed the task. The main reason for this is probably that PF is developed primarily as a deeply integrated part of the OpenBSD networking stack. Even after more than a decade of parallel development, the OpenBSD code still shares enough fundamentals with the other BSDs to make porting possible, but porting PF to a non-BSD system would require rewriting large chunks of PF itself as well as whatever integration is needed at the target side.

For some basic orientation tips for Linux users to find their way in BSD network configurations, see "Pointers for Linux Users" on page 6.

Can you recommend a GUI tool for managing my PF rule set?

This book is mainly oriented toward users who edit their rule sets in their favorite text editor. The sample rule sets in this book are simple enough that you probably wouldn't get a noticeable benefit from any of the visualization options the various GUI tools are known to offer.

A common claim is that the PF configuration files are generally readable enough that a graphic visualization tool isn't really necessary. There are, however, several GUI tools available that can edit and/or generate PF

8. The three-letter abbreviation FAQ expands to either *frequently asked questions* or *frequently answered questions*—both equally valid.

configurations, including a complete, customized build of FreeBSD called *pfSense* (*http://www.pfsense.org/*), which includes a sophisticated GUI rule editor.

I recommend that you work through the parts of this book that apply to your situation and then decide whether you need to use a GUI tool to feel comfortable running and maintaining the systems you build.

Is there a tool I can use to convert my OtherProduct® setup to a PF configuration?

The best strategy when converting network setups, including firewall setups, from one product to another is to go back to the specifications or policies for your network or firewall configuration and then implement the policies using the new tool.

Other products will inevitably have a slightly different feature set, and the existing configuration you created for OtherProduct® is likely to mirror slightly different approaches to specific problems, which do not map easily, or at all, to features in PF and related tools.

Having a documented policy, and taking care to update it as your needs change, will make your life easier. This documentation should contain a complete prose specification of what your setup is meant to achieve. (You might start out by putting comments in your configuration file to explain the purpose of your rules.) This makes it possible to verify whether the configuration you're running actually implements the design goals. In some corporate settings, there may even be a formal requirement for a written policy.

The impulse to look for a way to automate your conversion is quite understandable and perhaps expected in a system administrator. I urge you to resist the impulse and to perform your conversion after reevaluating your business and technical needs and (preferably) after creating or updating a formal specification or policy in the process.

Some of the GUI tools that serve as administration frontends claim the ability to output configuration files for several firewall products and could conceivably be used as conversion tools. However, this has the effect of inserting another layer of abstraction between you and your rule set, and it puts you at the mercy of the tool author's understanding of how PF rule sets work. I recommend working through at least the relevant parts of this book before spending serious time on considering an automated conversion.

I heard PF is based on IPFilter, which I know from working with Solaris. Can I just copy my IPFilter configuration across and have a working setup right away?

If people claim that PF is "based on" IPFilter, they are saying something that isn't true. PF was written from scratch to be a replacement for the newly deleted IPFilter code. For that first version of PF, one of the design goals was to keep the syntax fairly compatible with the older software so the transition to OpenBSD 3.0 would be as painless as possible and not break existing setups too badly or in unpredictable ways.

However, a version or two down the road, it was reasonable to believe that no OpenBSD users were still likely to upgrade from a version that contained IPFilter, so staying compatible with the older system fell off the list of priorities. Some syntax similarities remain, even after 25 OpenBSD releases and more than 12 years of active development. Trying to load one system's configuration on the other—for example, copying across an IPFilter configuration to an OpenBSD system and trying to load it there or copying a modern PF configuration to a Solaris system and trying to load it as an IPFilter configuration—is guaranteed to fail in almost all cases, except for a few specially crafted but still quite trivial and, in fact, rather useless configurations.

Why did the PF rule syntax change all of a sudden?

The world changed, and PF changed with it. More specifically, the OpenBSD developers have a very active and pragmatically critical relationship to their code, and like all parts of OpenBSD, the PF code is under constant review.

The lessons learned over more than a decade of PF development and use led to internal changes in the code that eventually made it clear to the developers that changing the syntax slightly would make sense. The changes would make the PF syntax more consistent and make life easier for users in the long run at the price of some light edits of configuration files. The result for you, the user, is that PF is now even easier to use and that it performs better than the earlier versions. If you're upgrading your system to OpenBSD 4.7 or newer, you're in for a real treat.

And with OpenBSD 5.5, you'll find another good reason to upgrade: the new queuing system for traffic shaping, which is intended to replace the venerable ALTQ system. ALTQ is still part of OpenBSD 5.5, although in slightly modified form, but it has already been removed from the OpenBSD kernel in time for the OpenBSD 5.6 release. Chapter 7 contains a section specifically about migrating to the new traffic-shaping system.

Where can I find out more?

There are several good sources of information about PF and the systems on which it runs. You've already found one in this book. You can find references to a number of printed and online resources in Appendix A.

If you have a BSD system with PF installed, consult the online manual pages, or *man pages*, for information about your exact release of the software. Unless otherwise indicated, the information in this book refers to the world as it looks from the command line on an OpenBSD 5.5 system.

A Little Encouragement: A PF Haiku

If you're not quite convinced yet, or even if you are, a little encouragement may be in order. Over the years, a good many people have said and written their bit about PF—sometimes odd, sometimes wonderful, and sometimes just downright strange.

The poem quoted here is a good indication of the level of feeling PF sometimes inspires in its users. This poem appeared on the PF mailing list, in a thread that started with a message with the subject "Things pf can't do?" in May 2004. The message was written by someone who didn't have a lot of firewall experience and who consequently found it hard to get the desired setup.

This, of course, led to some discussion, with several participants saying that if PF was hard on a newbie, the alternatives weren't any better. The thread ended in the following haiku of praise from Jason Dixon, dated May 20, 2004.

```
Compared to working with iptables, PF is like this haiku:

A breath of fresh air,
floating on white rose petals,
eating strawberries.

Now I'm getting carried away:

Hartmeier codes now,
Henning knows not why it fails,
fails only for nOOb.

Tables load my lists,
tarpit for the asshole spammer,
death to his mail store.

CARP due to Cisco,
redundant blessed packets,
licensed free for me.
```

Some of the concepts Dixon mentions here may sound a bit unfamiliar, but if you read on, it'll all make sense soon.

2

PF CONFIGURATION BASICS

In this chapter, we'll create a very simple setup with PF. We'll begin with the simplest configuration possible: a single machine configured to communicate with a single network. This network could very well be the Internet.

Your two main tools for configuring PF are your favorite text editor and the `pfctl` command-line administration tool. PF configurations, usually stored in */etc/pf.conf*, are called *rule sets* because each line in the configuration file is a *rule* that helps determine what the packet-filtering subsystem should do with the network traffic it sees. In ordinary, day-to-day administration, you edit your configuration in the */etc/pf.conf* file and then load your changes using `pfctl`. There are Web interfaces for PF administration tasks, but they're not part of the base system. The PF developers aren't hostile toward these options, but they've yet to see a graphical interface for configuring PF that's clearly preferable to editing *pf.conf* and using `pfctl` commands.

The First Step: Enabling PF

Before you can get started on the fun parts of shaping your network with PF and related tools, you need to make sure that PF is available and enabled. The details depend on your specific operating system: OpenBSD, FreeBSD, or NetBSD. Check your setup by following the instructions for your operating system and then move on to "A Simple PF Rule Set: A Single, Stand-Alone Machine" on page 16.

The `pfctl` command is a program that requires higher privilege than the default for ordinary users. In the rest of this book, you'll see commands that require extra privilege prefixed with `sudo`. If you haven't started using `sudo` yet, you should. `sudo` is in the base system on OpenBSD. On FreeBSD, DragonFly BSD, and NetBSD, it's within easy reach via the ports system or pkgsrc system, respectively, as *security/sudo*.

Here are a couple general notes regarding using `pfctl`:

- The command to disable PF is `pfctl -d`. Once you've entered that command, all PF-based filtering that may have been in place will be disabled, and all traffic will be allowed to pass.
- For convenience, `pfctl` can handle several operations on a single command line. To enable PF and load the rule set in a single command, enter the following:

```
$ sudo pfctl -ef /etc/pf.conf
```

Setting Up PF on OpenBSD

In OpenBSD 4.6 and later, you don't need to enable PF because it's enabled by default with a minimal configuration in place.[1] If you were watching the system console closely while the system was starting up, you may have noticed the `pf enabled` message appear soon after the kernel messages completed.

If you didn't see the `pf enabled` message on the console at startup, you have several options to check that PF is indeed enabled. One simple way to check is to enter the command you would otherwise use to enable PF from the command line:

```
$ sudo pfctl -e
```

If PF is already enabled, the system responds with this message:

```
pfctl: pf already enabled
```

1. If you're setting up your first PF configuration on an OpenBSD version earlier than this, the best advice is to upgrade to the most recent stable version. If for some reason you must stay with the older version, it might be useful to consult the first edition of this book as well as the man pages and other documentation for the specific version you're using.

If PF isn't enabled, the `pfctl -e` command will enable PF and display this:

```
pf enabled
```

In versions prior to OpenBSD 4.6, PF wasn't enabled by default. You can override the default by editing your */etc/rc.conf.local* file (or creating the file, if it doesn't exist). Although it isn't necessary on recent OpenBSD versions, it doesn't hurt to add this line to your */etc/rc.conf.local* file:

```
pf=YES                  # enable PF
```

If you take a look at the */etc/pf.conf* file in a fresh OpenBSD installation, you get your first exposure to a working rule set.

The default OpenBSD *pf.conf* file starts off with a `set skip on lo` rule to make sure traffic on the loopback interface group isn't filtered in any way. The next active line is a simple `pass` default to let your network traffic pass by default. Finally, an explicit `block` rule blocks remote X11 traffic to your machine.

As you probably noticed, the default *pf.conf* file also contains a few comment lines starting with a hash mark (`#`). In those comments, you'll find suggested rules that hint at useful configurations, such as FTP passthrough via `ftp-proxy` (see Chapter 3) and `spamd`, the OpenBSD spam-deferral daemon (see Chapter 6). These items are potentially useful in various real-world scenarios, but because they may not be relevant in all configurations, they are commented out in the file by default.

If you look for PF-related settings in your */etc/rc.conf* file, you'll find the setting `pf_rules=`. In principle, this lets you specify that your configuration is in a file other than the default */etc/pf.conf*. However, changing this setting is probably not worth the trouble. Using the default setting lets you take advantage of a number of automatic housekeeping features, such as automatic nightly backup of your configuration to */var/backups*.

On OpenBSD, the */etc/rc* script has a built-in mechanism to help you out if you reboot with either no *pf.conf* file or one that contains an invalid rule set. Before enabling any network interfaces, the *rc* script loads a rule set that allows a few basic services: SSH from anywhere, basic name resolution, and NFS mounts. This allows you to log in and correct any errors in your rule set, load the corrected rule set, and then go on working from there.

Setting Up PF on FreeBSD

Good code travels well, and FreeBSD users will tell you that good code from elsewhere tends to find its way into FreeBSD sooner or later. PF is no exception, and from FreeBSD 5.2.1 and the 4.*x* series onward, PF and related tools became part of FreeBSD.

If you read through the previous section on setting up PF on OpenBSD, you saw that on OpenBSD, PF is enabled by default. That isn't the case on FreeBSD, where PF is one of three possible packet-filtering options. Here, you need to take explicit steps to enable PF, and compared to OpenBSD, it seems that you need a little more magic in your */etc/rc.conf*. A look at your */etc/defaults/rc.conf* file shows that the FreeBSD default values for PF-related settings are as follows:

```
pf_enable="NO"                  # Set to YES to enable packet filter (PF)
pf_rules="/etc/pf.conf"         # rules definition file for PF
pf_program="/sbin/pfctl"        # where pfctl lives
pf_flags=""                     # additional flags for pfctl
pflog_enable="NO"               # set to YES to enable packet filter logging
pflog_logfile="/var/log/pflog" # where pflogd should store the logfile
pflog_program="/sbin/pflogd"    # where pflogd lives
pflog_flags=""                  # additional flags for pflogd
pfsync_enable="NO"              # expose pf state to other hosts for syncing
pfsync_syncdev=""               # interface for pfsync to work through
pfsync_ifconfig=""              # additional options to ifconfig(8) for pfsync
```

Fortunately, you can safely ignore most of these—at least for now. The following are the only options that you need to add to your */etc/rc.conf* configuration:

```
pf_enable="YES"                  # Enable PF (load module if required)
pflog_enable="YES"               # start pflogd(8)
```

There are some differences between FreeBSD releases with respect to PF. Refer to the *FreeBSD Handbook* available from *http://www.freebsd.org/*—specifically the PF section of the "Firewalls" chapter—to see which information applies in your case. The PF code in FreeBSD 9 and 10 is equivalent to the code in OpenBSD 4.5 with some bug fixes. The instructions in this book assume that you're running FreeBSD 9.0 or newer.

On FreeBSD, PF is compiled as a kernel-loadable module by default. If your FreeBSD setup runs with a GENERIC kernel, you should be able to start PF with the following:

```
$ sudo kldload pf
$ sudo pfctl -e
```

Assuming you have put the lines just mentioned in your */etc/rc.conf* and created an */etc/pf.conf* file, you could also use the PF *rc* script to run PF. The following enables PF:

```
$ sudo /etc/rc.d/pf start
```

And this disables the packet filter:

```
$ sudo /etc/rc.d/pf stop
```

NOTE *On FreeBSD, the* /etc/rc.d/pf *script requires at least a line in* /etc/rc.conf *that reads* `pf_enable="YES"` *and a valid* /etc/pf.conf *file. If either of these requirements isn't met, the script will exit with an error message. There is no* /etc/pf.conf *file in a default FreeBSD installation, so you'll need to create one before you reboot the system with PF enabled. For our purposes, creating an empty* /etc/pf.conf *with* `touch` *will do, but you could also work from a copy of the* /usr/share/examples/pf/pf.conf *file supplied by the system.*

The supplied sample file */usr/share/examples/pf/pf.conf* contains no active settings. It has only comment lines starting with a `#` character and commented-out rules, but it does give you a preview of what a working rule set will look like. For example, if you remove the `#` sign before the line that says `set skip on lo` to uncomment the line and then save the file as your */etc/pf.conf*, your loopback interface group will not be filtered once you enable PF and load the rule set. However, even if PF is enabled on your FreeBSD system, we haven't gotten around to writing an actual rule set, so PF isn't doing much of anything and all packets will pass.

As of this writing (August 2014), the FreeBSD *rc* scripts don't set up a default rule set as a fallback if the configuration read from */etc/pf.conf* fails to load. This means that enabling PF with no rule set or with *pf.conf* content that is syntactically invalid will leave the packet filter enabled with a default `pass all` rule set.

Setting Up PF on NetBSD

On NetBSD 2.0, PF became available as a loadable kernel module that could be installed via packages (*security/pflkm*) or compiled into a static kernel configuration. In NetBSD 3.0 and later, PF is part of the base system. On NetBSD, PF is one of several possible packet-filtering systems, and you need to take explicit action to enable it.

Some details of PF configuration have changed between NetBSD releases. This book assumes you are using NetBSD 6.0 or later.[2]

To use the loadable PF module for NetBSD, add the following lines to your */etc/rc.conf* to enable loadable kernel modules, PF, and the PF log interface, respectively.

```
lkm="YES" # do load kernel modules
pf=YES
pflogd=YES
```

To load the *pf* module manually and enable PF, enter this:

```
$ sudo modload /usr/lkm/pf.o
$ sudo pfctl -e
```

2. For instructions on using PF in earlier releases, see the documentation for your release and look up supporting literature listed in Appendix A of this book.

Alternatively, you can run the *rc.d* scripts to enable PF and logging, as follows:

```
$ sudo /etc/rc.d/pf start
$ sudo /etc/rc.d/pflogd start
```

To load the module automatically at startup, add the following line to */etc/lkm.conf*:

```
/usr/lkm/pf.o - - - - BEFORENET
```

If your */usr* filesystem is on a separate partition, add this line to your */etc/rc.conf*:

```
critical_filesystems_local="${critical_filesystems_local} /usr"
```

If there are no errors at this point, you have enabled PF on your system, and you're ready to move on to creating a complete configuration.

The supplied */etc/pf.conf* file contains no active settings; it has only comment lines starting with a hash mark (`#`) and commented-out rules. However, it does give you a preview of what a working rule set will look like. For example, if you remove the hash mark before the line that says `set skip on lo` to uncomment it and then save the file, your loopback interface will not be filtered once you enable PF and load the rule set. However, even if PF is enabled on your NetBSD system, we haven't gotten around to writing an actual rule set, so PF isn't doing much of anything but passing packets.

NetBSD implements a default or fallback rule set via the file */etc/defaults/pf.boot.conf*. This rule set is intended only to let your system complete its boot process in case the */etc/pf.conf* file doesn't exist or contains an invalid rule set. You can override the default rules by putting your own customizations in */etc/pf.boot.conf*.

A Simple PF Rule Set: A Single, Stand-Alone Machine

Mainly to have a common, minimal baseline, we will start building rule sets from the simplest possible configuration.

A Minimal Rule Set

The simplest possible PF setup is on a single machine that will not run any services and talks to only one network, which may be the Internet.

We'll begin with an */etc/pf.conf* file that looks like this:

```
block in all
pass out all keep state
```

This rule set denies all incoming traffic, allows traffic we send, and retains state information on our connections. PF reads rules from top to bottom; the *last* rule in a rule set that matches a packet or connection is the one that is applied.

Here, any connection coming into our system from anywhere else will match the `block in all` rule. Even with this tentative result, the rule evaluation will continue to the next rule (`pass out all keep state`), but the traffic will not even match the first criterion (the `out` direction) in this rule. With no more rules to evaluate, the status will not change, and the traffic will be blocked. In a similar manner, any connection initiated from the machine with this rule set will not match the first rule (once again, the wrong direction) but will match the second rule, which is a `pass` rule, and the connection is allowed to pass.

We'll examine the way that PF evaluates rules and how ordering matters in a bit more detail in Chapter 3, in the context of a slightly longer rule set.

For any rule that has a `keep state` part, PF keeps information about the connection, including various counters and sequence numbers, as an entry in the *state table*. The state table is where PF keeps information about existing connections that have already matched a rule, and new packets that arrive are compared to existing state table entries to find a match first. Only when a packet doesn't match any existing state will PF move on to a full *rule set evaluation*, checking whether the packet matches a rule in the loaded rule set. We can also instruct PF to act on state information in various ways, but in a simple case like this, our main goal is to allow return traffic for connections we initiate to return to us.

Note that on OpenBSD 4.1 and later, the default for `pass` rules is to keep state information,[3] and we no longer need to specify `keep state` explicitly in a simple case like this. This means the rule set could be written like this:

```
# minimal rule set, OpenBSD 4.1 onward keeps state by default
block in all
pass out all
```

In fact, you could even leave out the `all` keyword here if you like.

The other BSDs have mostly caught up with this change by now, and for the rest of this book, we'll stick to the newer rules, with an occasional reminder in case you are using an older system.

It goes pretty much without saying that passing all traffic generated by a specific host implies that the host in question is, in fact, trustworthy. This is something you do only if this is a machine you know you can trust.

3. In fact, the new default corresponds to `keep state flags S/SA`, ensuring that only initial SYN packets during connection setup create state, eliminating some puzzling error scenarios. To filter statelessly, you can specify `no state` for the rules where you don't want to record or keep state information. On FreeBSD, OpenBSD 4.1–equivalent PF code was merged into version 7.0. If you're using a PF version old enough that it does not have this default, it is a very strong indicator that you should consider upgrading your operating system as soon as feasible.

When you're ready to use this rule set, load it with the following:

```
$ sudo pfctl -ef /etc/pf.conf
```

The rule set should load without any error messages or warnings. On all but the slowest systems, you should be returned to the `$` prompt immediately.

Testing the Rule Set

It's always a good idea to test your rule sets to make sure they work as expected. Proper testing will become essential once you move on to more complicated configurations.

To test the simple rule set, see whether it can perform domain name resolution. For example, you could see whether `$ host nostarch.com` returns information, such as the IP address of the host *nostarch.com* and the hostnames of that domain's mail exchangers. Or just see whether you can surf the Web. If you can connect to external websites by name, the rule set allows your system to perform domain name resolution. Basically, any service you try to access from your own system should work, and any service you try to access on your system from another machine should produce a `Connection refused` message.

Slightly Stricter: Using Lists and Macros for Readability

The rule set in the previous section is an extremely simple one—probably too simplistic for practical use. But it's a useful starting point to build from to create a slightly more structured and complete setup. We'll start by denying all services and protocols and then allow only those we know that we need,[4] using lists and macros for better readability and control.

A *list* is simply two or more objects of the same type that you can refer to in a rule set, such as this:

```
pass proto tcp to port { 22 80 443 }
```

Here, `{ 22 80 443 }` is a list.

A *macro* is a pure readability tool. If you have objects that you'll refer to more than once in your configuration, such as an IP address for an important host, it could be useful to define a macro instead. For example, you might define this macro early in your rule set:

```
external_mail = 192.0.2.12
```

4. Why write the rule set to default deny? The short answer is that it gives you better control. The point of packet filtering is to take control, not to play catch-up with what the bad guys do. Marcus Ranum has written a very entertaining and informative article about this called "The Six Dumbest Ideas in Computer Security" (*http://www.ranum.com/security/computer_security/editorials/dumb/index.html*).

Then you could refer to that host as `$external_mail` later in the rule set:

```
pass proto tcp to $external_mail port 25
```

These two techniques have great potential for keeping your rule sets readable, and as such, they are important factors that contribute to the overall goal of keeping you in control of your network.

A Stricter Baseline Rule Set

Up to this point, we've been rather permissive with regard to any traffic we generate ourselves. A permissive rule set can be very useful while we check that basic connectivity is in place or we check whether filtering is part of a problem we're seeing. Once the "Do we have connectivity?" phase is over, it's time to start tightening up to create a baseline that keeps us in control.

To begin, add the following rule to */etc/pf.conf*:

```
block all
```

This rule is completely restrictive and will block all traffic in all directions. This is the initial baseline filtering rule that we'll use in all complete rule sets over the next few chapters. We basically start from zero, with a configuration where *nothing* is allowed to pass. Later on, we'll add rules that cut our traffic more slack, but we'll do so incrementally and in a way that keeps us firmly in control.

Next, we'll define a few macros for later use in the rule set:

```
tcp_services = "{ ssh, smtp, domain, www, pop3, auth, https, pop3s }"
udp_services = "{ domain }"
```

Here, you can see how the combination of lists and macros can be turned to our advantage. Macros can be lists, and as demonstrated in the example, PF understands rules that use the names of services as well as port numbers, as listed in your */etc/services* file. We'll take care to use all these elements and some further readability tricks as we tackle complex situations that require more elaborate rule sets.

Having defined these macros, we can use them in our rules, which we'll now edit slightly to look like this:

```
block all
pass out proto tcp to port $tcp_services
pass proto udp to port $udp_services
```

The strings `$tcp_services` and `$udp_services` are macro references. Macros that appear in a rule set are expanded in place when the rule set loads, and the running rule set will have the full lists inserted where the macros are referenced. Depending on the exact nature of the macros, they may cause single rules with macro references to expand into several rules. Even in a small rule set like this, the use of macros makes the rules easier

to grasp and maintain. The amount of information that needs to appear in the rule set shrinks, and with sensible macro names, the logic becomes clearer. To follow the logic in a typical rule set, more often than not, we don't need to see full lists of IP addresses or port numbers in place of every macro reference.

From a practical rule set maintenance perspective, it's important to keep in mind which services to allow on which protocol in order to keep a comfortably tight regime. Keeping separate lists of allowed services according to protocol is likely to be useful in keeping your rule set both functional and readable.

TCP VS. UDP

We've taken care to separate out UDP services from TCP services. Several services run primarily on well-known port numbers on either TCP or UDP, and a few alternate between using TCP and UDP according to specific conditions.

The two protocols are quite different in several respects. TCP is connection oriented and reliable, a perfect candidate for stateful filtering. In contrast, UDP is stateless and connectionless, but PF creates and maintains data equivalent to state information for UDP traffic in order to ensure UDP return traffic is allowed back if it matches an existing state.

One common example where state information for UDP is useful is when handling name resolution. When you ask a name server to resolve a domain name to an IP address or to resolve an IP address back to a hostname, it's reasonable to assume that you want to receive the answer. Retaining state information, or the functional equivalent about your UDP traffic, makes this possible.

Reloading the Rule Set and Looking for Errors

After we've changed our *pf.conf* file, we need to load the new rules as follows:

```
$ sudo pfctl -f /etc/pf.conf
```

If there are no syntax errors, `pfctl` shouldn't display any messages during the rule load.

If you prefer to display verbose output, use the `-v` flag:

```
$ sudo pfctl -vf /etc/pf.conf
```

When you use verbose mode, `pfctl` should expand your macros into their separate rules before returning you to the command-line prompt, as follows:

```
$ sudo pfctl -vf /etc/pf.conf
tcp_services = "{ ssh, smtp, domain, www, pop3, auth, https, pop3s }"
udp_services = "{ domain }"
block drop all
pass out proto tcp from any to any port = ssh flags S/SA keep state
pass out proto tcp from any to any port = smtp flags S/SA keep state
pass out proto tcp from any to any port = domain flags S/SA keep state
pass out proto tcp from any to any port = www flags S/SA keep state
pass out proto tcp from any to any port = pop3 flags S/SA keep state
pass out proto tcp from any to any port = auth flags S/SA keep state
pass out proto tcp from any to any port = https flags S/SA keep state
pass out proto tcp from any to any port = pop3s flags S/SA keep state
pass proto udp from any to any port = domain keep state
$ _
```

Compare this output to the content of the */etc/pf.conf* file you actually wrote. Our single TCP services rule is expanded into eight different ones: one for each service in the list. The single UDP rule takes care of only one service, and it expands from what we wrote to include the default options. Notice that the rules are displayed in full, with default values such as `flags S/SA keep state` applied in place of any options you do not specify explicitly. This is the configuration as it's actually loaded.

Checking Your Rules

If you've made extensive changes to your rule set, check them before attempting to load the rule set by using the following:

```
$ pfctl -nf /etc/pf.conf
```

The `-n` option tells PF to parse the rules only, without loading them—more or less as a dry run and to allow you to review and correct any errors. If `pfctl` finds any syntax errors in your rule set, it'll exit with an error message that points to the line number where the error occurred.

Some firewall guides advise you to make sure that your old configuration is truly gone, or you'll run into trouble—your firewall might be in some kind of intermediate state that doesn't match either the before or after state. That's simply not true when you're using PF. The last valid rule set loaded is active until you either disable PF or load a new rule set. `pfctl` checks the syntax and then loads your new rule set completely before switching over to the new one. This is often referred to as *atomic rule set load* and means that once a valid rule set has been loaded, there's no intermediate state with a partial rule set or no rules loaded. One consequence is that traffic that matches states that are valid in both the old and new rule set will not be disrupted.

Unless you've actually followed the advice from some of those old guides and *flushed* your existing rules (that *is* possible, using `pfctl -F all` or similar) before attempting to load a new one from your configuration file, the last valid configuration will remain loaded. In fact, flushing the rule set is rarely a good idea because it effectively puts your packet filter in a `pass all` mode, which in turn both opens the door to any comers and runs the risk of disrupting useful traffic while you're getting ready to load your rules.

Testing the Changed Rule Set

Once you have a rule set that `pfctl` loads without any errors, it's time to see whether the rules you've written behave as expected. Testing name resolution with a command such as `$ host nostarch.com`, as we did earlier, should still work. However, it's better to choose a domain you haven't accessed recently, such as one for a political party you wouldn't consider voting for, to be sure that you're not pulling DNS information from the cache.

You should be able to surf the Web and use several mail-related services, but due to the nature of this updated rule set, attempts to access TCP services other than the ones defined—SSH, SMTP, and so forth—on any remote system should fail. And, as with our simple rule set, your system should refuse all connections that don't match existing state table entries; only return traffic for connections initiated by this machine will be allowed in.

Displaying Information About Your System

The tests you've performed on your rule sets should have shown that PF is running and that your rules are behaving as expected. There are several ways to keep track of what happens in your running system. One of the more straightforward ways of extracting information about PF is to use the already familiar `pfctl` program.

Once PF is enabled and running, the system updates various counters and statistics in response to network activity. To confirm that PF is running and to view statistics about its activity, you can use `pfctl -s`, followed by the type of information you want to display. A long list of information types is available (see `man 8 pfctl` and look for the `-s` options). We'll get back to some of those display options in Chapter 9 and go into further detail about some of the statistics they provide in Chapter 10, when we use the data to optimize the configuration we're building.

The following shows an example of just the top part of the output of `pfctl -s info` (taken from my home gateway). The high-level information that indicates the system actually passes traffic can be found in this upper part.

```
$ sudo pfctl -s info
Status: Enabled for 24 days 12:11:27            Debug: err

Interface Stats for nfe0                IPv4             IPv6
  Bytes In                        43846385394                0
  Bytes Out                       20023639992               64
  Packets In
    Passed                           49380289                0
    Blocked                             49530                0
  Packets Out
    Passed                           45701100                1
    Blocked                             1034                0

State Table                          Total             Rate
  current entries                      319
  searches                        178598618            84.3/s
  inserts                           4965347             2.3/s
  removals                          4965028             2.3/s
```

The first line of the `pfctl` output indicates that PF is enabled and has been running for a little more than three weeks, which is equal to the time since I last performed a system upgrade that required a reboot.

The `Interface Stats` part of the display is an indication that the system's administrator has chosen one interface (here, `nfe0`) as the log interface for the system and shows the bytes in and out handled by the interface. If no log interface has been chosen, the display is slightly different. Now would be a good time to check what output your system produces. The next few items are likely to be more interesting in our context, showing the number of packets blocked or passed in each direction. This is where we find an early indication of whether the filtering rules we wrote are catching any traffic. In this case, either the rule set matches expected traffic well, or we have fairly well-behaved users and guests, with the number of packets passed being overwhelmingly larger than the number of packets blocked in both directions.

The next important indicator of a working system that's processing traffic is the block of `State Table` statistics. The state table `current entries` line shows that there are 319 active states or connections, while the state table has been searched (`searches`) for matches to existing states on average a little more than 84 times per second, for a total of just over 178 million times since the counters were reset. The `inserts` and `removals` counters show the number of times states have been created and removed, respectively. As expected, the number of insertions and removals differs by the number of currently active states, and the rate counters show that for the time since the counters were last reset, the rate of states created and removed matches exactly up to the resolution of this display.

The information here is roughly in line with the statistics you should expect to see on a gateway for a small network configured for IPv4 only. There's no reason to be alarmed by the packet passed in the IPv6 column. OpenBSD comes with IPv6 built in. During network interface configuration, by default, the TCP/IP stack sends IPv6 neighbor solicitation requests for the link local address. In a normal IPv4-only configuration, only the first few packets actually pass, and by the time the PF rule set from */etc/pf.conf* is fully loaded, IPv6 packets are blocked by the block all default rule. (In this example, they don't show up in `nfe0`'s statistics because IPv6 is tunneled over a different interface.)

Looking Ahead

You should now have a machine that can communicate with other Internet-connected machines, using a very basic rule set that serves as a starting point for controlling your network traffic. As you progress through this book, you'll learn how to add rules that do various useful things. In Chapter 3, we'll extend the configuration to act as a gateway for a small network. Serving the needs of several computers has some consequences, and we'll look at how to let at least some ICMP and UDP traffic through—for your own troubleshooting needs if nothing else.

In Chapter 3, we'll also consider network services that have consequences for your security, like FTP. Using packet filtering intelligently to handle services that are demanding, security-wise, is a recurring theme in this book.

3

INTO THE REAL WORLD

The previous chapter demonstrated the configuration for basic packet filtering on a single machine. In this chapter, we'll build on that basic setup but move into more conventional territory: the packet-filtering *gateway*. Although most of the items in this chapter are potentially useful in a single-machine setup, our main focus is to set up a gateway that forwards a selection of network traffic and handles common network services for a basic local network.

A Simple Gateway

We'll start with building what you probably associate with the term *firewall*: a machine that acts as a gateway for at least one other machine. In addition to forwarding packets between its various networks, this machine's mission will be to improve the signal-to-noise ratio in the network traffic it handles. That's where our PF configuration comes in.

But before diving into the practical configuration details, we need to dip into some theory and flesh out some concepts. Bear with me; this will end up saving you some headaches I've seen on mailing lists, newsgroups, and Web forums all too often.

Keep It Simple: Avoid the Pitfalls of in, out, and on

In the single-machine setup, life is relatively simple. Traffic you create should either pass out to the rest of the world or be blocked by your filtering rules, and you get to decide what you want to let in from elsewhere.

When you set up a gateway, your perspective changes. You go from the "It's me versus the network out there" mindset to "I'm the one who decides what to pass to or from all the networks I'm connected to." The machine has several, or at least two, network interfaces, each connected to a separate network, and its primary function (or at least the one we're interested in here) is to forward network traffic between networks. Conceptually, the network would look something like Figure 3-1.

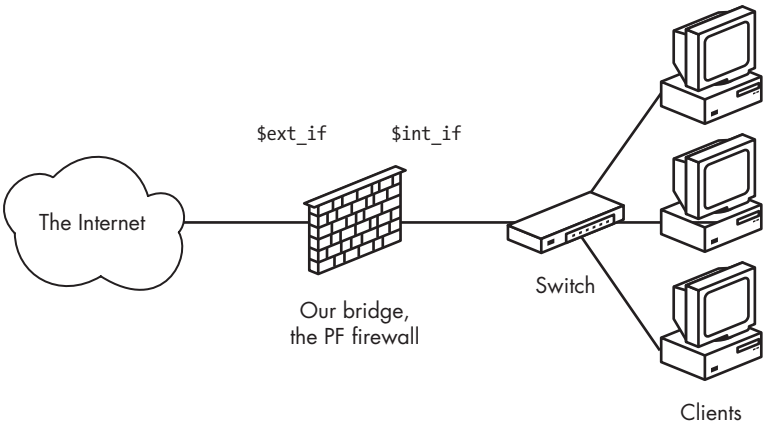

Figure 3-1: Network with a single gateway

It's very reasonable to think that if you want traffic to pass from the network connected to `re1` to hosts on the network connected to `re0`, you'll need a rule like the following:[1]

```
pass in proto tcp on re1 from re1:network to re0:network \
                  port $ports keep state
```

However, one of the most common and most complained-about mistakes in firewall configuration is not realizing that the `to` keyword doesn't

1. In fact, the `keep state` part denotes the default behavior and is redundant if you're working with a PF version taken from OpenBSD 4.1 or later. However, there's generally no need to remove the specification from existing rules you come across when upgrading from earlier versions. To ease the transition, the examples in this book will make this distinction when needed.

in itself guarantee passage to the end point. The `to` keyword here means only that a packet or connection must have a destination address that matches those criteria in order to match the rule. The rule we just wrote lets the traffic pass `in` to just the gateway itself and `on` the specific interface named in the rule. To allow the packets in a bit further and to move on to the next network, we need a matching rule that says something like this:

```
pass out proto tcp on re0 from re1:network to re0:network \
                    port $ports keep state
```

But please stop and take a moment to read those rules one more time. This last rule allows only packets with a destination in the network directly connected to `re0` to pass, and nothing else. If that's exactly what you want, fine. In other contexts, such rules are, while perfectly valid, more specific than the situation calls for. It's very easy to let yourself dive deeply into specific details and lose the higher-level view of the configuration's purpose—and maybe earn yourself a few extra rounds of debugging in the process.

If there are good reasons for writing very specific rules, like the preceding ones, you probably already know that you need them and why. By the time you have finished this book (if not a bit earlier), you should be able to articulate the circumstances when more specific rules are needed. However, for the basic gateway configurations in this chapter, it's likely that you'll want to write rules that are not interface-specific. In fact, in some cases, it isn't useful to specify the direction either; you'd simply use a rule like the following to let your local network access the Internet:

```
pass proto tcp from re1:network to port $ports keep state
```

For simple setups, interface-bound `in` and `out` rules are likely to add more clutter to your rule sets than they're worth. For a busy network admin, a readable rule set is a safer one. (And we'll look at some additional safety measures, like `antispoof`, in Chapter 10.)

For the remainder of this book, with some exceptions, we'll keep the rules as simple as possible for readability.

Network Address Translation vs. IPv6

Once we start handling traffic between separate networks, it's useful to look at how network addresses work and why you're likely to come across several different addressing schemes. The subject of network addresses has been a rich source of both confusion and buzzwords over the years. The underlying facts are sometimes hard to establish, unless you go to the source and wade through a series of RFCs. Over the next few paragraphs, I'll make an effort to clear up some of the confusion.

For example, a widely held belief is that if you have an internal network that uses a totally different address range from the one assigned to the interface attached to the Internet, you're safe, and no one from the outside

can get at your network resources. This belief is closely related to the idea that the IP address of your firewall in the local network must be either `192.168.0.1` or `10.0.0.1`.

There's an element of truth in both notions, and those addresses are common defaults. But the real story is that it's possible to sniff one's way past network address translation, although PF offers some tricks that make that task harder.

The real reason we use a specific set of internal address ranges and a different set of addresses for unique external address ranges isn't primarily to address security concerns. Rather, it's the easiest way to work around a design problem in the Internet protocols: a limited range of possible addresses.

In the 1980s, when the Internet protocols were formulated, most computers on the Internet (or ARPANET, as it was known at the time) were large machines with anything from several dozen to several thousand users each. At the time, a 32-bit address space with more than four billion addresses seemed quite sufficient, but several factors have conspired to prove that assumption wrong. One factor is that the address-allocation process led to a situation where the largest chunks of the available address space were already allocated before some of the world's more populous nations even connected to the Internet. The other, and perhaps more significant, factor was that by the early 1990s, the Internet was no longer a research project, but rather a commercially available resource with consumers and companies of all sizes consuming IP address space at an alarming rate.

The long-term solution was to redefine the Internet to use a larger address space. In 1998, the specification for IPv6, with 128 bits of address space for a total of 2^{128} addresses, was published as RFC 2460. But while we were waiting for IPv6 to become generally available, we needed a stopgap solution. That solution came as a series of RFCs that specified how a gateway could forward traffic with IP addresses translated so that a large local network would look like just one computer to the rest of the Internet. Certain previously unallocated IP address ranges were set aside for these private networks. These were free for anyone to use, on the condition that traffic in those ranges wouldn't be allowed out on the Internet untranslated. Thus, *network address translation (NAT)* was born in the mid-1990s and quickly became the default way to handle addressing in local networks.[2]

PF supports IPv6 as well as the various IPv4 address translation tricks. (In fact, the BSDs were among the earliest IPv6 adopters, thanks to the efforts of the KAME project.[3]) All systems that have PF also support both the IPv4 and the IPv6 address families. If your IPv4 network needs a NAT

2. RFC 1631, "The IP Network Address Translator (NAT)," dated May 1994, and RFC 1918, "Address Allocation for Private Internets," dated February 1996, provide the details about NAT.

3. To quote the project home page at *http://www.kame.net/*, "The KAME project was a joint effort of six companies in Japan to provide a free stack of IPv6, IPsec, and Mobile IPv6 for BSD variants." The main research and development activities were considered complete in March 2006, with only maintenance activity continuing now that the important parts have been incorporated into the relevant systems.

configuration, you can integrate the translation as needed in your PF rule set. In other words, if you're using a system that supports PF, you can be reasonably sure that your IPv6 needs have been taken care of, at least on the operating-system level. However, some operating systems with a PF port use older versions of the code, and it's important to be aware that the general rule that newer PF code is better applies equally to the IPv6 context.

The examples in this book use mainly IPv4 addresses and NAT where appropriate, but most of the material is equally relevant to networks that have implemented IPv6.

Final Preparations: Defining Your Local Network

In Chapter 2, we set up a configuration for a single, standalone machine. We're about to extend that configuration to a gateway version, and it's useful to define a few more macros to help readability and to conceptually separate the local networks where you have a certain measure of control from everything else. So how do you define your "local" network in PF terms?

Earlier in this chapter, you saw the *interface*`:network` notation. This is a nice piece of shorthand, but you can make your rule set even more readable and easier to maintain by taking the macro a bit further. For example, you could define a `$localnet` macro as the network directly attached to your internal interface (`re1:network` in our examples). Or you could change the definition of `$localnet` to an IP address/netmask notation to denote a network, such as `192.168.100.0/24` for a subnet of private IPv4 addresses or `2001:db8:dead:beef::/64` for an IPv6 range.

If your network environment requires it, you could define your `$localnet` as a list of networks. For example, a sensible `$localnet` definition combined with `pass` rules that use the macro, such as the following, could end up saving you a few headaches:

```
pass proto { tcp, udp } from $localnet to port $ports
```

We'll stick to the convention of using macros such as `$localnet` for readability from here on.

Setting Up a Gateway

We'll take the single-machine configuration we built from the ground up in the previous chapter as our starting point for building our packet-filtering gateway. We assume that the machine has acquired another network card (or that you have set up a network connection from your local network to one or more other networks via Ethernet, PPP, or other means).

In our context, it isn't too interesting to look at the details of how the interfaces are configured. We just need to know that the interfaces are up and running.

For the following discussion and examples, only the interface names will differ between a PPP setup and an Ethernet one, and we'll do our best to get rid of the actual interface names as quickly as possible.

First, because packet forwarding is off by default in all BSDs, we need to turn it on in order to let the machine forward the network traffic it receives on one interface to other networks via one or more separate interfaces. Initially, we'll do this on the command line with a `sysctl` command for traditional IPv4:

```
# sysctl net.inet.ip.forwarding=1
```

If we need to forward IPv6 traffic, we use this `sysctl` command:

```
# sysctl net.inet6.ip6.forwarding=1
```

This is fine for now. However, in order for this to work once you reboot the computer at some time in the future, you need to enter these settings into the relevant configuration files.

In OpenBSD and NetBSD, you do this by editing */etc/sysctl.conf* and adding IP-forwarding lines to the end of the file so the last lines look like this:

```
net.inet.ip.forwarding=1
net.inet6.ip6.forwarding=1
```

In FreeBSD, make the change by putting these lines in your */etc/rc.conf*:

```
gateway_enable="YES" #for ipv4
ipv6_gateway_enable="YES" #for ipv6
```

The net effect is identical; the FreeBSD *rc* script sets the two values via `sysctl` commands. However, a larger part of the FreeBSD configuration is centralized into the *rc.conf* file.

Now it's time to check whether all of the interfaces you intend to use are up and running. Use **`ifconfig -a`** or **`ifconfig`** ***`interface_name`*** to find out.

The output of `ifconfig -a` on one of my systems looks like this:

```
$ ifconfig -a
lo0: flags=8049<UP,LOOPBACK,RUNNING,MULTICAST> mtu 33224
        groups: lo
        inet 127.0.0.1 netmask 0xff000000
        inet6 ::1 prefixlen 128
        inet6 fe80::1%lo0 prefixlen 64 scopeid 0x5
xl0: flags=8843<UP,BROADCAST,RUNNING,SIMPLEX,MULTICAST> mtu 1500
        lladdr 00:60:97:83:4a:01
        groups: egress
        media: Ethernet autoselect (100baseTX full-duplex)
        status: active
        inet 194.54.107.18 netmask 0xfffffff8 broadcast 194.54.107.23
        inet6 fe80::260:97ff:fe83:4a01%xl0 prefixlen 64 scopeid 0x1
```

```
fxp0: flags=8843<UP,BROADCAST,RUNNING,SIMPLEX,MULTICAST> mtu 1500
        lladdr 00:30:05:03:fc:41
        media: Ethernet autoselect (100baseTX full-duplex)
        status: active
        inet 194.54.103.65 netmask 0xffffffc0 broadcast 194.54.103.127
        inet6 fe80::230:5ff:fe03:fc41%fxp0 prefixlen 64 scopeid 0x2
pflog0: flags=141<UP,RUNNING,PROMISC> mtu 33224
enc0: flags=0<> mtu 1536
```

Your setup is most likely somewhat different. Here, the physical interfaces on the gateway are `xl0` and `fxp0`. The logical interfaces `lo0` (the loopback interface), `enc0` (the encapsulation interface for IPSEC use), and `pflog0` (the PF logging device) are probably on your system, too.

If you're on a dial-up connection, you probably use some variant of PPP for the Internet connection, and your external interface is the `tun0` pseudo-device. If your connection is via some sort of broadband connection, you may have an Ethernet interface to play with. However, if you're in the significant subset of ADSL users who use PPP over Ethernet (PPPoE), the correct external interface will be one of the pseudo-devices `tun0` or `pppoe0` (depending on whether you use userland `pppoe(8)` or kernel mode `pppoe(4)`), not the physical Ethernet interface.

Depending on your specific setup, you may need to do some other device-specific configuration for your interfaces. After you have that set up, you can move on to the TCP/IP level and deal with the packet-filtering configuration.

If you still intend to allow any traffic initiated by machines on the inside, your */etc/pf.conf* for your initial gateway setup could look roughly like this:

```
ext_if = "re0" # macro for external interface - use tun0 or pppoe0 for PPPoE
int_if = "re1" # macro for internal interface
localnet = $int_if:network
# ext_if IPv4 address could be dynamic, hence ($ext_if)
match out on $ext_if inet from $localnet nat-to ($ext_if) # NAT, match IPv4 only
block all
pass from { self, $localnet }
```

Note the use of macros to assign logical names to the network interfaces. Here, Realtek Ethernet cards are used, but this is the last time we'll find this of any interest whatsoever in our context.

In truly simple setups like this one, we may not gain very much by using macros like these, but once the rule sets grow a little larger, you'll learn to appreciate the readability they add.

One possible refinement to this rule set would be to remove the macro `ext_if` and replace the `$ext_if` references with the string `egress`, which is the name of the interface group that contains the interface that has the default route. Interface groups are not macros, so you would write the name `egress` without a leading `$` character.

Also note the `match` rule with `nat-to`. This is where you handle NAT from the nonroutable address inside your local network to the sole official address assigned to you. If your network uses official, routable IPv4

addresses, you simply leave this line out of your configuration. The `match` rules, which were introduced in OpenBSD 4.6, can be used to apply actions when a connection matches the criteria without deciding whether a connection should be blocked or passed.

The parentheses surrounding the last part of the `match` rule (`$ext_if`) are there to compensate for the possibility that the IP address of the external interface may be dynamically assigned. This detail will ensure that your network traffic runs without serious interruptions, even if the interface's IP address changes.

It's time to sum up the rule set we've built so far: (1) We block all traffic originating outside our own network. (2) We make sure all IPv4 traffic initiated by hosts in our local network will pass into the outside world only with the source address rewritten to the routable address assigned to the gateway's external interface. (3) Finally, we let all traffic from our local network (IPv4 and IPv6 both) and from the gateway itself pass. The keyword `self` in the final `pass` rule is a macro-ish reserved word in PF syntax that denotes all addresses assigned to all interfaces on the local host.

If your operating system runs a pre-OpenBSD 4.7 PF version, your first gateway rule set would look something like this:

```
ext_if = "re0" # macro for external interface - use tun0 or pppoe0 for PPPoE
int_if = "re1" # macro for internal interface
localnet = $int_if:network
# ext_if IP address could be dynamic, hence ($ext_if)
nat on $ext_if inet from $localnet to any -> ($ext_if)  # NAT, match IPv4 only
block all
pass from { self, $localnet } to any keep state
```

The `nat` rule here handles the translation much as does the `match` rule with `nat-to` in the previous example.

On the other hand, this rule set probably allows more traffic than you actually want to pass out of your network. In one of the networks where I've done a bit of work, the main part of the rule set is based on a macro called `client_out`:

```
client_out = "{ ftp-data, ftp, ssh, domain, pop3, auth, nntp, http,\
                https, 446, cvspserver, 2628, 5999, 8000, 8080 }"
```

It has this `pass` rule:

```
pass proto tcp from $localnet to port $client_out
```

This may be a somewhat peculiar selection of ports, but it's exactly what my colleagues there needed at the time. Some of the numbered ports were needed for systems that were set up for specific purposes at other sites. Your needs probably differ at least in some details, but this should cover some of the more useful services.

Here's another `pass` rule that is useful to those who want the ability to administer machines from elsewhere:

```
pass in proto tcp to port ssh
```

Or use this form, if you prefer:

```
pass in proto tcp to $ext_if port ssh
```

When you leave out the `from` part entirely, the default is `from any`, which is quite permissive. It lets you log in from anywhere, which is great if you travel a lot and need SSH access from unknown locations around the world. If you're not all that mobile—say you haven't quite developed the taste for conferences in far-flung locations, or you feel your colleagues can fend for themselves while you're on vacation—you may want to tighten up with a `from` part that includes only the places where you and other administrators are likely to log in from for legitimate reasons.

Our very basic rule set is still not complete. Next, we need to make the name service work for our clients. We start with another macro at the start of our rule set:

```
udp_services = "{ domain, ntp }"
```

This is supplemented with a rule that passes the traffic we want through our firewall:

```
pass quick proto { tcp, udp } to port $udp_services
```

Note the `quick` keyword in this rule. We've started writing rule sets that consist of several rules, and it's time to revisit the relationships and interactions between them.

As noted in the previous chapter, the rules are evaluated from top to bottom in the sequence they're written in the configuration file. For each packet or connection evaluated by PF, *the last matching rule* in the rule set is the one that's applied.

The `quick` keyword offers an escape from the ordinary sequence. When a packet matches a `quick` rule, the packet is treated according to the present rule. The rule processing stops without considering any further rules that might have matched the packet. As your rule sets grow longer and more complicated, you'll find this quite handy. For example, it's useful when you need a few isolated exceptions to your general rules.

This `quick` rule also takes care of NTP, which is used for time synchronization. Common to both the name service and time synchronization protocols is that they may, under certain circumstances, communicate alternately over TCP and UDP.

Testing Your Rule Set

You may not have gotten around to writing that formal test suite for your rule sets just yet, but there's every reason to test that your configuration works as expected.

The same basic tests in the standalone example from the previous chapter still apply. But now you need to test from the other hosts in your network as well as from your packet-filtering gateway. For each of the services you specified in your `pass` rules, test that machines in your local network get meaningful results. From any machine in your local network, enter a command like this:

```
$ host nostarch.com
```

It should return exactly the same results as when you tested the standalone rule set in the previous chapter, and traffic for the services you have specified should pass.[4]

You may not think it's necessary, but it doesn't hurt to check that the rule set works as expected from outside your gateway as well. If you've done exactly what this chapter says so far, it shouldn't be possible to contact machines in your local network from the outside.

WHY ONLY IP ADDRESSES—NOT HOSTNAMES OR DOMAIN NAMES?

Looking at the examples up to this point, you've probably noticed that the rule sets all have macros that expand into IP addresses or address ranges but never into hostnames or domain names. You're probably wondering why. After all, you've seen that PF lets you use service names in your rule set, so why not include hostnames or domain names?

The answer is that if you used domain names and hostnames in your rule set, the rule set would be valid only after the name service was running and accessible. In the default configuration, PF is loaded before any network services are running. This means that if you want to use domain names and hostnames in your PF configuration, you'll need to change the system's startup sequence (by editing */etc/rc.local*, perhaps) to load the name service–dependent rule set only after the name service is available. If you have only a limited number of hostnames or domain names you want to reference in your PF configuration, it's likely at least as useful to add those as IP addresses to name-mapping entries in your */etc/hosts* file and leave the *rc* scripts alone.

4. This is true unless, of course, the information changed in the meantime. Some sysadmins are fond of practical jokes, but most of the time changes in DNS zone information are due to real-world needs in that particular organization or network.

That Sad Old FTP Thing

The short list of real-life TCP ports we looked at a few moments back contained, among other things, *FTP*, the classic *file transfer protocol*. FTP is a relic of the early Internet, when experiments were the norm and security was not really on the horizon in any modern sense. FTP actually predates TCP/IP,[5] and it's possible to track the protocol's development through more than 50 RFCs. After more than 30 years, FTP is both a sad old thing and a problem child—emphatically so for anyone trying to combine FTP and firewalls. FTP is an old and weird protocol with a lot to dislike. Here are the most common points against it:

- Passwords are transferred in the clear.[6]
- The protocol demands the use of at least two TCP connections (control and data) on separate ports.
- When a session is established, data is communicated via ports usually selected at random.

All of these points make for challenges security-wise, even before considering any potential weaknesses in client or server software that may lead to security issues. As any network graybeard will tell you, these things tend to crop up when you need them the least.

Under any circumstances, other more modern and more secure options for file transfer exist, such as SFTP and SCP, which feature both authentication and data transfer via encrypted connections. Competent IT professionals should have a preference for some form of file transfer other than FTP.

Regardless of our professionalism and preferences, we sometimes must deal with things we would prefer not to use at all. In the case of FTP through firewalls, we can combat problems by redirecting the traffic to a small program that's written specifically for this purpose. The upside for us is that handling FTP offers us a chance to look at two fairly advanced PF features: *redirection* and *anchors*.

The easiest way to handle FTP in a default-to-block scenario such as ours is to have PF redirect the traffic for that service to an external application that acts as a *proxy* for the service. The proxy maintains its own named sub–rule set (an *anchor* in PF terminology), where it inserts or deletes rules as needed for the FTP traffic. The combination of redirection and the anchor provides a clean, well-defined interface between the packet-filtering subsystem and the proxy.

---

5. The earliest RFC describing the FTP protocol is RFC 114, dated April 10, 1971. The switch to TCP/IP happened with FTP version 5, as defined in RFCs 765 and 775, dated June and December 1980, respectively.

6. An encrypted version of the protocol, dubbed FTPS, is specified in RFC4217, but support remains somewhat spotty.

If We Must: ftp-proxy with Divert or Redirect

Enabling FTP transfers through your gateway is amazingly simple, thanks to the FTP-proxy program included in the OpenBSD base system. The program is called—you guessed it—`ftp-proxy`.

To enable `ftp-proxy`, you need to add this line to your */etc/rc.conf.local* file on OpenBSD:

```
ftpproxy_flags=""
```

On FreeBSD, */etc/rc.conf* needs to contain at least the first of these two lines:

```
ftpproxy_enable="YES"
ftpproxy_flags="" # and put any command line options here
```

If you need to specify any command-line options to `ftp-proxy`, you put them in the `ftpproxy_flags` variable.

You can start the proxy manually by running */usr/sbin/ftp-proxy* if you like (or even better, use the */etc/rc.d/ftp-proxy* script with the `start` option on OpenBSD), and you may want to do this in order to check that the changes to the PF configuration you're about to make have the intended effect.

For a basic configuration, you need to add only three elements to your */etc/pf.conf*: the anchor and two `pass` rules. The anchor declaration looks like this:

```
anchor "ftp-proxy/*"
```

In pre-OpenBSD 4.7 versions, two anchor declarations were needed:

```
nat-anchor "ftp-proxy/*"
rdr-anchor "ftp-proxy/*"
```

The proxy will insert the rules it generates for the FTP sessions here.

Then, you also need a `pass` rule to let FTP traffic into the proxy:

```
pass in quick inet proto tcp to port ftp divert-to 127.0.0.1 port 8021
```

Note the `divert-to` part. This redirects the traffic to the local port, where the proxy listens via the highly efficient, local-connections-only divert(4) interface. In OpenBSD versions 4.9 and older, the traffic diversion happened via an `rdr-to`. If you're upgrading an existing pre-OpenBSD 5.0 configuration, you'll need to update your `rdr-to` rules for the FTP proxy to use `divert-to` instead.

If your operating system uses a pre-OpenBSD 4.7 PF version, you need this version of the redirection rule:

```
rdr pass on $int_if inet proto tcp from any to any port ftp -> 127.0.0.1 port 8021
```

Finally, make sure your rule set contains a `pass` rule to let the packets pass from the proxy to the rest of the world, where `$proxy` expands to the address to which the proxy daemon is bound:

```
pass out inet proto tcp from $proxy to any port ftp
```

Reload your PF configuration:

```
$ sudo pfctl -f /etc/pf.conf
```

Before you know it, your users will thank you for making FTP work.

Variations on the ftp-proxy Setup

The preceding example covers a basic setup where the clients in your local network need to contact FTP servers elsewhere. This configuration should work well with most combinations of FTP clients and servers.

You can change the proxy's behavior in various ways by adding options to the `ftpproxy_flags=` line. You may bump into clients or servers with specific quirks that you need to compensate for in your configuration, or you may want to integrate the proxy in your setup in specific ways, such as assigning FTP traffic to a specific queue. For these and other finer points of `ftp-proxy` configuration, your best bet is to start by studying the man page.

If you're interested in ways to run an FTP server protected by PF and `ftp-proxy`, you could look into running a separate `ftp-proxy` in reverse mode (using the `-R` option) on a separate port with its own redirecting `pass` rule. It's even possible to set up the proxy to run in IPv6 mode, but if you're ahead of the pack in running the modern protocol, you're less likely to bother with FTP as your main file transfer protocol.

NOTE *If your PF version predates the ones described here, you're running on an outdated, unsupported operating system. I strongly urge you to schedule an operating system upgrade as soon as possible. If an upgrade is for some reason not an option, please look up the first edition of this book and study the documentation for your operating system for information on how to use some earlier FTP proxies.*

Making Your Network Troubleshooting-Friendly

Making your network troubleshooting-friendly is a potentially large subject. Generally, the debugging- or troubleshooting-friendliness of your TCP/IP network depends on how you treat the Internet protocol that was designed specifically with debugging in mind: ICMP.

ICMP is the protocol for sending and receiving *control messages* between hosts and gateways, mainly to provide feedback to a sender about any unusual or difficult conditions en route to the target host.

There's a lot of ICMP traffic, which usually happens in the background while you are surfing the Web, reading mail, or transferring files. Routers

(remember, you're building one) use ICMP to negotiate packet sizes and other transmission parameters in a process often referred to as *path MTU discovery*.

You may have heard admins refer to ICMP as either "evil" or, if their understanding runs a little deeper, "a necessary evil." The reason for this attitude is purely historical. A few years back, it was discovered that the networking stacks of several operating systems contained code that could make the machine crash if it were sent a sufficiently large ICMP request.

One of the companies that was hit hard by this was Microsoft, and you can find a lot of material on the *ping of death* bug by using your favorite search engine. However, this all happened in the second half of the 1990s, and all modern operating systems have thoroughly sanitized their network code since then (at least, that's what we're led to believe).

One of the early work-arounds was to simply block either ICMP echo (ping) requests or even all ICMP traffic. That measure almost certainly led to poor performance and hard-to-debug network problems. In some places, however, these rule sets have been around for almost two decades, and the people who put them there are still scared. There's most likely little to no reason to worry about destructive ICMP traffic anymore, but here we'll look at how to manage just what ICMP traffic passes to or from your network.

In modern IPv6 networks, the updated `icmp6` protocol plays a more crucial role than ever in parameter passing and even host configuration, and network admins are playing a high-stakes game while learning the finer points of blocking or passing `icmp6` traffic. To a large extent, issues that are relevant for IPv4 ICMP generally apply to IPv6 ICMP6 as well, but in addition, ICMP6 is used for several mechanisms that were handled differently in IPv4. We'll dip into some of these issues after walking through the issues that are relevant for both IP protocol versions.

Do We Let It All Through?

The obvious question becomes, "If ICMP is such a good and useful thing, shouldn't we let it all through all the time?" The answer is that it depends.

Letting diagnostic traffic pass unconditionally makes debugging easier, of course, but it also makes it relatively easy for others to extract information about your network. So, a rule like the following might not be optimal if you want to cloak the internal workings of your IPv4 network:

```
pass inet proto icmp
```

If you want the same free flow of messages for your IPv6 traffic, the corresponding rule is this:

```
pass inet6 proto icmp6
```

In all fairness, it should also be said that you might find some ICMP and ICMP6 traffic quite harmlessly riding piggyback on your `keep state` rules.

The Easy Way Out: The Buck Stops Here

The easiest solution could very well be to allow all ICMP and ICMP6 traffic from your local network through and to let probes from elsewhere stop at your gateway:

```
pass inet proto icmp icmp-type $icmp_types from $localnet
pass inet6 proto icmp6 icmp6-type $icmp6_types from $localnet
pass inet proto icmp icmp-type $icmp_types to $ext_if
pass inet6 proto icmp6 icmp6-type $icmp6_types to $ext_if
```

This is assuming, of course that you've identified the list of desirable ICMP and ICMP6 types to fill out your macro definitions. We'll get back to those shortly. Stopping probes at the gateway might be an attractive option anyway, but let's look at a few other options that'll demonstrate some of PF's flexibility.

Letting ping Through

The rule set we have developed so far in this chapter has one clear disadvantage: Common troubleshooting commands, such as `ping` and `traceroute` (and their IPv6 equivalents, `ping6` and `traceroute6`), will not work. That may not matter too much to your users, and because it was the `ping` command that scared people into filtering or blocking ICMP traffic in the first place, there are apparently some people who feel we're better off without it. However, you'll find these troubleshooting tools useful. And with a couple of small additions to the rule set, they will be available to you.

The diagnostic commands `ping` and `ping6` rely on the ICMP and ICMP6 *echo request* (and the matching *echo reply*) types, and in order to keep our rule set tidy, we start by defining another set of macros:

```
icmp_types = "echoreq"
icmp6_types = "echoreq"
```

Then, we add rules that use the definitions:

```
pass inet proto icmp icmp-type $icmp_types
pass inet6 proto icmp6 icmp6-type $icmp6_types
```

The macros and the rules mean that ICMP and ICMP6 packets with type *echo request* will be allowed through and matching *echo replies* will be allowed to pass back due to PF's stateful nature. This is all the `ping` and `ping6` commands need in order to produce their expected results.

If you need more or other types of ICMP or ICMP6 packets to go through, you can expand `icmp_types` and `icmp6_types` to lists of those packet types you want to allow.

Helping traceroute

The traceroute command (and the IPv6 variant traceroute6) is useful when your users claim that the Internet isn't working. By default, Unix traceroute uses UDP connections according to a set formula based on destination. The following rules work with the traceroute and traceroute6 commands on all forms of Unix I've had access to, including GNU/Linux:

```
# allow out the default range for traceroute(8):
# "base+nhops*nqueries-1" (33434+64*3-1)
pass out on egress inet proto udp to port 33433:33626 # For IPv4
pass out on egress inet6 proto udp to port 33433:33626 # For IPv6
```

This also gives you a first taste of what port ranges look like. They're quite useful in some contexts.

Experience so far indicates that traceroute and traceroute6 implementations on other operating systems work roughly the same way. One notable exception is Microsoft Windows. On that platform, the *tracert.exe* program and its IPv6 sister *tracert6.exe* use ICMP echo requests for this purpose. So if you want to let Windows traceroutes through, you need only the first rule, much as when letting ping through. The Unix traceroute program can be instructed to use other protocols as well and will behave remarkably like its Microsoft counterpart if you use its -I command-line option. You can check the traceroute man page (or its source code, for that matter) for all the details.

This solution is based on a sample rule I found in an openbsd-misc post. I've found that list, and the searchable list archives (accessible among other places from *http://marc.info/*), to be a valuable resource whenever you need OpenBSD or PF-related information.

Path MTU Discovery

The last bit I'll remind you about when it comes to troubleshooting is the path MTU discovery. Internet protocols are designed to be device-independent, and one consequence of device independence is that you cannot always predict reliably what the optimal packet size is for a given connection. The main constraint on your packet size is called the *maximum transmission unit*, or *MTU*, which sets the upper limit on the packet size for an interface. The ifconfig command will show you the MTU for your network interfaces.

Modern TCP/IP implementations expect to be able to determine the correct packet size for a connection through a process that simply involves sending packets of varying sizes within the MTU of the local link with the "do not fragment" flag set. If a packet then exceeds the MTU somewhere along the way to the destination, the host with the lower MTU will return an ICMP packet indicating "type 3, code 4" and quoting its local MTU when the local upper limit has been reached. Now, you don't need to dive for the RFCs right away. Type 3 means *destination unreachable*, and code 4

is short for *fragmentation needed, but the "do not fragment" flag is set*. So if your connections to other networks, which may have MTUs that differ from your own, seem suboptimal, you could try changing your list of ICMP types slightly to let the IPv4 destination-unreachable packets through:

```
icmp_types = "{ echoreq, unreach }"
```

As you can see, this means you do not need to change the `pass` rule itself:

```
pass inet proto icmp icmp-type $icmp_types
```

Now I'll let you in on a little secret: In almost all cases, these rules aren't necessary for purposes of path MTU discovery (but they don't hurt either). However, even though the default PF `keep state` behavior takes care of most of the ICMP traffic you'll need, PF does let you filter on all variations of ICMP types and codes. For IPv6, you'd probably want to let the more common ICMP6 diagnostics through, such as the following:

```
icmp6_types = "{ echoreq unreach timex paramprob }"
```

This means that we let echo requests and destination unreachable, time exceeded, and parameter problem messages pass for IPv6 traffic. Thanks to the macro definitions, you don't need to touch the `pass` rule for the ICMP6 case either:

```
pass inet6 proto icmp6 icmp6-type $icmp6_types
```

But it's worth keeping in mind that IPv6 hosts rely on ICMP6 messages for automatic configuration-related tasks, and you may want to explicitly filter in order to allow or deny specific ICMP6 types at various points in your network.

For example, you'll want to let a router and its clients exchange router solicitation and router advertisement messages (ICMP6 type `routeradv` and `routersol`, respectively), while you may want to make sure that neighbor advertisements and neighbor solicitations (ICMP6 type `neighbradv` and `neighbrsol`, respectively) stay confined within their directly connected networks.

If you want to delve into more detail, the list of possible types and codes are documented in the `icmp(4)` and `icmp6(4)` man pages. The background information is available in the RFCs.[7]

7. The main RFCs describing ICMP and some related techniques are 792, 950, 1191, 1256, 2521, and 6145. ICMP updates for IPv6 are in RFC 3542 and RFC 4443. These documents are available in a number of places on the Web, such as *http://www.ietf.org/* and *http://www.faqs.org/*, and probably also via your package system.

Tables Make Your Life Easier

By now, you may be thinking that this setup gets awfully static and rigid. There will, after all, be some kinds of data relevant to filtering and redirection at a given time, but they don't deserve to be put into a configuration file! Quite right, and PF offers mechanisms for handling those situations.

Tables are one such feature. They're useful as lists of IP addresses that can be manipulated without reloading the entire rule set and also when fast lookups are desirable.

Table names are always enclosed in < >, like this:

```
table <clients> persist { 192.168.2.0/24, !192.168.2.5 }
```

Here, the network `192.168.2.0/24` is part of the table with one exception: The address `192.168.2.5` is excluded using the `!` operator (logical NOT). The keyword `persist` makes sure the table itself will exist, even if no rules currently refer to it.

It's also possible to load tables from files where each item is on a separate line, such as the file */etc/clients*:

```
192.168.2.0/24
!192.168.2.5
```

This, in turn, is used to initialize the table in */etc/pf.conf*:

```
table <clients> persist file "/etc/clients"
```

So, for example, you can change one of our earlier rules to read like this to manage outgoing traffic from your client computers:

```
pass inet proto tcp from <clients> to any port $client_out
```

With this in hand, you can manipulate the table's contents live, like this:

```
$ sudo pfctl -t clients -T add 192.168.1/16
```

Note that this changes the in-memory copy of the table only, meaning that the change will not survive a power failure or reboot, unless you arrange to store your changes.

You might opt to maintain the on-disk copy of the table with a `cron` job that dumps the table content to disk at regular intervals, using a command such as the following:

```
$ sudo pfctl -t clients -T show >/etc/clients
```

Alternatively, you could edit the */etc/clients* file and replace the in-memory table contents with the file data:

```
$ sudo pfctl -t clients -T replace -f /etc/clients
```

For operations you'll be performing frequently, sooner or later, you'll end up writing shell scripts. It's likely that routine operations on tables, such as inserting or removing items or replacing table contents, will be part of your housekeeping scripts in the near future.

One common example is to enforce network access restrictions via `cron` jobs that replace the contents of the tables referenced as `from` addresses in the `pass` rules at specific times. In some networks, you may even need different access rules for different days of the week. The only real limitations lie in your own needs and your creativity.

We'll be returning to some handy uses of tables frequently over the next chapters, and we'll look at a few programs that interact with tables in useful ways.

4

WIRELESS NETWORKS MADE EASY

It's rather tempting to say that on BSD—and OpenBSD, in particular—there's no need to "make wireless networking easy" because it already is. Getting a wireless network running isn't very different from getting a wired one up and running, but there are some issues that turn up simply because we're dealing with radio waves and not wires. We'll look briefly at some of the issues before moving on to the practical steps involved in creating a usable setup.

Once we have covered the basics of getting a wireless network up and running, we'll turn to some of the options for making your wireless network more interesting and harder to break.

A Little IEEE 802.11 Background

Setting up any network interface, in principle, is a two-step process: You establish a link, and then you move on to configuring the interface for TCP/IP traffic.

In the case of wired Ethernet-type interfaces, establishing the link usually consists of plugging in a cable and seeing the link indicator light up. However, some interfaces require extra steps. Networking over dial-up connections, for example, requires telephony steps, such as dialing a number to get a carrier signal.

In the case of IEEE 802.11–style wireless networks, getting the carrier signal involves quite a few steps at the lowest level. First, you need to select the proper channel in the assigned frequency spectrum. Once you find a signal, you need to set a few link-level network identification parameters. Finally, if the station you want to link to uses some form of link-level encryption, you need to set the correct kind and probably negotiate some additional parameters.

Fortunately, on OpenBSD systems, all configuration of wireless network devices happens via `ifconfig` commands and options, as with any other network interface. While most network configuration happens via `ifconfig` on other BSDs, too, on some systems, specific features require other configuration.[1] Still, because we're introducing wireless networks here, we need to look at security at various levels in the networking stack from this new perspective.

There are basically three kinds of popular and simple IEEE 802.11 privacy mechanisms, and we'll discuss them briefly over the next sections.

NOTE *For a more complete overview of issues surrounding security in wireless networks, see Professor Kjell Jørgen Hole's articles and slides at* http://www.kjhole.com/ *and* http://www.nowires.org/.

MAC Address Filtering

The short version of the story about PF and MAC address filtering is that we don't do it. A number of consumer-grade, off-the-shelf wireless access points offer MAC address filtering, but contrary to common belief, they don't really add much security. The marketing succeeds largely because most consumers are unaware that it's possible to change the MAC address of essentially any wireless network adapter on the market today.[2]

1. On some systems, the older, device-specific programs, such as `wicontrol` and `ancontrol`, are still around, but for the most part, they are deprecated and have long been replaced with `ifconfig` functionality. On OpenBSD, the consolidation into `ifconfig` has been completed.

2. A quick man page lookup on OpenBSD will tell you that the command to change the MAC address for the interface `rum0` is simply `ifconfig rum0 lladdr 00:ba:ad:f0:0d:11`.

NOTE *If you really want to try MAC address filtering, you could look into using the* `bridge(4)` *facility and the bridge-related rule options in* `ifconfig(8)` *on OpenBSD 4.7 and later. We'll look at bridges and some of the more useful ways to use them with packet filtering in Chapter 5. Note that you can use the bridge filtering without really running a bridge by just adding one interface to the bridge.*

WEP

One consequence of using radio waves instead of wires to move data is that it's comparatively easier for outsiders to capture data in transit over radio waves. The designers of the 802.11 family of wireless network standards seem to have been aware of this fact, and they came up with a solution that they went on to market under the name *Wired Equivalent Privacy*, or *WEP*.

Unfortunately, the WEP designers came up with their wired equivalent encryption without actually reading up on recent research or consulting active researchers in the field. So the link-level encryption scheme they recommended is considered a pretty primitive homebrew among cryptography professionals. It was no great surprise when WEP encryption was reverse-engineered and cracked within a few months after the first products were released.

Even though you can download free tools to descramble WEP-encoded traffic in a matter of minutes, for a variety of reasons, WEP is still widely supported and used. Essentially, all IEEE 802.11 equipment available today has support for at least WEP, and a surprising number offer MAC address filtering, too.

You should consider network traffic protected only by WEP to be just marginally more secure than data broadcast in the clear. Then again, the token effort needed to crack into a WEP network may be sufficient to deter lazy and unsophisticated attackers.

WPA

It dawned on the 802.11 designers fairly quickly that their WEP system wasn't quite what it was cracked up to be, so they came up with a revised and slightly more comprehensive solution called *Wi-Fi Protected Access*, or *WPA*.

WPA looks better than WEP, at least on paper, but the specification is complicated enough that its widespread implementation was delayed. In addition, WPA has attracted its share of criticism over design issues and bugs that have produced occasional interoperability problems. Combined with the familiar issues of access to documentation and hardware, free software support varies. Most free systems have WPA support, and even though you may find that it's not available for all devices, the situation has been improving over time. If your project specification includes WPA, look carefully at your operating system and driver documentation.

And, of course, it goes almost without saying that you'll need further security measures, such as SSH or SSL encryption, to maintain any significant level of confidentiality for your data stream.

The Right Hardware for the Task

Picking the right hardware is not necessarily a daunting task. On a BSD system, the following simple command is all you need to enter to see a listing of all manual pages with the word *wireless* in their subject lines.[3]

```
$ apropos wireless
```

Even on a freshly installed system, this command will give you a complete list of all wireless network drivers available in the operating system.

The next step is to read the driver manual pages and compare the lists of compatible devices with what is available as parts or built into the systems you're considering. Take some time to think through your specific requirements. For test purposes, low-end `rum` or `ural` USB dongles (or the newer `urtwn` and `run`) will work and are quite convenient. Later, when you're about to build a more permanent infrastructure, you may want to look into higher-end gear, although you may find that the inexpensive test gear will perform quite well. Some wireless chipsets require firmware that for legal reasons can't be distributed on the OpenBSD install media. In most cases, the *fw_update* script will be able to fetch the required firmware on first boot after a successful install, as long as a network connection is available. If you install the units in an already configured system, you can try running *fw_update* manually. You may also want to read Appendix B of this book for some further discussion.

Setting Up a Simple Wireless Network

For our first wireless network, it makes sense to use the basic gateway configuration from the previous chapter as our starting point. In your network design, it's likely that the wireless network isn't directly attached to the Internet at large but that the wireless network will require a gateway of some sort. For that reason, it makes sense to reuse the working gateway setup for this wireless access point, with some minor modifications introduced over the next few paragraphs. After all, doing so is more convenient than starting a new configuration from scratch.

NOTE *We're in infrastructure-building mode here, and we'll be setting up the access point first. If you prefer to look at the client setup first, see* *"The Client Side" on page 55.*

The first step is to make sure you have a supported card and to check that the driver loads and initializes the card properly. The boot-time system messages scroll by on the console, but they're also recorded in the file

3. In addition, it's possible to look up man pages on the Web. Check *http://www.openbsd.org/* and the other project websites. They offer keyword-based man page searching.

/var/run/dmesg.boot. You can view the file itself or use the `dmesg` command to see these messages. With a successfully configured PCI card, you should see something like this:

```
ral0 at pci1 dev 10 function 0 "Ralink RT2561S" rev 0x00: apic 2 int 11 (irq
11), address 00:25:9c:72:cf:60
ral0: MAC/BBP RT2561C, RF RT2527
```

If the interface you want to configure is a hot-pluggable type, such as a USB or PC Card device, you can see the kernel messages by viewing the */var/log/messages* file—for example, by running `tail -f` on the file before you plug in the device.

Next, you need to configure the interface: first to enable the link and, finally, to configure the system for TCP/IP. You can do this from the command line, like this:

```
$ sudo ifconfig ral0 up mediaopt hostap mode 11g chan 1 nwid unwiredbsd nwkey 0x1deadbeef9
```

This command does several things at once. It configures the `ral0` interface, enables the interface with the `up` parameter, and specifies that the interface is an access point for a wireless network with `mediaopt hostap`. Then, it explicitly sets the operating mode to `11g` and the channel to `11`. Finally, it uses the `nwid` parameter to set the network name to `unwiredbsd`, with the WEP key (`nwkey`) set to the hexadecimal string `0x1deadbeef9`.

Use `ifconfig` to check that the command successfully configured the interface:

```
$ ifconfig ral0
ral0: flags=8843<UP,BROADCAST,RUNNING,SIMPLEX,MULTICAST> mtu 1500
        lladdr 00:25:9c:72:cf:60
        priority: 4
        groups: wlan
        media: IEEE802.11 autoselect mode 11g hostap
        status: active
        ieee80211: nwid unwiredbsd chan 1 bssid 00:25:9c:72:cf:60 nwkey <not displayed> 100dBm
        inet6 fe80::225:9cff:fe72:cf60%ral0 prefixlen 64 scopeid 0x2
```

Note the contents of the `media` and `ieee80211` lines. The information displayed here should match what you entered on the `ifconfig` command line.

With the link part of your wireless network operational, you can assign an IP address to the interface. First, set an IPv4 address:

```
$ sudo ifconfig ral0 10.50.90.1 255.255.255.0
```

Setting an IPv6 is equally straightforward:

```
$ sudo ifconfig alias ral0 2001:db8::baad:f00d:1 64
```

On OpenBSD, you can combine both steps into one by creating a */etc/hostname.ral0* file, roughly like this:

```
up mediaopt hostap mode 11g chan 1 nwid unwiredbsd nwkey 0x1deadbeef9
inet6 alias 2001:db8::baad:f00d:1 64
```

Then, run **`sh /etc/netstart ral0`** (as root) or wait patiently for your next boot to complete.

Notice that the preceding configuration is divided over several lines. The first line generates an `ifconfig` command that sets up the interface with the correct parameters for the physical wireless network. The second line generates the command that sets the IPv4 address after the first command completes, followed by setting an IPv6 address for a dual-stack configuration. Because this is our access point, we set the channel explicitly, and we enable weak WEP encryption by setting the `nwkey` parameter.

On NetBSD, you can normally combine all of these parameters in one *rc.conf* setting:

```
ifconfig_ral0="mediaopt hostap mode 11g chan 1 nwid unwiredbsd nwkey
0x1deadbeef inet 10.50.90.1 netmask 255.255.255.0 inet6 2001:db8::baad:f00d:1
prefixlen 64 alias"
```

FreeBSD 8 and newer versions take a slightly different approach, tying wireless network devices to the unified `wlan(4)` driver. Depending on your kernel configuration, you may need to add the relevant module load lines to */boot/loader.conf*. On one of my test systems, */boot/loader.conf* looks like this:

```
if_rum_load="YES"
wlan_scan_ap_load="YES"
wlan_scan_sta_load="YES"
wlan_wep_load="YES"
wlan_ccmp_load="YES"
wlan_tkip_load="YES"
```

With the relevant modules loaded, setup is a multicommand affair, best handled by a *start_if.if* file for your wireless network. Here is an example of an */etc/start_if.rum0* file for a WEP access point on FreeBSD 8:

```
wlans_rum0="wlan0"
create_args_wlan0="wlandev rum0 wlanmode hostap"
ifconfig_wlan0="inet 10.50.90.1 netmask 255.255.255.0 ssid unwiredbsd \
wepmode on wepkey 0x1deadbeef9 mode 11g"
ifconfig_wlan0_ipv6="2001:db8::baad:f00d:1 prefixlen 64"
```

After a successful configuration, your `ifconfig` output should show both the physical interface and the `wlan` interface up and running:

```
rum0: flags=8843<UP,BROADCAST,RUNNING,SIMPLEX,MULTICAST> metric 0 mtu 2290
        ether 00:24:1d:9a:bf:67
```

```
        media: IEEE 802.11 Wireless Ethernet autoselect mode 11g <hostap>
        status: running
wlan0: flags=8843<UP,BROADCAST,RUNNING,SIMPLEX,MULTICAST> metric 0 mtu 1500
        ether 00:24:1d:9a:bf:67
        inet 10.50.90.1 netmask 0xffffff00 broadcast 10.50.90.255
        inet6 2001:db8::baad:f00d:1 prefixlen 64
        media: IEEE 802.11 Wireless Ethernet autoselect mode 11g <hostap>
        status: running
        ssid unwiredbsd channel 6 (2437 Mhz 11g) bssid 00:24:1d:9a:bf:67
        country US authmode OPEN privacy ON deftxkey UNDEF wepkey 1:40-bit
        txpower 0 scanvalid 60 protmode CTS dtimperiod 1 -dfs
```

The line `status: running` means that you're up and running, at least on the link level.

NOTE *Be sure to check the most up-to-date `ifconfig` man page for other options that may be more appropriate for your configuration.*

An OpenBSD WPA Access Point

WPA support was introduced in OpenBSD 4.4, with extensions to most wireless network drivers, and all basic WPA keying functionality was merged into `ifconfig(8)` in OpenBSD 4.9.

NOTE *There may still be wireless network drivers that don't have WPA support, so check the driver's man page to see whether WPA is supported before you try to configure your network to use it. You can combine 802.1x key management with an external authentication server for "enterprise" mode via the `security/wpa_supplicant` package, but we'll stick to the simpler preshared key setup for our purposes.*

The procedure for setting up an access point with WPA is quite similar to the one we followed for WEP. For a WPA setup with a preshared key (sometimes referred to as a *network password*), you would typically write a *hostname.if* file like this:

```
up media autoselect mediaopt hostap mode 11g chan 1 nwid unwiredbsd wpakey 0x1deadbeef9
inet6 alias 2001:db8::baad:f00d:1 64
```

If you're already running the WEP setup described earlier, disable those settings with the following:

```
$ sudo ifconfig ral0 -nwid -nwkey
```

Then, enable the new settings with this command:

```
$ sudo sh /etc/netstart ral0
```

You can check that the access point is up and running with `ifconfig`:

```
$ ifconfig ral0
ral0: flags=8843<UP,BROADCAST,RUNNING,SIMPLEX,MULTICAST> mtu 1500
        lladdr 00:25:9c:72:cf:60
        priority: 4
        groups: wlan
        media: IEEE802.11 autoselect mode 11g hostap
        status: active
        ieee80211: nwid unwiredbsd chan 1 bssid 00:25:9c:72:cf:60 wpapsk <not displayed>
wpaprotos wpa1,wpa2 wpaakms psk wpaciphers tkip,ccmp wpagroupcipher tkip 100dBm
        inet6 fe80::225:9cff:fe72:cf60%ral0 prefixlen 64 scopeid 0x2
        inet6 2001:db8::baad:f00d:1 prefixlen 64
        inet 10.50.90.1 netmask 0xff000000 broadcast 10.255.255.255
```

Note the `status: active` indication and that the WPA options we didn't set explicitly are shown with their sensible default values.

A FreeBSD WPA Access Point

Moving from the WEP access point we configured earlier to a somewhat safer WPA setup is straightforward. WPA support on FreeBSD comes in the form of `hostapd` (a program that is somewhat similar to OpenBSD's `hostapd` but not identical). We start by editing the */etc/start_if.rum0* file to remove the authentication information. The edited file should look something like this:

```
wlans_rum0="wlan0"
create_args_wlan0="wlandev rum0 wlanmode hostap"
ifconfig_wlan0="inet 10.50.90.1 netmask 255.255.255.0 ssid unwiredbsd mode 11g"
ifconfig_wlan0_ipv6="2001:db8::baad:f00d:1 prefixlen 64"
```

Next, we add the enable line for `hostapd` in */etc/rc.conf*:

```
hostapd_enable="YES"
```

And finally, `hostapd` will need some configuration of its own, in */etc/hostapd.conf*:

```
interface=wlan0
debug=1
ctrl_interface=/var/run/hostapd
ctrl_interface_group=wheel
ssid=unwiredbsd
wpa=1
wpa_passphrase=0x1deadbeef9
wpa_key_mgmt=WPA-PSK
wpa_pairwise=CCMP TKIP
```

Here, the interface specification is rather self-explanatory, while the `debug` value is set to produce minimal messages. The range is `0` through `4`, where `0` is no debug messages at all. You shouldn't need to change the `ctrl_interface*` settings unless you're developing `hostapd`. The first of the next five lines

sets the network identifier. The subsequent lines enable WPA and set the passphrase. The final two lines specify accepted key-management algorithms and encryption schemes. (For the finer details and updates, see the `hostapd(8)` and `hostapd.conf(5)` man pages.)

After a successful configuration (running `sudo /etc/rc.d/hostapd forcestart` comes to mind), `ifconfig` should produce output about the two interfaces similar to this:

```
rum0: flags=8843<UP,BROADCAST,RUNNING,SIMPLEX,MULTICAST> metric 0 mtu 2290
        ether 00:24:1d:9a:bf:67
        media: IEEE 802.11 Wireless Ethernet autoselect mode 11g <hostap>
        status: running
wlan0: flags=8843<UP,BROADCAST,RUNNING,SIMPLEX,MULTICAST> metric 0 mtu 1500
        ether 00:24:1d:9a:bf:67
        inet 10.50.90.1 netmask 0xffffff00 broadcast 10.50.90.255
        inet6 2001:db8::baad:f00d:1 prefixlen 64
        media: IEEE 802.11 Wireless Ethernet autoselect mode 11g <hostap>
        status: running
        ssid unwiredbsd channel 6 (2437 Mhz 11g) bssid 00:24:1d:9a:bf:67
        country US authmode WPA privacy MIXED deftxkey 2 TKIP 2:128-bit
        txpower 0 scanvalid 60 protmode CTS dtimperiod 1 -dfs
```

The line `status: running` means that you're up and running, at least on the link level.

The Access Point's PF Rule Set

With the interfaces configured, it's time to start configuring the access point as a packet-filtering gateway. You can start by copying the basic gateway setup from Chapter 3. Enable gatewaying via the appropriate entries in the access point's *sysctl.conf* or *rc.conf* file and then copy across the *pf.conf* file. Depending on the parts of the previous chapter that were most useful to you, the *pf.conf* file may look something like this:

```
ext_if = "re0" # macro for external interface - use tun0 or pppoe0 for PPPoE
int_if = "re1" # macro for internal interface
localnet = $int_if:network
# nat_address = 203.0.113.5 # Set addess for nat-to
client_out = "{ ssh, domain, pop3, auth, nntp, http,\
               https, cvspserver, 2628, 5999, 8000, 8080 }"
udp_services = "{ domain, ntp }"
icmp_types = "{ echoreq, unreach }"
# if IPv6, some ICMP6 accommodation is needed
icmp6_types = "{ echoreq unreach timex paramprob }"
# If ext_if IPv4 address is dynamic, ($ext_if) otherwise nat to specific address, ie
# match out on $ext_if inet from $localnet nat-to $nat_address
match out on $ext_if inet from $localnet nat-to ($ext_if)
block all
pass quick inet proto { tcp, udp } from $localnet to port $udp_services
pass log inet proto icmp icmp-type $icmp_types
pass inet6 proto icmp6 icmp6-type $icmp6_types
pass inet proto tcp from $localnet port $client_out
```

If you're running a PF version equal to OpenBSD 4.6 or earlier, the `match` rule with `nat-to` instead becomes this (assuming the external interface has one address, dynamically assigned):

```
nat on $ext_if from $localnet to any -> ($ext_if)
```

The only difference that's strictly necessary for your access point to work is the definition of `int_if`. You must change the definition of `int_if` to match the wireless interface. In our example, this means the line should now read as follows:

```
int_if = "ral0"  # macro for internal interface
```

More than likely, you'll also want to set up `dhcpd` to serve addresses and other relevant network information to IPv4 clients after they've associated with your access point. For IPv6 networks, you probably want to set up `rtadvd` (or even a DHCP6 daemon) to aid your IPv6 clients in their autoconfiguration. Setting up `dhcpd` and `rtadvd` is fairly straightforward if you read the man pages.

That's all there is to it. This configuration gives you a functional BSD access point, with at least token security (actually more like a *Keep Out!* sign) via WEP encryption or a slightly more robust link-level encryption with WPA. If you need to support FTP, copy the `ftp-proxy` configuration from the machine you set up in Chapter 3 and make changes similar to those you made for the rest of the rule set.

Access Points with Three or More Interfaces

If your network design dictates that your access point is also the gateway for a wired local network, or even several wireless networks, you need to make some minor changes to your rule set. Instead of just changing the value of the `int_if` macro, you might want to add another (descriptive) definition for the wireless interface, such as the following:

```
air_if = "ral0"
```

Your wireless interfaces are likely to be on separate subnets, so it might be useful to have a separate rule for each of them to handle any IPv4 NAT configuration. Here's an example for OpenBSD 4.7 and newer systems:

```
match out on $ext_if from $air_if:network nat-to ($ext_if)
```

And here's one on pre–OpenBSD 4.7 PF versions:

```
nat on $ext_if from $air_if:network to any -> ($ext_if) static-port
```

Depending on your policy, you might also want to adjust your `localnet` definition, or at least include `$air_if` in your `pass` rules where appropriate. And once again, if you need to support FTP, a separate pass with divert or redirection for the wireless network to `ftp-proxy` may be in order.

Handling IPSec, VPN Solutions

You can set up *virtual private networks (VPNs)* using built-in IPsec tools, OpenSSH, or other tools. However, due to the perceived poor security profile of wireless networks in general or for other reasons, you're likely to want to set up some additional security.

The options fall roughly into three categories:

SSH If your VPN is based on SSH tunnels, the baseline rule set already contains all the filtering you need. Your tunneled traffic will be indistinguishable from other SSH traffic to the packet filter.

IPsec with UDP key exchange (IKE/ISAKMP) Several IPsec variants depend critically on key exchange via `proto udp port 500` and use `proto udp port 4500` for *NAT Traversal (NAT-T)*. You need to let this traffic through in order to let the flows become established. Almost all implementations also depend critically on letting ESP protocol traffic (protocol number 50) pass between the hosts with the following:

```
pass proto esp from $source to $target
```

Filtering on IPsec encapsulation interfaces With a properly configured IPsec setup, you can set up PF to filter on the encapsulation interface `enc0` itself with the following:[4]

```
pass on enc0 proto ipencap from $source to $target keep state (if-bound)
```

See Appendix A for references to some of the more useful literature on the subject.

The Client Side

As long as you have BSD clients, setup is extremely easy. The steps involved in connecting a BSD machine to a wireless network are quite similar to the ones we just went through to set up a wireless access point. On OpenBSD, the configuration centers on the *hostname.if* file for the wireless interface. On FreeBSD, the configuration centers on *rc.conf* but will most likely involve a few other files, depending on your exact configuration.

4. In OpenBSD 4.8, the encapsulation interface became a cloneable interface, and you can configure several separate `enc` interfaces. All `enc` interfaces become members of the `enc` interface group.

OpenBSD Setup

Starting with the OpenBSD case, in order to connect to the WEP access point we just configured, your OpenBSD clients need a *hostname.if* (for example, */etc/hostname.ral0*) configuration file with these lines:

```
up media autoselect mode 11g chan 1 nwid unwiredbsd nwkey 0x1deadbeef9
dhcp
rtsol
```

The first line sets the link-level parameters in more detail than usually required. Only `up` and the `nwid` and `nwkey` parameters are strictly necessary. In almost all cases, the driver will associate with the access point on the appropriate channel and in the best available mode. The second line calls for a DHCP configuration and, in practice, causes the system to run a `dhclient` command to retrieve TCP/IP configuration information. The final line invokes `rtsol(8)` to initiate IPv6 configuration.

If you choose to go with the WPA configuration, the file will look like this instead:

```
up media autoselect mode 11g chan 1 nwid unwiredbsd wpakey 0x1deadbeef9
dhcp
rtsol
```

Again, the first line sets the link-level parameters, where the crucial ones are the network selection and encryption parameters `nwid` and `wpakey`. You can try omitting the `mode` and `chan` parameters; in almost all cases, the driver will associate with the access point on the appropriate channel and in the best available mode.

If you want to try out the configuration commands from the command line before committing the configuration to your */etc/hostname.if* file, the command to set up a client for the WEP network is as follows:

```
$ sudo ifconfig ral0 up mode 11g chan 1 nwid unwiredbsd nwkey 0x1deadbeef9
```

The `ifconfig` command should complete without any output. You can then use `ifconfig` to check that the interface was successfully configured. The output should look something like this:

```
$ ifconfig ral0
ral0: flags=8843<UP,BROADCAST,RUNNING,SIMPLEX,MULTICAST> mtu 1500
        lladdr 00:25:9c:72:cf:60
        priority: 4
        groups: wlan
        media: IEEE802.11 autoselect (OFDM54 mode 11g)
        status: active
        ieee80211: nwid unwiredbsd chan 1 bssid 00:25:9c:72:cf:60 nwkey <not displayed> 100dBm
        inet6 fe80::225:9cff:fe72:cf60%ral0 prefixlen 64 scopeid 0x2
```

Note that the `ieee80211:` line displays the network name and channel, along with a few other parameters. The information displayed here should match what you entered on the `ifconfig` command line.

Here is the command to configure your OpenBSD client to connect to the WPA network:

```
$ sudo ifconfig ral0 nwid unwiredbsd wpakey 0x1deadbeef9
```

The command should complete without any output. If you use `ifconfig` again to check the interface status, the output will look something like this:

```
$ ifconfig ral0
ral0: flags=8843<UP,BROADCAST,RUNNING,SIMPLEX,MULTICAST> mtu 1500
        lladdr 00:25:9c:72:cf:60
        priority: 4
        groups: wlan
        media: IEEE802.11 autoselect (OFDM54 mode 11g)
        status: active
        ieee80211: nwid unwiredbsd chan 1 bssid 00:25:9c:72:cf:60 wpapsk <not
displayed> wpaprotos wpa1,wpa2 wpaakms psk wpaciphers tkip,ccmp wpagroupcipher
tkip 100dBm
        inet6 fe80::225:9cff:fe72:cf60%ral0 prefixlen 64 scopeid 0x2
```

Check that the `ieee80211:` line displays the correct network name and sensible WPA parameters.

Once you are satisfied that the interface is configured at the link level, use the `dhclient` command to configure the interface for TCP/IP, like this:

```
$ sudo dhclient ral0
```

The `dhclient` command should print a summary of its dialogue with the DHCP server that looks something like this:

```
DHCPREQUEST on ral0 to 255.255.255.255 port 67
DHCPREQUEST on ral0 to 255.255.255.255 port 67
DHCPACK from 10.50.90.1 (00:25:9c:72:cf:60)
bound to 10.50.90.11 -- renewal in 1800 seconds.
```

To initialize the interface for IPv6, enter the following:

```
$ sudo rtsol ral0
```

The `rtsol` command normally completes without any messages. Check the interface configuration with `ifconfig` to see that the interface did in fact receive an IPv6 configuration.

FreeBSD Setup

On FreeBSD, you may need to do a bit more work than is necessary with OpenBSD. Depending on your kernel configuration, you may need to add the relevant module load lines to */boot/loader.conf*. On one of my test systems, */boot/loader.conf* looks like this:

```
if_rum_load="YES"
wlan_scan_ap_load="YES"
wlan_scan_sta_load="YES"
wlan_wep_load="YES"
wlan_ccmp_load="YES"
wlan_tkip_load="YES"
```

With the relevant modules loaded, you can join the WEP network we configured earlier by issuing the following command:

```
$ sudo ifconfig wlan create wlandev rum0 ssid unwiredbsd wepmode on wepkey 0x1deadbeef9 up
```

Then, issue this command to get an IPv4 configuration for the interface:

```
$ sudo dhclient wlan0
```

To initialize the interface for IPv6, enter the following:

```
$ sudo rtsol ral0
```

The `rtsol` command normally completes without any messages. Check the interface configuration with `ifconfig` to see that the interface did in fact receive an IPv6 configuration.

For a more permanent configuration, create a *start_if.rum0* file (replace *rum0* with the name of the physical interface if it differs) with content like this:

```
wlans_rum0="wlan0"
create_args_wlan0="wlandev rum0 ssid unwiredbsd wepmode on wepkey 0x1deadbeef9 up"
ifconfig_wlan0="DHCP"
ifconfig_wlan0_ipv6="inet6 accept_rtadv"
```

If you want to join the WPA network, you need to set up `wpa_supplicant` and change your network interface settings slightly. For the WPA access point, connect with the following configuration in your *start_if.rum0* file:

```
wlans_rum0="wlan0"
create_args_wlan0="wlandev rum0"
ifconfig_wlan0="WPA"
```

You also need an */etc/wpa_supplicant.conf* file that contains the following:

```
network={
  ssid="unwiredbsd"
  psk="0x1deadbeef9"
}
```

Finally, add a second `ifconfig_wlan0` line in *rc.conf* to ensure that `dhclient` runs correctly.

```
ifconfig_wlan0="DHCP"
```

For the IPv6 configuration, add the following line to *rc.conf*:

```
ifconfig_wlan0_ipv6="inet6 accept_rtadv"
```

Other WPA networks may require additional options. After a successful configuration, the `ifconfig` output should display something like this:

```
rum0: flags=8843<UP,BROADCAST,RUNNING,SIMPLEX,MULTICAST> metric 0 mtu 2290
        ether 00:24:1d:9a:bf:67
        media: IEEE 802.11 Wireless Ethernet autoselect mode 11g
        status: associated
wlan0: flags=8843<UP,BROADCAST,RUNNING,SIMPLEX,MULTICAST> metric 0 mtu 1500
        ether 00:24:1d:9a:bf:67
        inet 10.50.90.16 netmask 0xffffff00 broadcast 10.50.90.255
        inet6 2001:db8::baad:f00d:1635 prefixlen 64
        media: IEEE 802.11 Wireless Ethernet OFDM/36Mbps mode 11g
        status: associated
        ssid unwiredbsd channel 1 (2412 Mhz 11g) bssid 00:25:9c:72:cf:60
        country US authmode WPA2/802.11i privacy ON deftxkey UNDEF
        TKIP 2:128-bit txpower 0 bmiss 7 scanvalid 450 bgscan bgscanintvl 300
        bgscanidle 250 roam:rssi 7 roam:rate 5 protmode CTS roaming MANUAL
```

Guarding Your Wireless Network with authpf

Security professionals tend to agree that even though WEP encryption offers little protection, it's just barely enough to signal to would-be attackers that you don't intend to let all and sundry use your network resources. Using WPA increases security significantly, at the cost of some complexity in contexts that require the "enterprise"-grade options.

The configurations we've built so far in this chapter are functional. Both the WEP and WPA configurations will let all reasonably configured wireless clients connect, and that may be a problem in itself because that configuration doesn't have any real support built in for letting you decide who uses your network.

As mentioned earlier, MAC address filtering is not really a solid defense against attackers because changing a MAC address is just too easy. The OpenBSD developers chose a radically different approach to this problem when they introduced `authpf` in OpenBSD version 3.1. Instead of tying access to a hardware identifier, such as the network card's MAC address, they decided that the robust and highly flexible user authentication mechanisms already in place were more appropriate for the task. The user shell `authpf` lets the system load PF rules on a per-user basis, effectively deciding which user gets to do what.

To use `authpf`, you create users with the `authpf` program as their shell. In order to get network access, the user logs in to the gateway using SSH. Once the user successfully completes SSH authentication, `authpf` loads the rules you have defined for the user or the relevant class of users.

These rules, which usually are written to apply only to the IP address the user logged in from, stay loaded and in force for as long as the user stays logged in via the SSH connection. Once the SSH session is terminated, the rules are unloaded, and in most scenarios, all non-SSH traffic from the user's IP address is denied. With a reasonable setup, only traffic originated by authenticated users will be let through.

NOTE *On OpenBSD, `authpf` is one of the login classes offered by default, as you'll notice the next time you create a user with `adduser`.*

For systems where the `authpf` login class isn't available by default, you may need to add the following lines to your */etc/login.conf* file:

```
authpf:\
        :welcome=/etc/motd.authpf:\
        :shell=/usr/sbin/authpf:\
        :tc=default:
```

The next couple of sections contain a few examples that may or may not fit your situation directly but that I hope will give you ideas you can use.

A Basic Authenticating Gateway

Setting up an authenticating gateway with `authpf` involves creating and maintaining a few files besides your basic *pf.conf*. The main addition is *authpf.rules*. The other files are fairly static entities that you won't be spending much time on once they've been created.

Start by creating an empty */etc/authpf/authpf.conf* file. This file needs to be there in order for `authpf` to work, but it doesn't actually need any content, so creating an empty file with touch is appropriate.

The other relevant bits of */etc/pf.conf* follow. First, here are the interface macros:

```
ext_if = "re0"
int_if = "athn0"
```

In addition, if you define a table called <authpf_users>, authpf will add the IP addresses of authenticated users to the table:

```
table <authpf_users> persist
```

If you need to run NAT, the rules that take care of the translation could just as easily go in *authpf.rules*, but keeping them in the *pf.conf* file doesn't hurt in a simple setup like this:

```
pass out on $ext_if inet from $localnet nat-to ($ext_if)
```

Here's pre–OpenBSD 4.7 syntax:

```
nat on $ext_if inet from $localnet to any -> ($ext_if)
```

Next, we create the authpf anchor, where rules from *authpf.rules* are loaded once the user authenticates:

```
anchor "authpf/*"
```

For pre–OpenBSD 4.7 authpf versions, several anchors were required, so the corresponding section would be as follows:

```
nat-anchor "authpf/*"
rdr-anchor "authpf/*"
binat-anchor "authpf/*"
anchor "authpf/*"
```

This brings us to the end of the required parts of a *pf.conf* file for an authpf setup.

For the filtering part, we start with the block all default and then add the pass rules we need. The only essential item at this point is to let SSH traffic pass on the internal network:

```
pass quick on $int_if proto { tcp, udp } to $int_if port ssh
```

From here on out, it really is up to you. Do you want to let your clients have name resolution before they authenticate? If so, put the pass rules for the TCP and UDP service domain in your *pf.conf* file, too.

For a relatively simple and egalitarian setup, you could include the rest of our baseline rule set, changing the pass rules to allow traffic from the addresses in the <authpf_users> table, rather than any address in your local network:

```
pass quick proto { tcp, udp } from <authpf_users> to port $udp_services
pass proto tcp from <authpf_users> to port $client_out
```

For a more differentiated setup, you could put the rest of your rule set in */etc/authpf/authpf.rules* or per-user rules in customized *authpf.rules* files in each user's directory under */etc/authpf/users/*. If your users generally need some protection, your general */etc/authpf/authpf.rules* could have content like this:

```
client_out = "{ ssh, domain, pop3, auth, nntp, http, https }"
udp_services = "{ domain, ntp }"
pass quick proto { tcp, udp } from $user_ip to port $udp_services
pass proto tcp from $user_ip to port $client_out
```

The macro `user_ip` is built into `authpf` and expands to the IP address from which the user authenticated. These rules will apply to any user who completes authentication at your gateway.

A nice and relatively easy addition to implement is special-case rules for users with different requirements than your general user population. If an *authpf.rules* file exists in the user's directory under */etc/authpf/users/*, the rules in that file will be loaded for the user. This means that your naive user Peter who only needs to surf the Web and have access to a service that runs on a high port on a specific machine could get what he needs with a */etc/authpf/users/peter/authpf.rules* file like this:

```
client_out = "{ domain, http, https }"
pass inet from $user_ip to 192.168.103.84 port 9000
pass quick inet proto { tcp, udp } from $user_ip to port $client_out
```

On the other hand, Peter's colleague Christina runs OpenBSD and generally knows what she's doing, even if she sometimes generates traffic to and from odd ports. You could give her free rein by putting this in */etc/authpf/users/christina/authpf.rules*:

```
pass from $user_ip os = "OpenBSD" to any
```

This means Christina can do pretty much anything she likes over TCP/IP as long as she authenticates from her OpenBSD machines.

Wide Open but Actually Shut

In some settings, it makes sense to set up your network to be open and unencrypted at the link level, while enforcing some restrictions via `authpf`. The next example is very similar to Wi-Fi zones you may encounter in airports or other public spaces, where anyone can associate to the access points and get an IP address, but any attempt at accessing the Web will be redirected to one specific Web page until the user has cleared some sort of authentication.[5]

5. Thanks to Vegard Engen for the idea and for showing me his configuration, which is preserved here in spirit, if not in all its details.

This *pf.conf* file is again built on our baseline, with two important additions to the basic `authpf` setup—a macro and a redirection:

```
ext_if = "re0"
int_if = "ath0"
auth_web="192.168.27.20"
dhcp_services = "{ bootps, bootpc }" # DHCP server + client
table <authpf_users> persist
pass in quick on $int_if proto tcp from ! <authpf_users> to port http rdr-to $auth_web
match out on $ext_if from $int_if:network nat-to ($ext_if)
anchor "authpf/*"
block all
pass quick on $int_if inet proto { tcp, udp } to $int_if port $dhcp_services
pass quick inet proto { tcp, udp } from $int_if:network to any port domain
pass quick on $int_if inet proto { tcp, udp } to $int_if port ssh
For older authpf versions, use this file instead:
ext_if = "re0"
int_if = "ath0"
auth_web="192.168.27.20"
dhcp_services = "{ bootps, bootpc }" # DHCP server + client
table <authpf_users> persist
rdr pass on $int_if proto tcp from ! <authpf_users> to any port http -> $auth_web
nat on $ext_if from $localnet to any -> ($ext_if)
nat-anchor "authpf/*"
rdr-anchor "authpf/*"
binat-anchor "authpf/*"
anchor "authpf/*"
block all
pass quick on $int_if inet proto { tcp, udp } to $int_if port $dhcp_services
pass quick inet proto { tcp, udp } from $int_if:network to port domain
pass quick on $int_if inet proto { tcp, udp } to $int_if port ssh
```

The `auth_web` macro and the redirection make sure all Web traffic from addresses that are not in the `<authpf_users>` table leads all nonauthenticated users to a specific address. At that address, you set up a Web server that serves up whatever you need. This could range from a single page with instructions on whom to contact in order to get access to the network all the way up to a system that accepts credit cards and handles user creation.

Note that in this setup, name resolution will work, but all surfing attempts will end up at the `auth_web` address. Once the users clear authentication, you can add general rules or user-specific ones to the *authpf.rules* files as appropriate for your situation.

5

BIGGER OR TRICKIER NETWORKS

In this chapter, we'll build on the material in previous chapters to meet the real-life challenges of both large and small networks with relatively demanding applications or users. The sample configurations in this chapter are based on the assumption that your packet-filtering setups will need to accommodate services you run on your local network. We'll mainly look at this challenge from a Unix perspective, focusing on SSH, email, and Web services (with some pointers on how to take care of other services).

This chapter is about the things to do when you need to combine packet filtering with services that must be accessible outside your local network. How much this complicates your rule sets will depend on your network design and, to a certain extent, on the number of routable addresses you have available. We'll begin with configurations for official, routable IPv4 addresses as well as the generally roomier IPv6 address ranges. Then, we'll move on to situations with as few as one routable IPv4 address and the PF-based work-arounds that make the services usable even under these restrictions.

A Web Server and Mail Server on the Inside: Routable IPv4 Addresses

How complicated is your network? How complicated does it need to be?

We'll start with the baseline scenario of the sample clients from Chapter 3. We set up the clients behind a basic PF firewall and give them access to a range of services hosted elsewhere but no services running on the local network. These clients get three new neighbors: a mail server, a Web server, and a file server. In this scenario, we use official, routable IPv4 addresses because it makes life a little easier. Another advantage of this approach is that with routable addresses, we can let two of the new machines run DNS for our *example.com* domain: one as the master and the other as an authoritative slave.[1] And as you'll see, adding IPv6 addresses and running a dual-stack network won't necessarily make your rule set noticeably more complicated.

NOTE *For DNS, it always makes sense to have at least one authoritative slave server somewhere outside your own network (in fact, some top-level domains won't let you register a domain without it). You may also want to arrange for a backup mail server to be hosted elsewhere. Keep these things in mind as you build your network.*

At this stage, we keep the physical network layout fairly simple. We put the new servers in the same local network as the clients—possibly in a separate server room but certainly on the same network segment or switch as the clients. Conceptually, the new network looks something like Figure 5-1.

With the basic parameters for the network in place, we can start setting up a sensible rule set for handling the services we need. Once again, we start from the baseline rule set and add a few macros for readability.

The macros we need come rather naturally from the specifications:

- Web server:

```
webserver = "{ 192.0.2.227, 2001:db8::baad:f00d:f17 }"
```

- Web server services:

```
webports = "{ http, https }"
```

- Mail server:

```
emailserver = "{ 192.0.2.225, 2001:db8::baad:f00d:f117 }"
```

1. In fact, the *example.com* network here lives in the 192.0.2.0/24 block, which is reserved in RFC 3330 for example and documentation use. We use this address range mainly to differentiate from the NAT examples elsewhere in this book, which use addresses in the "private" RFC 1918 address space.

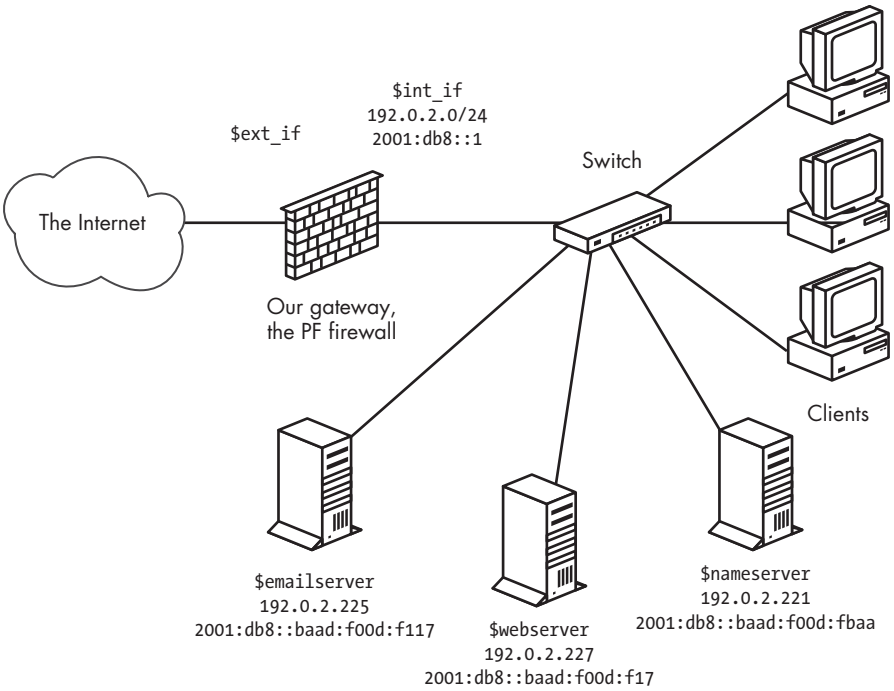

Figure 5-1: A basic network with servers and clients on the inside

- Mail server services:

```
email = "{ smtp, pop3, imap, imap3, imaps, pop3s }"
```

- Name servers:

```
nameservers = "{ 192.0.2.221,  192.0.2.223 , \
                 2001:db8::baad:f00d:fbaa, 2001:db8::baad:f00d:ff00 }"
```

NOTE *At this point, you've probably noticed that both the IPv4 and IPv6 addresses for our servers are placed fairly close together within their respective address ranges. Some schools of thought hold that in the case of IPv6, each interface should be allocated at least a /64 range if your total allocation can bear it. Others have advocated more modest allocations. The IETF's current best practice document on the matter is RFC6177, available from the IETF website (*http://www.ietf.org*).*

We assume that the file server doesn't need to be accessible to the outside world, unless we choose to set it up with a service that needs to be visible outside the local network, such as an authoritative slave name server for our domain. Then, with the macros in hand, we add the `pass` rules. Starting with the Web server, we make it accessible to the world with the following:

```
pass proto tcp to $webserver port $webports
```

IS SYNPROXY WORTH THE TROUBLE?

Over the years, the `synproxy state` option has received a lot of attention as a possible bulwark against ill-intentioned traffic from the outside. Specifically, the `synproxy state` option was intended to protect against SYN-flood attacks that could lead to resource exhaustion at the back end.

It works like this: When a new connection is created, PF normally lets the communication partners handle the connection setup themselves, simply passing the packets on if they match a `pass` rule. With `synproxy` enabled, PF handles the initial connection setup and hands over the connection to the communication partners only once it's properly established, essentially creating a buffer between the communication partners. The SYN proxying is slightly more expensive than the default `keep state`, but not necessarily noticeably so on reasonably scaled equipment.

The potential downsides become apparent in load-balancing setups where a SYN-proxying PF could accept connections that the backend isn't ready to accept, in some cases short-circuiting the redundancy by setting up connections to hosts other than those the load-balancing logic would have selected. The classic example here is a pool of HTTP servers with round-robin DNS. But the problem becomes especially apparent in protocols like SMTP, where the built-in redundancy dictates (by convention, at least—the actual RFC is a bit ambiguous) that if a primary mail exchanger isn't accepting connections, you should try a secondary instead.

When considering a setup where `synproxy` seems attractive, keep these issues in mind and analyze the potential impact on your setup that would come from adding `synproxy` to the mix. If you conclude that SYN proxying is needed, simply tack on `synproxy state` at the end of the rules that need the option. The rule of thumb is, if you are under active attack, inserting the `synproxy` option may be useful as a temporary measure. Under normal circumstances, it isn't needed as a permanent part of your configuration.

On a similar note, we let the world talk to the mail server:

```
pass proto tcp to $emailserver port $email
```

This lets clients anywhere have the same access as the ones in your local network, including a few mail-retrieval protocols that may run without encryption. That's common enough in the real world, but you might want to consider your options if you're setting up a new network.

For the mail server to be useful, it needs to be able to send mail to hosts outside the local network, too:

```
pass log proto tcp from $emailserver to port smtp
```

Keep in mind that the rule set starts with a `block all` rule, which means that only the mail server is allowed to initiate SMTP traffic from the local network to the rest of the world. If any of the other hosts on the network need to send email to or receive email from the outside world, they need to use the designated mail server. This could be a good way to ensure, for example, that you make it as hard as possible for any spam-sending zombie machines that might turn up in your network to deliver their payloads.

Finally, the name servers need to be accessible to clients outside our network who look up the information about *example.com* and any other domains for which we answer authoritatively:

```
pass proto { tcp, udp } to $nameservers port domain
```

Having integrated all the services that need to be accessible from the outside world, our rule set ends up looking roughly like this:

```
ext_if = "ep0" # macro for external interface - use tun0 or pppoe0 for PPPoE
int_if = "ep1"  # macro for internal interface
localnet = $int_if:network
webserver = "{ 192.0.2.227, 2001:db8::baad:f00d:f17 }"
webports = "{ http, https }"
emailserver = "{ 192.0.2.225, 2001:db8::baad:f00d:f117 }"
email = "{ smtp, pop3, imap, imap3, imaps, pop3s }"
nameservers = "{ 192.0.2.221, 192.0.2.223, \
                 2001:db8::baad:f00d:fbaa, 2001:db8::baad:f00d:ff00 }"
client_out = "{ ssh, domain, pop3, auth, nntp, http,\
                https, cvspserver, 2628, 5999, 8000, 8080 }"
udp_services = "{ domain, ntp }"
icmp_types = "{ echoreq, unreach }"
icmp6_types = "{ echoreq unreach timex paramprob }"
block all
pass quick proto { tcp, udp } from $localnet to port $udp_services
pass log inet proto icmp all icmp-type $icmp_types
pass inet6 proto icmp6 icmp6-type $icmp6_types
pass proto tcp from $localnet to port $client_out
pass proto { tcp, udp } to $nameservers port domain
pass proto tcp to $webserver port $webports
pass log proto tcp to $emailserver port $email
pass log proto tcp from $emailserver to port smtp
```

This is still a fairly simple setup, but unfortunately, it has one potentially troubling security disadvantage. The way this network is designed, the servers that offer services to the world at large are all *in the same local network* as your clients, and you'd need to restrict any internal services to only local access. In principle, this means that an attacker would need to compromise only one host in your local network to gain access to any resource there, putting the miscreant on equal footing with any user in your local network. Depending on how well each machine and resource are protected from unauthorized access, this could be anything from a minor annoyance to a major headache.

In the next section, we'll look at some options for segregating the services that need to interact with the world at large from the local network.

A Degree of Separation: Introducing the DMZ

In the previous section, you saw how to set up services on your local network and make them selectively available to the outside world through a sensible PF rule set. For more fine-grained control over access to your internal network, as well as the services you need to make it visible to the rest of the world, add a degree of physical separation. Even a separate *virtual local area network (VLAN)* will do nicely.

Achieving the physical and logical separation is fairly easy: Simply move the machines that run the public services to a separate network that's attached to a separate interface on the gateway. The net effect is a separate network that isn't quite part of your local network but isn't entirely in the public part of the Internet either. Conceptually, the segregated network looks like Figure 5-2.

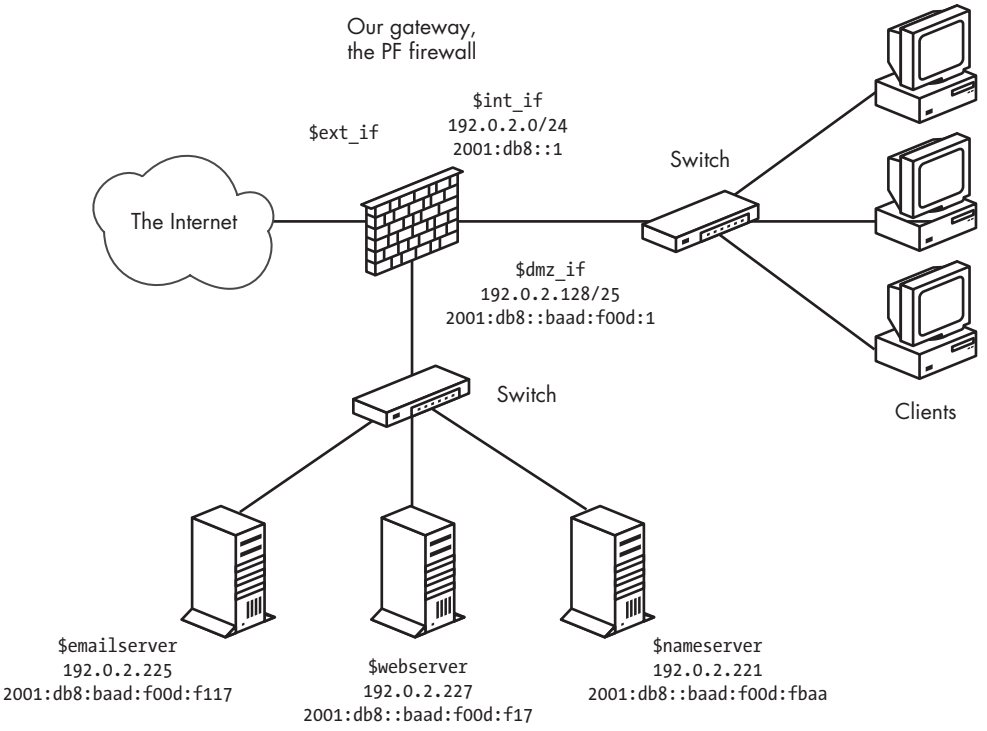

Figure 5-2: A network with the servers in a DMZ

NOTE *Think of this little network as a zone of relative calm between the territories of hostile factions. It's no great surprise that a few years back, someone coined the phrase* demilitarized zone (DMZ) *to describe this type of configuration.*

For address allocation, you can segment off an appropriately sized chunk of your official address space for the new DMZ network. Alternatively, you can move those parts of your network that don't have a specific need to run with publicly accessible and routable IPv4 addresses into a NAT environment. Either way, you end up with at least one more interface in your filtering configuration. As you'll see later, if you're really short of official IPv4 addresses, it's possible to run a DMZ setup in all-NAT environments as well.

The adjustments to the rule set itself don't need to be extensive. If necessary, you can change the configuration for each interface. The basic ruleset logic remains, but you may need to adjust the definitions of the macros (`webserver`, `mailserver`, `nameservers`, and possibly others) to reflect your new network layout.

In our example, we could choose to segment off the part of our address ranges where we've already placed our servers. If we leave some room for growth, we can set up the IPv4 range for the new `dmz_if` on a /25 subnet with a network address and netmask of 192.0.2.128/255.255.255.128. This leaves us with 192.0.2.129 through 192.0.2.254 as the usable address range for hosts in the DMZ. As we've already placed our servers in the 2001:db8::baad:f00d:0/112 network (with a measly 65,536 addresses to play with), the easiest way forward for the IPv6 range is to segment off that network, too, and assign the interface facing the network an appropriate IPv6 address, like the one in Figure 5-2.

With that configuration and no changes in the IP addresses assigned to the servers, you don't really need to touch the rule set at all for the packet filtering to work after setting up a physically segregated DMZ. That's a nice side effect, which could be due to either laziness or excellent long-range planning. Either way, it underlines the importance of having a sensible address-allocation policy in place.

It might be useful to tighten up your rule set by editing your `pass` rules so the traffic to and from your servers is allowed to pass only on the interfaces that are actually relevant to the services:

```
pass in on $ext_if proto { tcp, udp } to $nameservers port domain
pass in on $int_if proto { tcp, udp } from $localnet to $nameservers \
     port domain
pass out on $dmz_if proto { tcp, udp } to $nameservers port domain
pass in on $ext_if proto tcp to $webserver port $webports
pass in on $int_if proto tcp from $localnet to $webserver port $webports
pass out on $dmz_if proto tcp to $webserver port $webports
pass in log on $ext_if proto tcp to $mailserver port smtp
pass in log on $int_if proto tcp from $localnet to $mailserver \
     port $email
pass out log on $dmz_if proto tcp to $mailserver port smtp
pass in on $dmz_if from $mailserver to port smtp
pass out log on $ext_if proto tcp from $mailserver to port smtp
```

You could choose to make the other `pass` rules that reference your local network interface-specific, too, but if you leave them intact, they'll continue to work.

Sharing the Load: Redirecting to a Pool of Addresses

Once you've set up services to be accessible to the world at large, one likely scenario is that over time, one or more of your services will grow more sophisticated and resource-hungry or simply attract more traffic than you feel comfortable serving from a single server.

There are a number of ways to make several machines share the load of running a service, including ways to fine-tune the service itself. For the network-level load balancing, PF offers the basic functionality you need via redirection to tables or address pools. In fact, you can implement a form of load balancing without even touching your `pass` rules, at least if your environment is not yet dual-stack.

Take the Web server in our example. We already have the macro that represents a service, our Web server. For reasons that will become obvious in a moment, we need to reduce that macro to represent only the public IPv4 address (`webserver = "192.0.2.227"`), which, in turn, is associated with the hostname that your users have bookmarked, possibly *www.example.com*. When the time comes to share the load, set up the required number of identical, or at least equivalent, servers and then alter your rule set slightly to introduce the redirection. First, define a table that holds the addresses for your Web server pool's IPv4 addresses:

```
table <webpool> persist { 192.0.2.214, 192.0.2.215, 192.0.2.216, 192.0.2.217 }
```

Then, perform the redirection:

```
match in on $ext_if protp tcp to $webserver port $webports \
        rdr-to <webpool> round-robin
```

Unlike the redirections in earlier examples, such as the FTP proxy in Chapter 3, this rule sets up all members of the `webpool` table as potential redirection targets for incoming connections intended for the `webports` ports on the `webserver` address. Each incoming connection that matches this rule is redirected to one of the addresses in the table, spreading the load across several hosts. You may choose to retire the original Web server once the switch to this redirection is complete, or you may let it be absorbed in the new Web server pool.

On PF versions earlier than OpenBSD 4.7, the equivalent rule is as follows:

```
rdr on $ext_if proto tcp to $webserver port $webports -> <webpool> round-robin
```

In both cases, the `round-robin` option means that PF shares the load between the machines in the pool by cycling through the table of redirection addresses sequentially.

Some applications expect accesses from each individual source address to always go to the same host in the backend (for example, there are services that depend on client- or session-specific parameters that will be lost if new connections hit a different host in the backend). If your configuration needs to cater to such services, you can add the `sticky-address` option

to make sure that new connections from a client are always redirected to the same machine behind the redirection as the initial connection. The downside to this option is that PF needs to maintain source-tracking data for each client, and the default value for maximum source nodes tracked is set at 10,000, which may be a limiting factor. (See Chapter 10 for advice on adjusting this and similar limit values.)

When even load distribution isn't an absolute requirement, selecting the redirection address at `random` may be appropriate:

```
match in on $ext_if proto tcp to $webserver port $webports \
        rdr-to <webpool> random
```

NOTE *On pre–OpenBSD 4.7 PF versions, the* `random` *option isn't supported for redirection to tables or lists of addresses.*

Even organizations with large pools of official, routable IPv4 addresses have opted to introduce NAT between their load-balanced server pools and the Internet at large. This technique works equally well in various NAT-based setups, but moving to NAT offers some additional possibilities and challenges.

In order to accommodate an IPv4 and IPv6 dual-stack environment in this way, you'll need to set up separate tables for address pools and separate `pass` or `match` rules with redirections for IPv4 and IPv6. A single table of both IPv4 and IPv6 addresses may sound like an elegant idea at first, but the simple redirection rules outlined here aren't intelligent enough to make correct redirection decisions based on the address family of individual table entries.

Getting Load Balancing Right with relayd

After you've been running for a while with load balancing via round-robin redirection, you may notice that the redirection doesn't automatically adapt to external conditions. For example, unless special steps are taken, if a host in the list of redirection targets goes down, traffic will still be redirected to the IP addresses in the list of possibilities.

Clearly, a monitoring solution is needed. Fortunately, the OpenBSD base system provides one. The relay daemon `relayd`[2] interacts with your PF configuration, providing the ability to weed out nonfunctioning hosts from your pool. Introducing `relayd` into your setup, however, may require some minor changes to your rule set.

The `relayd` daemon works in terms of two main classes of services that it refers to as *redirects* and *relays*. It expects to be able to add or subtract hosts' IP addresses to or from the PF tables it controls. The daemon interacts

2. Originally introduced in OpenBSD 4.1 under the name `hoststated`, the daemon has seen active development (mainly by Reyk Floeter and Pierre-Yves Ritschard) over several years, including a few important changes to the configuration syntax, and it was renamed `relayd` in time for the OpenBSD 4.3 release.

with your rule set through a special-purpose anchor named `relayd` (and in pre–OpenBSD 4.7 versions, also a redirection anchor, `rdr-anchor`, with the same name).

To see how we can make our sample configuration work a little better by using `relayd`, we'll look back at the load-balancing rule set. Starting from the top of your *pf.conf* file, add the anchor for `relayd` to insert rules as needed:

```
anchor "relayd/*"
```

On pre–OpenBSD 4.7 versions, you also need the redirection anchor:

```
rdr-anchor "relayd/*"
anchor "relayd/*"
```

In the load-balancing rule set, we had the following definition for our Web server pool:

```
table webpool persist { 192.0.2.214, 192.0.2.215, 192.0.2.216, 192.0.2.217 }
```

It has this `match` rule to set up the redirection:

```
match in on $ext_if proto tcp to $webserver port $webports \
        rdr-to <webpool> round-robin
```

Or on pre–OpenBSD 4.7 versions, you'd use the following:

```
rdr on $ext_if proto tcp to $webserver port $webports -> <webpool> round-robin
```

To make this configuration work slightly better, we remove the redirection and the table (remember to take care of both sets in a dual-stack configuration), and we let `relayd` handle the redirection or redirections by setting up its own versions inside the anchor. (Don't remove the `pass` rule, however, because your rule set will still need to have a `pass` rule that lets traffic flow to the IP addresses in `relayd`'s tables. If you had separate rules for your `inet` and `inet6` traffic, you may be able to merge those rules back into one.)

Once the *pf.conf* parts have been taken care of, we turn to `relayd`'s own *relayd.conf* configuration file. The syntax in this configuration file is similar enough to *pf.conf* to make it fairly easy to read and understand. First, we add the macro definitions we'll be using later:

```
web1="192.0.2.214"
web2="192.0.2.215"
web3="192.0.2.216"
web4="192.0.2.217"
webserver="192.0.2.227"
sorry_server="192.0.2.200"
```

All of these correspond to definitions we could have put in a *pf.conf* file. The default checking interval in `relayd` is 10 seconds, which means that a host could be down for almost 10 seconds before it's taken offline. Being cautious, we'll set the checking interval to 5 seconds to minimize visible downtime, with the following line:

```
interval 5 # check hosts every 5 seconds
```

Now, we make a table called `webpool` that uses most of the macros:

```
table <webpool> { $web1, $web2, $web3, $web4 }
```

For reasons we'll return to shortly, we define one other table:

```
table <sorry> { $sorry_server }
```

At this point, we're ready to set up the redirect:

```
redirect www {
       listen on $webserver port 80 sticky-address
       tag relayd
       forward to <webpool> check http "/status.html" code 200 timeout 300
       forward to <sorry> timeout 300 check icmp
}
```

This redirect says that connections to port 80 should be redirected to the members of the `webpool` table. The `sticky-address` option has the same effect here as the `rdr-to` in PF rules: New connections from the same source IP address (within the time interval defined by the `timeout` value) are redirected to the same host in the backend pool as the previous ones.

The `relayd` daemon should check to see whether a host is available by asking it for the file */status.html*, using the protocol HTTP, and expecting the return code to be equal to 200. This is the expected result for a client asking a running Web server for a file it has available.

No big surprises so far, right? The `relayd` daemon will take care of excluding hosts from the table if they go down. But what if all the hosts in the `webpool` table go down? Fortunately, the developers thought of that, too, and introduced the concept of backup tables for services. This is the last part of the definition for the `www` service, with the table `sorry` as the backup table: The hosts in the `sorry` table take over if the `webpool` table becomes empty. This means that you need to configure a service that's able to offer a "Sorry, we're down" message in case all the hosts in your `webpool` fail.

If you're running an IPv6-only service, you should, of course, substitute your IPv6 addresses for the ones given in the example earlier. If you're running a dual-stack setup, you should probably set up the load-balancing mechanism separately for each protocol, where the configurations differ only in names (append a `4` or `6`, for example, to the IPv4 and IPv6 sets of names, respectively) and the addresses themselves.

With all of the elements of a valid relayd configuration in place, you can enable your new configuration.

Before you actually start relayd, add an empty set of relayd_flags to your */etc/rc.conf.local* to enable:

```
relayd_flags="" # for normal use: ""
```

Reload your PF rule set and then start relayd. If you want to check your configuration before actually starting relayd, you can use the -n command-line option to relayd:

```
$ sudo relayd -n
```

If your configuration is correct, relayd displays the message configuration OK and exits.

To actually start the daemon, you could start relayd without any command-line flags, but as with most daemons, it's better to start it via its rc script wrapper stored in */etc/rc.d/*, so the following sequence reloads your edited PF configuration and enables relayd.

```
$ sudo pfctl -f /etc/pf.conf
$ sudo sh /etc/rc.d/relayd start
```

With a correct configuration, both commands will silently start, without displaying any messages. (If you prefer more verbose messages, both pfctl and relayd offer the -v flag. For relayd, you may want to add the -v flag to the *rc.conf.local* entry.) You can check that relayd is running with top or ps. In both cases, you'll find three relayd processes, roughly like this:

```
$ ps waux | grep relayd
_relayd   9153  0.0  0.1   776  1424 ??  S      7:28PM    0:00.01 relayd: pf update engine
(relayd)
_relayd   6144  0.0  0.1   776  1440 ??  S      7:28PM    0:00.02 relayd: host check engine
(relayd)
root      3217  0.0  0.1   776  1416 ??  Is     7:28PM    0:00.01 relayd: parent (relayd)
```

And as we mentioned earlier, with an empty set of relayd_flags in your *rc.conf.local* file, relayd is enabled at startup. However, once the configuration is enabled, most of your interaction with relayd will happen through the relayctl administration program. In addition to letting you monitor status, relayctl lets you reload the relayd configuration and selectively disable or enable hosts, tables, and services. You can even view service status interactively, as follows:

```
$ sudo relayctl show summary
Id      Type            Name                            Avlblty Status
1       redirect        www                                     active
1       table           webpool:80                              active (2 hosts)
1       host            192.0.2.214                     100.00% up
2       host            192.0.2.215                     0.00%   down
```

```
3       host            192.0.2.216                     100.00% up
4       host            192.0.2.217                     0.00%   down
2       table           sorry:80                                active (1 hosts)
5       host            127.0.0.1                       100.00% up
```

In this example, the `webpool` is seriously degraded, with only two of four hosts up and running. Fortunately, the backup table is still functioning, and hopefully it'll still be up if the last two servers fail as well. For now, all tables are active with at least one host up. For tables that no longer have any members, the `Status` column changes to empty. Asking `relayctl` for host information shows the status information in a host-centered format:

```
$ sudo relayctl show hosts
Id      Type            Name                            Avlblty Status
1       table           webpool:80                              active (3 hosts)
1       host            192.0.2.214                     100.00% up
                        total: 11340/11340 checks
2       host            192.0.2.215                     0.00%   down
                        total: 0/11340 checks, error: tcp connect failed
3       host            192.0.2.216                     100.00% up
                        total: 11340/11340 checks
4       host            192.0.2.217                     0.00%   down
                        total: 0/11340 checks, error: tcp connect failed
2       table           sorry:80                                active (1 hosts)
5       host            127.0.0.1                       100.00% up
                        total: 11340/11340 checks
```

If you need to take a host out of the pool for maintenance (or any time-consuming operation), you can use `relayctl` to disable it, as follows:

```
$ sudo relayctl host disable 192.0.2.217
```

In most cases, the operation will display `command succeeded` to indicate that the operation completed successfully. Once you've completed maintenance and put the machine online, you can reenable it as part of `relayd`'s pool with this command:

```
$ sudo relayctl host enable 192.0.2.217
```

Again, you should see the message `command succeeded` almost immediately to indicate that the operation was successful.

In addition to the basic load balancing demonstrated here, `relayd` has been extended in recent OpenBSD versions to offer several features that make it attractive in more complex settings. For example, it can now handle Layer 7 proxying or relaying functions for HTTP and HTTPS, including protocol handling with header append and rewrite, URL-path append and rewrite, and even session and cookie handling. The protocol handling needs to be tailored to your application. For example, the following is a simple HTTPS relay for load balancing the encrypted Web traffic from clients to the Web servers.

```
http protocol "httpssl" {
          header append "$REMOTE_ADDR" to "X-Forwarded-For"
          header append "$SERVER_ADDR:$SERVER_PORT" to "X-Forwarded-By"
          header change "Keep-Alive" to "$TIMEOUT"
          query hash "sessid"
          cookie hash "sessid"
          path filter "*command=*" from "/cgi-bin/index.cgi"

          ssl { sslv2, ciphers "MEDIUM:HIGH" }
          tcp { nodelay, sack, socket buffer 65536, backlog 128 }
}
```

This protocol handler definition demonstrates a range of simple operations on the HTTP headers and sets both SSL parameters and specific TCP parameters to optimize connection handling. The header options operate on the protocol headers, inserting the values of the variables by either appending to existing headers (`append`) or changing the content to a new value (`change`).

The URL and cookie hashes are used by the load balancer to select to which host in the target pool the request is forwarded. The `path filter` specifies that any `get` request, including the first quoted string as a substring of the second, is to be dropped. The `ssl` options specify that only SSL version 2 ciphers are accepted, with key lengths in the medium-to-high range—in other words, 128 bits or more.[3] Finally, the `tcp` options specify `nodelay` to minimize delays, specify the use of the selective acknowledgment method (RFC 2018), and set the socket buffer size and the maximum allowed number of pending connections the load balancer keeps track of. These options are examples only; in most cases, your application will perform well with these settings at their default values.

The relay definition using the protocol handler follows a pattern that should be familiar given the earlier definition of the `www` service:

```
relay wwwssl {
          # Run as a SSL accelerator
          listen on $webserver port 443 ssl
          protocol "httpssl"
          table <webhosts> loadbalance check ssl
}
```

Still, your SSL-enabled Web applications will likely benefit from a slightly different set of parameters.

NOTE *We've added a `check ssl`, assuming that each member of the `webhosts` table is properly configured to complete an SSL handshake. Depending on your application, it may be useful to look into keeping all SSL processing in `relayd`, thus offloading the encryption-handling tasks from the backends.*

3. See the OpenSSL man page for further explanation of cipher-related options.

Finally, for CARP-based failover of the hosts running `relayd` on your network (see Chapter 8 for information about CARP), `relayd` can be configured to support CARP interaction by setting the CARP demotion counter for the specified interface groups at shutdown or startup.

Like all others parts of the OpenBSD system, `relayd` comes with informative man pages. For the angles and options not covered here (there are a few), dive into the man pages for `relayd`, `relayd.conf`, and `relayctl` and start experimenting to find just the configuration you need.

A Web Server and Mail Server on the Inside—The NAT Version

Let's backtrack a little and begin again with the baseline scenario where the sample clients from Chapter 3 get three new neighbors: a mail server, a Web server, and a file server. This time around, externally visible IPv4 addresses are either not available or too expensive, and running several other services on a machine that's primarily a firewall isn't desirable. This means we're back to the situation where we do our NAT at the gateway. Fortunately, the redirection mechanisms in PF make it relatively easy to keep servers on the inside of a gateway that performs NAT.

The network specifications are the same as for the *example.com* setup we just worked through: We need to run a Web server that serves up data in cleartext (`http`) and encrypted (`https`) form, and we want a mail server that sends and receives email while letting clients inside and outside the local network use a number of well-known submission and retrieval protocols. In short, we want pretty much the same features as in the setup from the previous section, but with only one routable address.

Of the three servers, only the Web server and the mail server need to be visible to the outside world, so we add macros for their IP addresses and services to the Chapter 3 rule set:

```
webserver = "192.168.2.7"
webports = "{ http, https }"
emailserver = "192.168.2.5"
email = "{ smtp, pop3, imap, imap3, imaps, pop3s }"
```

With only one routable address and the servers hidden in NATed address space, we need to set up rules at the gateway that redirect the traffic we want our servers to handle. We could define a set of `match` rules to set up the redirection and then address the `block` or `pass` question in a separate set of rules later, like this:

```
match in on $ext_if proto tcp to $ext_if port $webports rdr-to $webserver
match in on $ext_if proto tcp to $ext_if port $email rdr-to $emailserver

pass proto tcp to $webserver port $webports
pass proto tcp to $emailserver port $email
pass proto tcp from $emailserver to port smtp
```

This combination of `match` and `pass` rules is very close to the way things were done in pre–OpenBSD 4.7 PF versions, and if you're upgrading from a previous version, this is the kind of quick edit that could bridge the syntax gap quickly. But you could also opt to go for the new style and write this slightly more compact version instead:

```
pass in on $ext_if inet proto tcp to $ext_if port $webports rdr-to $webserver tag RDR
pass in on $ext_if inet proto tcp to $ext_if port $email rdr-to $mailserver tag RDR
pass on $int_if inet tagged RDR
```

Note the use of `pass` rules with `rdr-to`. This combination of filtering and redirection will help make things easier in a little while, so try this combination for now.

On pre–OpenBSD 4.7 PF, the rule set will be quite similar, except in the way that we handle the redirections.

```
webserver = "192.168.2.7"
webports = "{ http, https }"
emailserver = "192.168.2.5"
email = "{ smtp, pop3, imap, imap3, imaps, pop3s }"

rdr on $ext_if proto tcp to $ext_if port $webports -> $webserver
rdr on $ext_if proto tcp to $ext_if port $email -> $emailserver

pass proto tcp to $webserver port $webports
pass proto tcp to $emailserver port $email
pass proto tcp from $emailserver to any port smtp
```

DMZ with NAT

With an all-NAT setup, the pool of available addresses to allocate for a DMZ is likely to be larger than in our previous example, but the same principles apply. When you move the servers off to a physically separate network, you'll need to check that your rule set's macro definitions are sane and adjust the values if necessary.

Just as in the routable-addresses case, it might be useful to tighten up your rule set by editing your pass rules so the traffic to and from your servers is allowed to pass on only the interfaces that are actually relevant to the services:

```
pass in on $ext_if inet proto tcp to $ext_if port $webports rdr-to $webserver
pass in on $int_if inet proto tcp from $localnet to $webserver port $webports
pass out on $dmz_if proto tcp to $webserver port $webports
pass in log on $ext_if inet proto tcp to $ext_if port $email rdr-to $mailserver
pass in log on $int_if proto tcp from $localnet to $mailserver port $email
pass out log on $dmz_if proto tcp to $mailserver port smtp
pass in on $dmz_if from $mailserver to port smtp
pass out log on $ext_if proto tcp from $mailserver to port smtp
```

The version for pre–OpenBSD 4.7 PF differs in some details, with the redirection still in separate rules:

```
pass in on $ext_if proto tcp to $webserver port $webports
pass in on $int_if proto tcp from $localnet to $webserver port $webports
pass out on $dmz_if proto tcp to $webserver port $webports
pass in log on $ext_if proto tcp to $mailserver port smtp
pass in log on $int_if proto tcp from $localnet to $mailserver port $email
pass out log on $dmz_if proto tcp to $mailserver port smtp
pass in on $dmz_if from $mailserver to port smtp
pass out log on $ext_if proto tcp from $mailserver to port smtp
```

You could create specific `pass` rules that reference your local network interface, but if you leave the existing `pass` rules intact, they'll continue to work.

Redirection for Load Balancing

The redirection-based load-balancing rules from the previous example work equally well in a NAT regime, where the public address is the gateway's external interface and the redirection addresses are in a private range.

Here's the `webpool` definition:

```
table <webpool> persist { 192.168.2.7, 192.168.2.8, 192.168.2.9, 192.168.2.10 }
```

The main difference between the routable-address case and the NAT version is that after you've added the `webpool` definition, you edit the existing `pass` rule with redirection, which then becomes this:

```
pass in on $ext_if inet proto tcp to $ext_if port $webports rdr-to <webpool> round-robin
```

Or for pre–OpenBSD 4.7 PF versions, use this:

```
rdr on $ext_if proto tcp to $ext_if port $webports -> <webpool> round-robin
```

From that point on, your NATed DMZ behaves much like the one with official, routable addresses.

NOTE *You can configure a valid IPv6 setup to coexist with a NATed IPv4 setup like this one, but if you choose to do so, be sure to treat `inet` and `inet6` traffic separately in your PF rules. And contrary to popular belief, rules with `nat-to` and `rdr-to` options work in IPv6 configurations the same as in IPv4.*

Back to the Single NATed Network

It may surprise you to hear that there are cases where setting up a small network is more difficult than working with a large one. For example, returning to the situation where the servers are on the same physical

network as the clients, the basic NATed configuration works very well—up to a point. In fact, everything works brilliantly as long as all you're interested in is getting traffic from hosts outside your local network to reach your servers.

Here's the full configuration:

```
ext_if = "re0" # macro for external interface - use tun0 or pppoe0 for PPPoE
int_if = "re1" # macro for internal interface
localnet = $int_if:network
# for ftp-proxy
proxy = "127.0.0.1"
icmp_types = "{ echoreq, unreach }"
client_out = "{ ssh, domain, pop3, auth, nntp, http, https, \
                446, cvspserver, 2628, 5999, 8000, 8080 }"
udp_services = "{ domain, ntp }"
webserver = "192.168.2.7"
webports = "{ http, https }"
emailserver = "192.168.2.5"
email = "{ smtp, pop3, imap, imap3, imaps, pop3s }"
# NAT: ext_if IP address could be dynamic, hence ($ext_if)
match out on $ext_if from $localnet nat-to ($ext_if)
block all
# for ftp-proxy: Remember to put the following line, uncommented, in your
# /etc/rc.conf.local to enable ftp-proxy:
# ftpproxy_flags=""
anchor "ftp-proxy/*"
pass in quick proto tcp to port ftp rdr-to $proxy port 8021
pass out proto tcp from $proxy to port ftp
pass quick inet proto { tcp, udp } to port $udp_services
pass proto tcp to port $client_out
# allow out the default range for traceroute(8):
# "base+nhops*nqueries-1" (33434+64*3-1)
pass out on $ext_if inet proto udp to port 33433 >< 33626 keep state
# make sure icmp passes unfettered
pass inet proto icmp icmp-type $icmp_types from $localnet
pass inet proto icmp icmp-type $icmp_types to $ext_if
pass in on $ext_if inet proto tcp to $ext_if port $webports rdr-to $webserver
pass in on $ext_if inet proto tcp to $ext_if port $email rdr-to $mailserver
pass on $int_if inet proto tcp to $webserver port $webports
pass on $int_if inet proto tcp to $mailserver port $email
```

The last four rules here are the ones that interest us the most. If you try to reach the services on the official address from hosts in your own network, you'll soon see that the requests for the redirected services from machines in your local network most likely never reach the external interface. This is because all the redirection and translation happens on the external interface. The gateway receives the packets from your local network on the internal interface, with the destination address set to the external interface's address. The gateway recognizes the address as one of its own and tries to handle the request as if it were directed at a local service; as a consequence, the redirections don't quite work from the inside.

The equivalent part to those last four lines of the preceding rule set for pre–OpenBSD 4.7 systems looks like this:

```
rdr on $ext_if proto tcp to $ext_if port  $webports -> $webserver
rdr on $ext_if proto tcp to $ext_if port  $email -> $emailserver

pass proto tcp to $webserver port $webports
pass proto tcp to $emailserver port $email
pass proto tcp from $emailserver to any port smtp
```

Fortunately, several work-arounds for this particular problem are possible. The problem is common enough that the PF User Guide lists four different solutions to the problem,[4] including moving your servers to a DMZ, as described earlier. Because this is a PF book, we'll concentrate on a PF-based solution (actually a pretty terrible work-around), which consists of treating the local network as a special case for our redirection and NAT rules.

We need to intercept the network packets originating in the local network and handle those connections correctly, making sure that any return traffic is directed to the communication partner who actually originated the connection. This means that in order for the redirections to work as expected from the local network, we need to add special-case redirection rules that mirror the ones designed to handle requests from the outside. First, here are the `pass` rules with redirections for OpenBSD 4.7 and newer:

```
pass in on $ext_if inet proto tcp to $ext_if port $webports rdr-to $webserver
pass in on $ext_if inet proto tcp to $ext_if port $email rdr-to $mailserver
pass in log on $int_if inet proto tcp from $int_if:network to $ext_if \
port $webports rdr-to $webserver
pass in log on $int_if inet proto tcp from $int_if:network to $ext_if \
port $email rdr-to $mailserver
match out log on $int_if proto tcp from $int_if:network to $webserver \
port $webports nat-to $int_if
pass on $int_if inet proto tcp to $webserver port $webports
match out log on $int_if proto tcp from $int_if:network to $mailserver \
port $email nat-to $int_if
pass on $int_if inet proto tcp to $mailserver port $email
```

The first two rules are identical to the original ones. The next two intercept the traffic from the local network, and the `rdr-to` actions in both rewrite the destination address, much as the corresponding rules do for the traffic that originates elsewhere. The `pass on $int_if` rules serve the same purpose as in the earlier version.

The `match` rules with `nat-to` are there as a routing work-around. Without them, the `webserver` and `mailserver` hosts would route return traffic for the redirected connections directly back to the hosts in the local network, where the traffic wouldn't match any outgoing connection. With the `nat-to` in

4. See the "Redirection and Reflection" section in the PF User Guide (*http://www.openbsd.org/faq/pf/rdr.html#reflect*).

place, the servers consider the gateway as the source of the traffic and will direct return traffic back the same path it came originally. The gateway matches the return traffic to the states created by connections from the clients in the local network and applies the appropriate actions to return the traffic to the correct clients.

The equivalent rules for pre–OpenBSD 4.7 versions are at first sight a bit more confusing, but the end result is the same.

```
rdr on $int_if proto tcp from $localnet to $ext_if port $webports -> $webserver
rdr on $int_if proto tcp from $localnet to $ext_if port $email -> $emailserver
no nat on $int_if proto tcp from $int_if to $localnet
nat on $int_if proto tcp from $localnet to $webserver port $webports -> $int_if
nat on $int_if proto tcp from $localnet to $emailserver port $email -> $int_if
```

This way, we twist the redirections and the address translation logic to do what we need, and we don't need to touch the `pass` rules at all. (I've had the good fortune to witness via email and IRC the reactions of several network admins at the moment when the truth about this five-line reconfiguration sank in.)

Filtering on Interface Groups

Your network could have several subnets that may never need to interact with your local network except for some common services, like email, Web, file, and print. How you handle the traffic from and to such subnets depends on how your network is designed. One useful approach is to treat each less-privileged network as a separate local network attached to its own separate interface on a common filtering gateway and then to give it a rule set that allows only the desired direct interaction with the neighboring networks attached to the main gateway.

You can make your PF configuration more manageable and readable by grouping logically similar interfaces into interface groups and by applying filtering rules to the groups rather than the individual interfaces. Interface groups, as implemented via the `ifconfig` *`group`* option, originally appeared in OpenBSD 3.6 and have been adopted in FreeBSD 7.0 onward.

All configured network interfaces can be configured to belong to one or more groups. Some interfaces automatically belong to one of the default groups. For example, all IEEE 802.11 wireless network interfaces belong to the `wlan` group, while interfaces associated with the default routes belong to the `egress` group. Fortunately, an interface can be a member of several groups, and you can add interfaces to interface groups via the appropriate `ifconfig` command, as in this example:

```
# ifconfig sis2 group untrusted
```

For a permanent configuration, the equivalent under OpenBSD would be in the *hostname.sis2* file or the `ifconfig_sis2=` line in the *rc.conf* file on FreeBSD 7.0 or later.

Where it makes sense, you can then treat the interface group much the same as you would handle a single interface in filtering rules:

```
pass in on untrusted to any port $webports
pass out on egress to any port $webports
```

If by now you're thinking that in most, if not all, the rule-set examples up to this point, it would be possible to filter on the group `egress` instead of the macro `$ext_if`, you've grasped an important point. It could be a useful exercise to go through any existing rule sets you have and see what using interface groups can do to help readability even further. Remember that an interface group can have one or more members.

Note that filtering on interface groups makes it possible to write essentially hardware-independent rule sets. As long as your *hostname.if* files or `ifconfig_if=` lines put the interfaces in the correct groups, rule sets that consistently filter on interface groups will be fully portable between machines that may or may not have identical hardware configurations.

On systems where the interface group feature isn't available, you may be able to achieve some of the same effects via creative use of macros, as follows:

```
untrusted = "{ ath0 ath1 wi0 ep0 }"
egress = "sk0"
```

The Power of Tags

In some networks, the decision of where a packet should be allowed to pass can't be made to map easily to criteria like subnet and service. The fine-grained control the site's policy demands could make the rule set complicated and potentially hard to maintain.

Fortunately, PF offers yet another mechanism for classification and filtering in the form of *packet tagging*. The useful way to implement packet tagging is to `tag` incoming packets that match a specific `pass` rule and then let the packets pass elsewhere based on which identifiers the packet is `tagged` with. In OpenBSD 4.6 and later, it's even possible to have separate `match` rules that `tag` according to the match criteria, leaving decisions on passing, redirecting, or taking other actions to rules later in the rule set.

One example could be the wireless access points we set up in Chapter 4, which we could reasonably expect to inject traffic into the local network with an apparent source address equal to the access point's `$ext_if` address. In that scenario, a useful addition to the rule set of a gateway with several of these access points might be the following (assuming, of course, that definitions of the `wifi_allowed` and `wifi_ports` macros fit the site's requirements):

```
wifi = "{ 10.0.0.115, 10.0.0.125, 10.0.0.135, 10.0.0.145 }"
pass in on $int_if from $wifi to $wifi_allowed port $wifi_ports tag wifigood
pass out on $ext_if tagged wifigood
```

As the complexity of the rule set grows, consider using `tag` in incoming `match` and `pass` rules to make your rule set readable and easier to maintain.

Tags are sticky, and once a packet has been tagged by a matching rule, the tag stays, which means that a packet can have a tag even if it wasn't applied by the last matching rule. However, a packet can have only one tag at any time. If a packet matches several rules that apply tags, the tag will be overwritten with a new one by each new matching `tag` rule.

For example, you could set several tags on incoming traffic via a set of `match` or `pass` rules, supplemented by a set of `pass` rules that determine where packets pass out based on the tags set on the incoming traffic.

The Bridging Firewall

An Ethernet *bridge* consists of two or more interfaces that are configured to forward Ethernet frames transparently and that aren't directly visible to the upper layers, such as the TCP/IP stack. In a filtering context, the bridge configuration is often considered attractive because it means that the filtering can be performed on a machine that doesn't have its own IP addresses. If the machine in question runs OpenBSD or a similarly capable operating system, it can still filter and redirect traffic.

The main advantage of such a setup is that attacking the firewall itself is more difficult.[5] The disadvantage is that all admin tasks must be performed at the firewall's console, unless you configure a network interface that's reachable via a secured network of some kind or even a serial console. It also follows that bridges with no IP address configured can't be set as the gateway for a network and can't run any services on the bridged interfaces. Rather, you can think of a bridge as an intelligent bulge on the network cable, which can filter and redirect.

A few general caveats apply to using firewalls implemented as bridges:

- The interfaces are placed in promiscuous mode, which means that they'll receive (and to some extent process) every packet on the network.
- Bridges operate on the Ethernet level and, by default, forward all types of packets, not just TCP/IP.
- The lack of IP addresses on the interfaces makes some of the more effective redundancy features, such as CARP, unavailable.

The method for configuring bridges differs among operating systems in some details. The following examples are very basic and don't cover all possible wrinkles, but they should be enough to get you started.

5. How much security this actually adds is a matter of occasional heated debate on mailing lists such as *openbsd-misc* and other networking-oriented lists. Reading up on the pros and cons as perceived by core OpenBSD developers can be entertaining as well as enlightening.

Basic Bridge Setup on OpenBSD

The OpenBSD GENERIC kernel contains all the necessary code to configure bridges and filter on them. Unless you've compiled a custom kernel without the bridge code, the setup is quite straightforward.

NOTE *On OpenBSD 4.7 and newer, the* `brconfig` *command no longer exists. All bridge configuration and related functionality was merged into* `ifconfig` *for the OpenBSD 4.7 release. If you're running on an OpenBSD release where* `brconfig` *is available, you're running an out-of-date, unsupported configuration. Please upgrade to a more recent version as soon as feasible.*

To set up a bridge with two interfaces on the command line, you first create the bridge device. The first device of a kind is conventionally given the sequence number 0, so we create the `bridge0` device with the following command:

```
$ sudo ifconfig bridge0 create
```

Before the next `ifconfig` command, use `ifconfig` to check that the prospective member interfaces (in our case, `ep0` and `ep1`) are up, but not assigned IP addresses. Next, configure the bridge by entering the following:

```
$ sudo ifconfig bridge0 add ep0 add ep1 blocknonip ep0 blocknonip ep1 up
```

The OpenBSD `ifconfig` command contains a fair bit of filtering code itself. In this example, we use the `blocknonip` option for each interface to block all non-IP traffic.

NOTE *The OpenBSD* `ifconfig` *command offers its own set of filtering options in addition to other configuration options. The* `bridge(4)` *and* `ifconfig(8)` *man pages provide further information. Because it operates on the Ethernet level, it's possible to use* `ifconfig` *to specify filtering rules that let the bridge filter on MAC addresses. Using these filtering capabilities, it's also possible to let the bridge tag packets for further processing in your PF rule set via the* `tagged` *keyword. For tagging purposes, a bridge with one member interface will do.*

To make the configuration permanent, create or edit */etc/hostname.ep0* and enter the following line:

```
up
```

For the other interface, */etc/hostname.ep1* should contain the same line:

```
up
```

Finally, enter the bridge setup in */etc/hostname.bridge0*:

```
add ep0 add ep1 blocknonip ep0 blocknonip ep1 up
```

Your bridge should now be up, and you can go on to create the PF filter rules.

Basic Bridge Setup on FreeBSD

For FreeBSD, the procedure is a little more involved than on OpenBSD. In order to be able to use bridging, your running kernel must include the `if_bridge` module. The default kernel configurations build this module, so under ordinary circumstances, you can go directly to creating the interface. To compile the bridge device into the kernel, add the following line in the kernel configuration file:

```
device if_bridge
```

You can also load the device at boot time by putting the following line in the */etc/loader.conf* file.

```
if_bridge_load="YES"
```

Create the bridge by entering this:

```
$ sudo ifconfig bridge0 create
```

Creating the `bridge0` interface also creates a set of bridge-related `sysctl` values:

```
$ sudo sysctl net.link.bridge
net.link.bridge.ipfw: 0
net.link.bridge.pfil_member: 1
net.link.bridge.pfil_bridge: 1
net.link.bridge.ipfw_arp: 0
net.link.bridge.pfil_onlyip: 1
```

It's worth checking that these `sysctl` values are available. If they are, it's confirmation that the bridge has been enabled. If they're not, go back and see what went wrong and why.

NOTE *These values apply to filtering on the bridge interface itself. You don't need to touch them because IP-level filtering on the member interfaces (the ends of the pipe) is enabled by default.*

Before the next `ifconfig` command, check that the prospective member interfaces (in our case, `ep0` and `ep1`) are up but haven't been assigned IP addresses. Then configure the bridge by entering this:

```
$ sudo ifconfig bridge0 addm ep0 addm ep1 up
```

To make the configuration permanent, add the following lines to */etc/rc.conf*:

```
ifconfig_ep0="up"
ifconfig_ep1="up"
cloned_interfaces="bridge0"
ifconfig_bridge0="addm ep0 addm ep1 up"
```

This means your bridge is up and you can go on to create the PF filter rules. See the `if_bridge(4)` man page for further FreeBSD-specific bridge information.

Basic Bridge Setup on NetBSD

On NetBSD, the default kernel configuration doesn't have the filtering bridge support compiled in. You need to compile a custom kernel with the following option added to the kernel configuration file. Once you have the new kernel with the bridge code in place, the setup is straightforward.

```
options         BRIDGE_IPF      # bridge uses IP/IPv6 pfil hooks too
```

To create a bridge with two interfaces on the command line, first create the `bridge0` device:

```
$ sudo ifconfig bridge0 create
```

Before the next `brconfig` command, use `ifconfig` to check that the prospective member interfaces (in our case, `ep0` and `ep1`) are up but haven't been assigned IP addresses. Then, configure the bridge by entering this:

```
$ sudo brconfig bridge0 add ep0 add ep1 up
```

Next, enable the filtering on the `bridge0` device:

```
$ sudo brconfig bridge0 ipf
```

To make the configuration permanent, create or edit */etc/ifconfig.ep0* and enter the following line:

```
up
```

For the other interface, */etc/ifconfig.ep1* should contain the same line:

```
up
```

Finally, enter the bridge setup in */etc/ifconfig.bridge0*:

```
create
!add ep0 add ep1 up
```

Your bridge should now be up, and you can go on to create the PF filter rules. For further information, see the PF on NetBSD documentation at *http://www.netbsd.org/Documentation/network/pf.html*.

The Bridge Rule Set

Figure 5-3 shows the *pf.conf* file for a bulge-in-the-wire version of the baseline rule set we started in this chapter. As you can see, the network changes slightly.

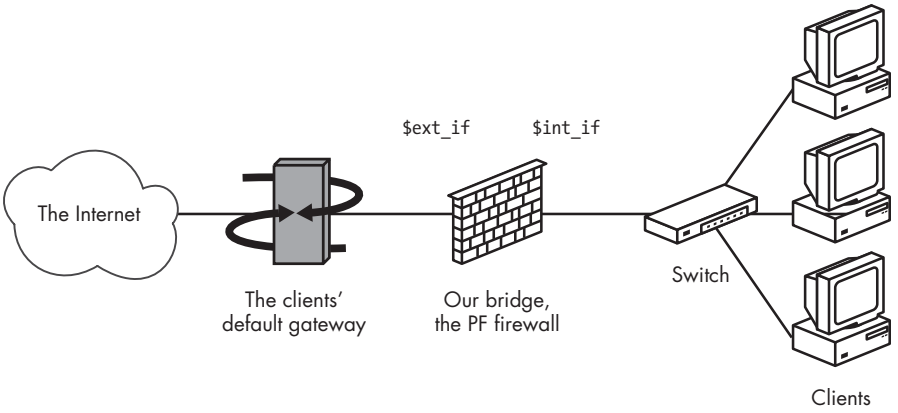

Figure 5-3: A network with a bridge firewall

The machines in the local network share a common default gateway, which isn't the bridge but could be placed either inside or outside the bridge.

```
ext_if = ep0
int_if  = ep1
localnet= "192.0.2.0/24"
webserver = "192.0.2.227"
webports = "{ http, https }"
emailserver = "192.0.2.225"
email = "{ smtp, pop3, imap, imap3, imaps, pop3s }"
nameservers = "{ 192.0.2.221, 192.0.2.223 }"
client_out = "{ ssh, domain, pop3, auth, nntp, http, https, \
               446, cvspserver, 2628, 5999, 8000, 8080 }"
udp_services = "{ domain, ntp }"
icmp_types = "{ echoreq, unreach }"
set skip on $int_if
block all
pass quick on $ext_if inet proto { tcp, udp } from $localnet \
        to port $udp_services
pass log on $ext_if inet proto icmp all icmp-type $icmp_types
pass on $ext_if inet proto tcp from $localnet to port $client_out
pass on $ext_if inet proto { tcp, udp } to $nameservers port domain
pass on $ext_if proto tcp to $webserver port $webports
pass log on $ext_if proto tcp to $emailserver port $email
pass log on $ext_if proto tcp from $emailserver to port smtp
```

Significantly more complicated setups are possible. But remember that while redirections will work, you won't be able to run services on any of the interfaces without IP addresses.

Handling Nonroutable IPv4 Addresses from Elsewhere

Even with a properly configured gateway to handle filtering and potentially NAT for your own network, you may find yourself in the unenviable position of needing to compensate for other people's misconfigurations.

Establishing Global Rules

One depressingly common class of misconfigurations is the kind that lets traffic with nonroutable addresses out to the Internet. Traffic from nonroutable IPv4 addresses plays a part in several *denial-of-service (DoS)* attack techniques, so it's worth considering explicitly blocking traffic from nonroutable addresses from entering your network. One possible solution is outlined here. For good measure, it also blocks any attempt to initiate contact to nonroutable addresses through the gateway's external interface.

```
martians = "{ 127.0.0.0/8, 192.168.0.0/16, 172.16.0.0/12, \
              10.0.0.0/8, 169.254.0.0/16, 192.0.2.0/24, \
              0.0.0.0/8, 240.0.0.0/4 }"

block in quick on $ext_if from $martians to any
block out quick on $ext_if from any to $martians
```

Here, the `martians` macro denotes the RFC 1918 addresses and a few other ranges mandated by various RFCs not to be in circulation on the open Internet. Traffic to and from such addresses is quietly dropped on the gateway's external interface.

NOTE *The `martians` macro could easily be implemented as a table instead, with all of the table advantages as an added bonus for your rule set. In fact, if you view the loaded rules in a rule set that contains this combination of macro and rules, you'll see that macro expansion and rule-set optimization most likely replaced your list with one table per rule. However, if you roll your own table, you'll get to pick a nicer name for it yourself.*

The specific details of how to implement this kind of protection will vary according to your network configuration and may be part of a wider set of network security measures. Your network design might also dictate that you include or exclude address ranges other than these.

Restructuring Your Rule Set with Anchors

We've mentioned anchors a few times already, in the context of applications such as FTP-proxy or `relayd` that use anchors to interact with a running PF configuration. Anchors are named sub–rule sets where it's possible to insert or remove rules as needed without reloading the whole rule set.

Once you have a rule set where an otherwise unused anchor is defined, you can even manipulate anchor contents from the command line using `pfctl`'s `-a` switch, like this:

```
echo "block drop all" | pfctl -a baddies -f -
```

Here, a rule is inserted into the existing anchor `baddies`, overwriting any previous content.

You can even load rules from a separate file into an anchor:

```
pfctl -a baddies -f /etc/anchor-baddies
```

Or you can list the current contents of an anchor:

```
pfctl -a baddies -s rules
```

NOTE *There are a few more `pfctl` options that you'll find useful for handling anchors. See the `pfctl` man page for inspiration.*

You can also split your configuration by putting the contents of anchors into separate files to be loaded at rule-set load time. That way it becomes possible to edit the rules in the anchors separately, reload the edited anchor, and, of course, do any other manipulation like the ones described above. To do this, first add a line like this to *pf.conf*:

```
anchor ssh-good load anchor ssh-good from "/etc/anchor-ssh-good"
```

This references the file */etc/anchor-ssh-good*, which could look like this:

```
table <sshbuddies> file "/etc/sshbuddies"
     pass inet proto tcp from <sshbuddies> to any port ssh
```

Perhaps simply to make it possible to delegate the responsibility for the table `sshbuddies` to a junior admin, the anchor loads the table from the file */etc/sshbuddies*, which could look like this:

```
192.168.103.84
10.11.12.13
```

This way, you can manipulate the contents of the anchor in the following ways: Add rules by editing the file and reloading the anchor, replace the rules by feeding other rules from the command line via standard input (as shown in the earlier example), or change the behavior of the rules inside the anchor by manipulating the contents of the table they reference.

NOTE *For more extensive anchors, like the ones discussed in the following paragraphs, it's probably more useful to use `include` clauses in your* pf.conf *if you want to maintain the anchors as separate files.*

The concept hinted at previously (specifying a set of common criteria that apply to all actions within an anchor) is appealing in situations where your configuration is large enough to need a few extra structuring aids. For example, "on interface" could be a useful common criterion for traffic arriving on a specific interface because that traffic tends to have certain similarities. For example, look at the following:

```
anchor "dmz" on $dmz_if {
    pass in proto { tcp udp } to $nameservers port domain
    pass in proto tcp to $webservers port { www https }
    pass in proto tcp to $mailserver port smtp
    pass in log (all, to pflog1) in proto tcp from $mailserver \
                to any port smtp
    }
```

A separate anchor ext would serve the egress interface group:

```
anchor ext on egress {
    match out proto tcp to port { www https } set queue (qweb, qpri) set prio (5,6)
    match out proto { tcp udp } to port domain set queue (qdns, qpri) set prio (6,7)
    match out proto icmp set queue (q_dns, q_pri) set prio (7,6)
    pass in log proto tcp to port smtp rdr-to 127.0.0.1 port spamd queue spamd
    pass in log proto tcp from <nospamd> to port smtp
    pass in log proto tcp from <spamd-white> to port smtp
    pass out log proto tcp to port smtp
    pass log (all) proto { tcp, udp } to port ssh keep state (max-src-conn 15, \
        max-src-conn-rate 7/3, overload <bruteforce> flush global)
}
```

Another obvious logical optimization if you group rules in anchors based on interface affinity is to lump in tags to help policy-routing decisions. A simple but effective example could look like this:

```
anchor "dmz" on $dmz_if {
    pass in proto { tcp udp } to $nameservers port domain tag GOOD
    pass in proto tcp to $webservers port { www https } tag GOOD
    pass in proto tcp to $mailserver port smtp tag GOOD
    pass in log (all, to pflog1) in proto tcp from $mailserver
                to any port smtp tag GOOD
    block log quick ! tagged GOOD
    }
```

Even if the anchor examples here have all included a blocking decision inside the anchor, the decision to block or pass based on tag information doesn't have to happen inside the anchor.

After this whirlwind tour of anchors as a structuring tool, it may be tempting to try to convert your entire rule set to an anchors-based structure. If you try to do so, you'll probably find ways to make the internal logic clearer. But don't be surprised if certain rules need to be global, outside of

anchors tied to common criteria. And you'll almost certainly find that what turns out to be useful in your environment is at least a little different from what inspired the scenarios I've presented here.

How Complicated Is Your Network?—Revisited

Early on in this chapter, we posed the questions "How complicated is your network?" and "How complicated does it need to be?" Over the subsections of this chapter, we've presented a number of tools and techniques that make it possible to build complex infrastructure with PF and related tools and that help manage that complexity while keeping the network administrator sane.

If you're in charge of one site where you need to apply all or most of the techniques we've mentioned in this chapter, I feel your pain. On the other hand, if you're in charge of a network that diverse, the subsequent chapters on traffic shaping and managing resource availability are likely to be useful to you as well.

The rest of this book deals mainly with optimizing your setup for performance and resource availability, with the exception of one chapter where we deviate slightly and take on a lighter tone. Before we dive into how to optimize performance and ensure high availability, it's time to take a look at how to make your infrastructure unavailable or hard to reach for selected groups or individuals. The next chapter deals exclusively with making life harder for the unwashed masses—or perhaps even well-organized criminals—who try to abuse services in your care.

6

TURNING THE TABLES FOR PROACTIVE DEFENSE

In the previous chapter, you saw how you might need to spend considerable time and energy making sure that the services you want to offer will be available even when you have strict packet filtering in place. Now, with your working setup in place, you'll soon notice that some services tend to attract a little more unwanted attention than others.

Here's the scenario: You have a network with packet filtering to match your site's needs, including some services that need to be accessible to users from elsewhere. Unfortunately, when services are available, there's a risk that someone will want to exploit them for some sort of mischief.

You'll almost certainly have remote login via SSH (Secure Shell), as well as SMTP email running on your network—both are tempting targets. In this chapter, we'll look at ways to make it harder to gain unauthorized access via SSH, and then we'll turn to some of the more effective ways to deny spammers use of your servers.

Turning Away the Brutes

The Secure Shell service, commonly referred to as SSH, is a fairly crucial service for Unix administrators. It's frequently the main interface to the machine and a favorite target of script kiddie attacks.

SSH Brute-Force Attacks

If you run an SSH login service that's accessible from the Internet, you've probably seen entries like this in your authentication logs:

```
Sep 26 03:12:34 skapet sshd[25771]: Failed password for root from 200.72.41.31 port 40992 ssh2
Sep 26 03:12:34 skapet sshd[5279]: Failed password for root from 200.72.41.31 port 40992 ssh2
Sep 26 03:12:35 skapet sshd[5279]: Received disconnect from 200.72.41.31: 11: Bye Bye
Sep 26 03:12:44 skapet sshd[29635]: Invalid user admin from 200.72.41.31
Sep 26 03:12:44 skapet sshd[24703]: input_userauth_request: invalid user admin
Sep 26 03:12:44 skapet sshd[24703]: Failed password for invalid user admin from 200.72.41.31
port 41484 ssh2
Sep 26 03:12:44 skapet sshd[29635]: Failed password for invalid user admin from 200.72.41.31
port 41484 ssh2
Sep 26 03:12:45 skapet sshd[24703]: Connection closed by 200.72.41.31
Sep 26 03:13:10 skapet sshd[11459]: Failed password for root from 200.72.41.31 port 43344 ssh2
Sep 26 03:13:10 skapet sshd[7635]: Failed password for root from 200.72.41.31 port 43344 ssh2
Sep 26 03:13:10 skapet sshd[11459]: Received disconnect from 200.72.41.31: 11: Bye Bye
Sep 26 03:13:15 skapet sshd[31357]: Invalid user admin from 200.72.41.31
Sep 26 03:13:15 skapet sshd[10543]: input_userauth_request: invalid user admin
Sep 26 03:13:15 skapet sshd[10543]: Failed password for invalid user admin from 200.72.41.31
port 43811 ssh2
Sep 26 03:13:15 skapet sshd[31357]: Failed password for invalid user admin from 200.72.41.31
port 43811 ssh2
Sep 26 03:13:15 skapet sshd[10543]: Received disconnect from 200.72.41.31: 11: Bye Bye
Sep 26 03:13:25 skapet sshd[6526]: Connection closed by 200.72.41.31
```

This is what a *brute-force attack* looks like. Someone or something is trying by brute force to find a username and password combination that lets them get into your system.

The simplest response would be to write a *pf.conf* rule that blocks all access, but that leads to another class of problems, including how to let people with legitimate business on your system access it. Setting up your `sshd` to accept only key-based authentication would help but most likely would not stop the kiddies from trying. You might consider moving the service to another port, but then again, the ones flooding you on port 22 would probably be able to scan their way to port 22222 for a repeat performance.[1]

Since OpenBSD 3.7 (and equivalents), PF has offered a slightly more elegant solution.

1. At the time this chapter was first written, this was purely theoretical; I hadn't yet had any credible reports that this was happening. That changed during 2012 when reliable sources started reporting the appearance of brute-force sequences at odd ports. See *http://bsdly.blogspot.com/2013/02/theres-no-protection-in-high-ports.html* for more.

Setting Up an Adaptive Firewall

To thwart brute-force attacks, you can write your `pass` rules so they maintain certain limits on what connecting hosts can do. For good measure, you can banish violators to a table of addresses to which you deny some or all access. You can even choose to drop all existing connections from machines that overreach your limits. To enable this feature, first set up the table by adding the following line to your configuration before any filtering rules:

```
table <bruteforce> persist
```

Then, early in your rule set, `block` brute forcers, as shown here:

```
block quick from <bruteforce>
```

Finally, add your `pass` rule:

```
pass proto tcp to $localnet port $tcp_services \
     keep state (max-src-conn 100, max-src-conn-rate 15/5, \
         overload <bruteforce> flush global)
```

This rule is very similar to what you've seen in earlier examples. The interesting part in this context is the contents of the parentheses, called *state-tracking options*:

- `max-src-conn` is the number of simultaneous connections allowed from one host. In this example, it's set to `100`. You may want a slightly higher or lower value, depending on your network's traffic patterns.
- `max-src-conn-rate` is the rate of new connections allowed from any single host. Here, it's set to `15` connections per 5 seconds, denoted as `15/5`. Choose a rate that suits your setup.
- `overload <bruteforce>` means that the address of any host that exceeds the preceding limits is added to the table `bruteforce`. Our rule set blocks all traffic from addresses in the `bruteforce` table. Once a host exceeds any of these limits and is put in the overload table, the rule no longer matches traffic from that host. Make sure that overloaders are handled, if only by a default block rule or similar.
- `flush global` says that when a host reaches the limit, all states for its connections are terminated (flushed). The `global` option means that for good measure, `flush` applies to all states created by traffic from that host, no matter which rule created a state.

As you can imagine, the effect of this tiny addition to the rule set is dramatic. After a few tries, brute forcers end up in the `bruteforce` table. That means that all their existing connections are terminated (flushed) and any new attempts will be blocked, most likely with `Fatal: timeout before authentication` messages at their end. You have created an *adaptive firewall* that adjusts automatically to conditions in your network and acts on undesirable activity.

NOTE *These adaptive rules are effective only for protection against the traditional, rapid-fire type of brute-force attempts. The low-intensity, distributed password-guessing attempts that were first identified as such in 2008 and have been recurring ever since (known among other names as* The Hail Mary Cloud[2]*) don't produce traffic that will match these rules.*

It's likely that you will want some flexibility in your rule set and want to allow a larger number of connections for some services, but you also might like to be a little more tight-fisted when it comes to SSH. In that case, you could supplement the general-purpose `pass` rule with something like the following one early in your rule set:

```
pass quick proto { tcp, udp } to port ssh \
     keep state (max-src-conn 15, max-src-conn-rate 5/3, \
        overload <bruteforce> flush global)
```

You should be able to find the set of parameters that's just right for your situation by reading the relevant man pages and the *PF User Guide* (see Appendix A).

NOTE *Remember that these sample rules are intended as illustrations and your network's needs may be better served by different rules. Setting the number of simultaneous connections or the rate of connections too low may block legitimate traffic. There's a potential risk of self-inflicted denial of service when the configuration includes many hosts behind a common NATing gateway and the users on the NATed hosts have legitimate business on the other side of a gateway with strict* `overload` *rules.*

The state-tracking options and the `overload` mechanism don't need to apply exclusively to the SSH service, and blocking all traffic from offenders isn't always desired. You could, for example, use a rule like this:

```
pass proto { tcp, udp } to port $mail_services \
     keep state (max 1500, max-src-conn 100)
```

Here, `max` specifies the maximum number of states that can be created for each rule with no `overload` to protect a mail or Web service from receiving more connections than it can handle (keep in mind that the number of rules loaded depends on what the `$mail_services` macro expands to). Once the `max` limit is reached, new connections will not match this rule until the old ones terminate. Alternatively, you could remove the `max` restriction, add an `overload` part to the rule, and assign offenders to a queue with a minimal bandwidth allocation (see the discussion of traffic shaping in Chapter 7 for details on setting up queues).

2. For an overview of the Hail Mary Cloud sequence of brute-force attempts, see the article "The Hail Mary Cloud and the Lessons Learned" at *http://bsdly.blogspot.com/2013/10/the-hail-mary-cloud-and-lessons-learned.html*. More resources are referenced there and in Appendix A.

Some sites use `overload` to implement a multitiered system, where hosts that trip one `overload` rule are transferred to one or more intermediate "probation" tables for special treatment. It can be useful in Web contexts not to block traffic from hosts in the overload tables outright but rather to redirect all HTTP requests from these hosts to specific Web pages (as in the `authpf` example near the end of Chapter 4).

Tidying Your Tables with pfctl

With the `overload` rules from the previous section in place, you now have an adaptive firewall that automatically detects undesirable behavior and adds offenders' IP addresses to tables. Watching the logs and the tables can be fun in the short run, but because those rules only add to the tables, we run into the next challenge: keeping the content of the tables up-to-date and relevant.

When you've run a configuration with an adaptive rule set for a while, at some point, you'll discover that an IP address one of your `overload` rules blocked last week due to a brute-force attack was actually a dynamically assigned address, which is now assigned to a different ISP customer with a legitimate reason to communicate with hosts in your network.[3] If your adaptive rules catch a lot of traffic on a busy network, you may also find that the overload tables will grow over time to take up an increasing amount of memory.

The solution is to *expire* table entries—to remove entries after a certain amount of time. In OpenBSD 4.1, `pfctl` acquired the ability to expire table entries based on the time since their statistics were last reset.[4] (In almost all instances, this reset time is equal to the time since the table entry was added.) The keyword is `expire`, and the table entry's age is specified in seconds. Here's an example:

```
$ sudo pfctl -t bruteforce -T expire 86400
```

This command will remove `bruteforce` table entries that had their statistics reset more than 86,400 seconds (24 hours) ago.

NOTE *The choice of 24 hours as the expiry time is a fairly arbitrary one. You should choose a value that you feel is a reasonable amount of time for any problem at the other end to be noticed and fixed. If you have adaptive rules in place, it's a good idea to set up `crontab` entries to run table expiry at regular intervals with a command much like the preceding one to make sure your tables are kept up-to-date.*

3. From a longer-term perspective, it's fairly normal for entire networks and larger ranges of IP addresses to be reassigned to new owners in response to events in the physical, business-oriented world.

4. Before `pfctl` acquired the ability to expire table entries, table expiry was more likely than not handled by the special-purpose utility `expiretable`. If your `pfctl` doesn't have the `expire` option, you should seriously consider upgrading to a newer system. If upgrading is for some reason not practical, look for `expiretable` in your package system.

Giving Spammers a Hard Time with spamd

Email is a fairly essential service that needs special attention due to the large volume of unwanted messages, or *spam*. The volume of unsolicited commercial messages was already a painful problem when malware makers discovered that email-borne worms would work and started using email to spread their payload. During the early 2000s, the combined volume of spam and email-borne malware had increased to the point where running an SMTP mail service without some sort of spam countermeasures had become almost unthinkable.

Spam-fighting measures are almost as old as the spam problem itself. The early efforts focused on analysis of the messages' contents (known as *content filtering*) and to some extent on interpretation of the messages' rather trivially forgeable headers, such as the purported sender address (`From:`) or the store and forward paths of intermediate deliveries recorded in the `Received:` headers.

When the OpenBSD team designed its spam-fighting solution `spamd`, first introduced with OpenBSD 3.3 in 2003, the developers instead focused on the network level and the immediate communication partner in the SMTP conversations along with any available information about hosts that tried to deliver messages. The developers set out to create a small, simple, and secure program. The early implementation was based almost entirely on creative use of PF tables combined with data from trusted external sources.

NOTE *In addition to the OpenBSD spam-deferral daemon, the content-filtering-based antispam package SpamAssassin* (http://spamassassin.apache.org/) *features a program called* `spamd`. *Both programs are designed to help fight spam, but they take very different approaches to the underlying problem and don't interoperate directly. However, when both programs are correctly configured and running, they complement each other well.*

Network-Level Behavior Analysis and Blacklisting

The original `spamd` design is based on the observation that spammers send a lot of mail and the incredibly small likelihood of you being the first person to receive a particular message. In addition, spam is sent via a few spammer-friendly networks and numerous hijacked machines. Both the individual messages and the machines that send them will be reported to blacklist maintainers quickly, and the blacklist data consisting of known spam senders' IP addresses forms the basis for `spamd`'s processing.

When dealing with blacklisted hosts, `spamd` employs a method called *tarpitting*. When the daemon receives an SMTP connection, it presents its banner and immediately switches to a mode where it answers SMTP traffic at the rate of 1 byte per second, using a tiny selection of SMTP commands designed to make sure that mail is never delivered but rather rejected back into the sender's queue once the message headers have been transferred. The intention is to waste as much time as possible on the sending end

while costing the receiver pretty much nothing. This specific tarpitting implementation with 1-byte SMTP replies is often referred to as *stuttering*. Blacklist-based tarpitting with stuttering was the default mode for `spamd` up to and including OpenBSD 4.0.

NOTE *On FreeBSD and NetBSD,* `spamd` *is not part of the base system but is available through ports and packages as* mail/spamd. *If you're running PF on FreeBSD or NetBSD, you need to install the port or package before following the instructions over the next few pages.*

Setting Up spamd in Blacklisting Mode

To set up `spamd` to run in traditional, blacklisting-only mode, you first put a special-purpose table and a matching redirection in *pf.conf* and then turn your attention to `spamd`'s own *spamd.conf*. `spamd` then hooks into the PF rule set via the table and the redirection.

The following are the *pf.conf* lines for this configuration:

```
table <spamd> persist
pass in on $ext_if inet proto tcp from <spamd> to \
      { $ext_if, $localnet } port smtp rdr-to 127.0.0.1 port 8025
```

And here is the pre–OpenBSD 4.7 syntax:

```
table <spamd> persist
rdr pass on $ext_if inet proto tcp from <spamd> to \
         { $ext_if, $localnet } port smtp -> 127.0.0.1 port 8025
```

The table, `<spamd>`, is there to store the IP addresses you import from trusted blacklist sources. The redirection takes care of all SMTP attempts from hosts that are already in the blacklist. `spamd` listens on port 8025 and responds s-l-o-w-l-y (1 byte per second) to all SMTP connections it receives as a result of the redirection. Later on in the rule set, you would have a rule that makes sure legitimate SMTP traffic passes to the mail server.

spamd.conf is where you specify the sources of your blacklist data and any exceptions or local overrides you want.

NOTE *On OpenBSD 4.0 and earlier (and by extension, ports based on versions prior to OpenBSD 4.1),* spamd.conf *was in* /etc. *Beginning with OpenBSD 4.1,* spamd.conf *is found in* /etc/mail *instead. The FreeBSD port installs a sample configuration in* /usr/local/etc/spamd/spamd.conf.sample.

Near the beginning of *spamd.conf*, you'll notice a line without a # comment sign that looks like `all:\`. This line specifies the blacklists you'll use. Here is an example:

```
all:\
:uatraps:whitelist:
```

Add all blacklists that you want to use below the `all:\` line, separating each with a colon (`:`). To use whitelists to subtract addresses from your blacklist, add the name of the whitelist immediately after the name of each blacklist, as in `:blacklist:whitelist:`.

Next is the blacklist definition:

```
uatraps:\
        :black:\
        :msg="SPAM. Your address %A has sent spam within the last 24 hours":\
        :method=http:\
        :file=www.openbsd.org/spamd/traplist.gz
```

Following the name (`uatraps`), the first data field specifies the list type—in this case, `black`. The `msg` field contains the message to be displayed to blacklisted senders during the SMTP dialogue. The `method` field specifies how `spamd-setup` fetches the list data—in this case, via HTTP. Other possibilities include fetching via FTP (`ftp`), from a file in a mounted filesystem (`file`), or via execution of an external program (`exec`). Finally, the `file` field specifies the name of the file `spamd` expects to receive.

The definition of a whitelist follows much the same pattern but omits the message parameter:

```
whitelist:\
        :white:\
        :method=file:\
        :file=/etc/mail/whitelist.txt
```

NOTE *The suggested blacklists in the current default* spamd.conf *are actively maintained and have rarely, if ever, contained false positives. However, earlier versions of that file also suggested lists that excluded large blocks of the Internet, including several address ranges that claim to cover entire countries. If your site expects to exchange legitimate mail with any of the countries in question, those lists may not be optimal for your setup. Other popular lists have been known to list entire* `/16` *ranges as spam sources, and it's well worth reviewing the details of the list's maintenance policy before putting a blacklist into production.*

Put the lines for `spamd` and the startup parameters you want in your */etc/rc.conf.local* on OpenBSD or in */etc/rc.conf* on FreeBSD or NetBSD. Here's an example:

```
spamd_flags="-v -b" # for normal use: "" and see spamd-setup(8)
```

Here, we enable `spamd` and set it to run in blacklisting mode with the `-b` flag. In addition, the `-v` flag enables verbose logging, which is useful for keeping track of `spamd`'s activity for debugging purposes.

On FreeBSD, the */etc/rc.conf* settings that control spamd's behavior are obspamd_enable, which should be set to "YES" in order to enable spamd, and obspamd_flags, where you fill in any command-line options for spamd:

```
obspamd_enable="YES"
obspamd_flags="-v -b" # for normal use: "" and see spamd-setup(8)
```

NOTE *To have spamd run in pure blacklist mode on OpenBSD 4.1 or newer, you can achieve the same effect by setting the spamd_black variable to "YES" and then restarting spamd.*

Once you've finished editing the setup, start spamd with the options you want and complete the configuration with spamd-setup. Finally, create a cron job that calls spamd-setup to update the blacklist at reasonable intervals. In pure blacklist mode, you can view and manipulate the table contents using pfctl table commands.

spamd Logging

By default, spamd logs to your general system logs. To send the spamd log messages to a separate log file, add an entry like this to *syslog.conf*:

```
!!spamd
daemon.err;daemon.warn;daemon.info;daemon.debug          /var/log/spamd
```

Once you're satisfied that spamd is running and doing what it's supposed to do, you'll probably want to add the spamd log file to your log rotations, too. After you've run spamd-setup and the tables are filled, you can view the table contents using pfctl.

NOTE *In the sample* pf.conf *fragment at the beginning of this section, the redirection (rdr-to) rule is also a pass rule. If you opted for a match rule instead (or if you're using an older PF version and chose to write a rdr rule that doesn't include a pass part), be sure to set up a pass rule to let traffic through to your redirection. You may also need to set up rules to let legitimate email through. However, if you're already running an email service on your network, you can probably go on using your old SMTP pass rules.*

Given a set of reliable and well-maintained blacklists, spamd in pure blacklisting mode does a good job of reducing spam. However, with pure blacklisting, you catch traffic only from hosts that have already tried to deliver spam elsewhere, and you put your trust in external data sources to determine which hosts deserve to be tarpitted. For a setup that provides a more immediate response to network-level behavior and offers some real gains in spam prevention, consider *greylisting*, which is a crucial part of how the modern spamd works.

Greylisting: My Admin Told Me Not to Talk to Strangers

Greylisting consists mainly of interpreting the current SMTP standards and adding a little white lie to make life easier.

Spammers tend to use other people's equipment to send their messages, and the software they install without the legal owner's permission needs to be relatively lightweight in order to run undetected. Unlike legitimate mail senders, spammers typically don't consider any individual message they send to be important. Taken together, this means that typical spam and malware sender software aren't set up to interpret SMTP status codes correctly. This is a fact that we can use to our advantage, as Evan Harris proposed in his 2003 paper titled "The Next Step in the Spam Control War: Greylisting."[5]

As Harris noted, when a compromised machine is used to send spam, the sender application tends to try delivery only once, without checking for any results or return codes. Real SMTP implementations interpret SMTP return codes and act on them, and real mail servers retry if the initial attempt fails with any kind of temporary error.

In his paper, Harris outlined a practical approach:

- On first SMTP contact from a previously unknown communication partner, *do not* receive email on the first delivery attempt, but instead, respond with a status code that indicates a temporary local problem, and store the sender IP address for future reference.
- If the sender retries immediately, reply as before with the temporary failure status code.
- If the sender retries after a set minimum amount of time (1 hour, for example) but not more than a maximum waiting period (4 hours, for example), accept the message for delivery and record the sender IP address in your whitelist.

This is the essence of greylisting. And fortunately, you can set up and maintain a greylisting `spamd` on your PF-equipped gateway.

Setting Up spamd in Greylisting Mode

OpenBSD's `spamd` acquired its ability to greylist in OpenBSD 3.5. Beginning with OpenBSD 4.1, `spamd` runs in greylisting mode by default.

In the default greylisting mode, the `spamd` table used for blacklisting, as described in the previous section, becomes superfluous. You can still use blacklists, but `spamd` will use a combination of private data structures for blacklist data and the `spamdb` database to store greylisting-related data. A typical set of rules for `spamd` in default mode looks like this:

```
table <spamd-white> persist
table <nospamd> persist file "/etc/mail/nospamd"
```

5. The original Harris paper and a number of other useful articles and resources can be found at *http://www.greylisting.org/*.

```
pass in log on egress proto tcp to port smtp \
            rdr-to 127.0.0.1 port spamd
pass in log on egress proto tcp from <nospamd> to port smtp
pass in log on egress proto tcp from <spamd-white> to port smtp
pass out log on egress proto tcp to port smtp
```

This includes the necessary `pass` rules to let legitimate email flow to the intended destinations from your own network. The `<spamd-white>` table is the whitelist, maintained by `spamd`. The hosts in the `<spamd-white>` table have passed the greylisting hurdle, and mail from these machines is allowed to pass to the real mail servers or their content-filtering frontends. In addition, the `nospamd` table is there for you to load addresses of hosts that you don't want to expose to `spamd` processing, and the matching `pass` rule makes sure SMTP traffic from those hosts passes.

In your network, you may want to tighten those rules to pass SMTP traffic only to and from hosts that are allowed to send and receive email via SMTP. We'll get back to the `nospamd` table in "Handling Sites That Do Not Play Well with Greylisting" on page 113.

The following are the equivalent rules in pre–OpenBSD 4.7 syntax:

```
table <spamd-white> persist
table <nospamd> persist file "/etc/mail/nospamd"
rdr pass in log on egress proto tcp to port smtp \
            -> 127.0.0.1 port spamd
pass in log on egress proto tcp from <nospamd> to port smtp
pass in log on egress proto tcp from <spamd-white> to port smtp
pass out log on egress proto tcp to port smtp
```

On FreeBSD, in order to use `spamd` in greylisting mode, you need a file descriptor filesystem (see `man 5 fdescfs`) mounted at */dev/fd/*. To implement this, add the following line to */etc/fstab* and make sure the `fdescfs` code is in your kernel, either compiled in or by loading the module via the appropriate `kldload` command.

```
fdescfs /dev/fd fdescfs rw 0 0
```

To begin configuring `spamd`, place the lines for `spamd` and the startup parameters you want in */etc/rc.conf.local*. Here's an example:

```
spamd_flags="-v -G 2:4:864" # for normal use: "" and see spamd-setup(8)
```

On FreeBSD, the equivalent line should go in */etc/rc.conf*:

```
obspamd_flags="-v -G 2:4:864" # for normal use: "" and see spamd-setup(8)
```

You can fine-tune several of the greylisting-related parameters via `spamd` command-line parameters trailing the `-G` option.

WHY GREYLISTING WORKS

A significant amount of design and development effort has been put into making essential services, such as SMTP email transmission, fault-tolerant. In practical terms, this means that the best effort of a service such as SMTP is as close as you can get to having a perfect record for delivering messages. That's why we can rely on greylisting to eventually let us receive email from proper mail servers.

The current standard for Internet email transmission is defined in RFC 5321.* The following are several excerpts from Section 4.5.4.1, "Sending Strategy":

> "In a typical system, the program that composes a message has some method for requesting immediate attention for a new piece of outgoing mail, while mail that cannot be transmitted immediately MUST be queued and periodically retried by the sender. . . .
>
> "The sender *MUST* delay retrying a particular destination after one attempt has failed. In general, the retry interval *SHOULD* be at least 30 minutes; however, more sophisticated and variable strategies will be beneficial when the SMTP client can determine the reason for non-delivery.
>
> "Retries continue until the message is transmitted or the sender gives up; the give-up time generally needs to be at least 4–5 days."

Delivering email is a collaborative, best-effort process, and the RFC clearly states that if the site you are trying to send mail to reports that it can't receive at the moment, it is your duty (a must requirement) to try again later, giving the receiving server a chance to recover from its problem.

The clever wrinkle to greylisting is that it's a convenient white lie. When we claim to have a temporary local problem, that problem is really the equivalent of "My admin told me not to talk to strangers." Well-behaved senders with valid messages will call again, but spammers won't wait around for the chance to retry, since doing so increases their cost of delivering messages. This is why greylisting still works, and since it's based on strict adherence to accepted standards,† false positives are rare.

---

* The relevant parts of RFC 5321 are identical to the corresponding parts of RFC 2821, which is obsolete. Some of us were more than a little disappointed that the IETF didn't clarify these chunks of the text, now moving forward on the standards track. My reaction (actually, it's quite a rant) is at *http://bsdly.blogspot.com/2008/10/ietf-failed-to-account-for-greylisting.html*.

† The relevant RFCs are mainly RFC 1123 and RFC 5321, which made obsolete the earlier RFC 2821. Remember that temporary rejection is an SMTP fault-tolerance feature.

The colon-separated list `2:4:864` represents the values `passtime`, `greyexp`, and `whiteexp`:

- `passtime` denotes the minimum number of minutes `spamd` considers a reasonable time before retry. The default is 25 minutes, but here we've reduced it to 2 minutes.
- `greyexp` is the number of hours an entry stays in the greylisted state before it's removed from the database.
- `whiteexp` determines the number of hours a whitelisted entry is kept. The default values for `greyexp` and `whiteexp` are 4 hours and 864 hours (just over 1 month), respectively.

Greylisting in Practice

Users and administrators at sites that implement greylisting tend to agree that greylisting gets rid of most of their spam, with a significant drop in the load on any content filtering they have in place for their mail. We'll start by looking at what `spamd`'s greylisting looks like according to log files and then return with some data.

If you start `spamd` with the `-v` command-line option for verbose logging, your logs will include a few more items of information in addition to IP addresses. With verbose logging, a typical log excerpt looks like this:

```
Oct  2 19:53:21 delilah spamd[26905]: 65.210.185.131: connected (1/1), lists: spews1
Oct  2 19:55:04 delilah spamd[26905]: 83.23.213.115: connected (2/1)
Oct  2 19:55:05 delilah spamd[26905]: (GREY) 83.23.213.115: <gilbert@keyholes.net> ->
<wkitp98zpu.fsf@datadok.no>
Oct  2 19:55:05 delilah spamd[26905]: 83.23.213.115: disconnected after 0 seconds.
Oct  2 19:55:05 delilah spamd[26905]: 83.23.213.115: connected (2/1)
Oct  2 19:55:06 delilah spamd[26905]: (GREY) 83.23.213.115: <gilbert@keyholes.net> ->
<wkitp98zpu.fsf@datadok.no>
Oct  2 19:55:06 delilah spamd[26905]: 83.23.213.115: disconnected after 1 seconds.
Oct  2 19:57:07 delilah spamd[26905]: (BLACK) 65.210.185.131: <bounce-3C7E40A4B3@branch15.
summer-bargainz.com> -> <adm@dataped.no>
Oct  2 19:58:50 delilah spamd[26905]: 65.210.185.131: From: Auto lnsurance Savings <noreply@
branch15.summer-bargainz.com>
Oct  2 19:58:50 delilah spamd[26905]: 65.210.185.131: Subject: Start SAVlNG MONEY on Auto
lnsurance
Oct  2 19:58:50 delilah spamd[26905]: 65.210.185.131: To: adm@dataped.no
Oct  2 20:00:05 delilah spamd[26905]: 65.210.185.131: disconnected after 404 seconds. lists:
spews1
Oct  2 20:03:48 delilah spamd[26905]: 222.240.6.118: connected (1/0)
Oct  2 20:03:48 delilah spamd[26905]: 222.240.6.118: disconnected after 0 seconds.
Oct  2 20:06:51 delilah spamd[26905]: 24.71.110.10: connected (1/1), lists: spews1
Oct  2 20:07:00 delilah spamd[26905]: 221.196.37.249: connected (2/1)
Oct  2 20:07:00 delilah spamd[26905]: 221.196.37.249: disconnected after 0 seconds.
Oct  2 20:07:12 delilah spamd[26905]: 24.71.110.10: disconnected after 21 seconds. lists:
spews1
```

The first line is the beginning of a connection from a machine in the spews1 blacklist. The next six lines show the complete records of two connection attempts from another machine, which each time connects as the second active connection. This second machine isn't yet in any blacklist, so it's greylisted. Note the rather curious delivery address (*wkitp98zpu.fsf@datadok.no*) in the message that the greylisted machine tries to deliver. There's a useful trick that we'll look at in "Greytrapping" on page 109. The (GREY) and (BLACK) before the addresses indicate greylisting or blacklisting status. Then there's more activity from the blacklisted host, and a little later we see that after 404 seconds (or 6 minutes and 44 seconds), the blacklisted host gives up without completing the delivery.

The remaining lines show a few very short connections, including one from a machine already on a blacklist. This time, though, the machine disconnects too quickly to see any (BLACK) flag at the beginning of the SMTP dialogue, but we see a reference to the list name (spews1) at the end.

Roughly 400 seconds is about the amount of time that naive blacklisted spammers hang around (according to data from various sites) and about the time it takes (at the rate of 1 byte per second) to complete the EHLO ... dialogue until spamd rejects the message. However, while peeking at the logs, you're likely to find some spammers that hang around significantly longer. For example, in the data from our office gateway, one log entry stood out:

```
Dec 11 23:57:24 delilah spamd[32048]: 69.6.40.26: connected (1/1), lists:
spamhaus spews1 spews2
Dec 12 00:30:08 delilah spamd[32048]: 69.6.40.26: disconnected after 1964
seconds. lists: spamhaus spews1 spews2
```

This particular machine was already on several blacklists when it made 13 attempts at delivery from December 9 through December 12. The last attempt lasted 32 minutes and 44 seconds, without completing the delivery. Relatively intelligent spam senders drop the connection during the first few seconds, like the ones in the first log fragment. Others give up after around 400 seconds. A few hang on for hours. (The most extreme case we've recorded hung on for 42,673 seconds, which is almost 12 hours.)

Tracking Your Real Mail Connections: spamlogd

Behind the scenes, rarely mentioned and barely documented, is one of spamd's most important helper programs: the spamlogd whitelist updater. As the name suggests, spamlogd works quietly in the background, logging connections to and from your mail servers to keep your whitelist updated. The idea is to make sure that valid mail sent between hosts you communicate with regularly goes through with a minimum of fuss.

NOTE *If you've followed the discussion up to this point, spamlogd has probably been started automatically already. However, if your initial spamd configuration didn't include greylisting, spamlogd may not have been started, and you may experience strange symptoms, like the greylist and whitelist not being updated properly. Restarting spamd after you've enabled greylisting should ensure that spamlogd is loaded and available, too.*

In order to perform its job properly, spamlogd needs you to log SMTP connections to and from your mail servers, just as we did in the sample rule sets in Chapter 5:

```
emailserver = "192.0.2.225"
pass log proto tcp to $emailserver port $email
pass log proto tcp from $emailserver to port smtp
```

On OpenBSD 4.1 and higher (and equivalents), you can create several pflog interfaces and specify where rules should be logged. Here's how to separate the data spamlogd needs to read from the rest of your PF logs:

1. Create a separate pflog1 interface using ifconfig pflog1 create, or create a *hostname.pflog1* file with just the line up.
2. Change the rules to the following:

```
pass log (to pflog1) proto tcp to $emailserver port $email
pass log (to pflog1) proto tcp from $emailserver to port smtp
```

3. Add -l pflog1 to spamlogd's startup parameters.

This separates the spamd-related logging from the rest. (See Chapter 9 for more about logging.)

With the preceding rules in place, spamlogd will add the IP addresses that receive email you send to the whitelist. This isn't an ironclad guarantee that the reply will pass immediately, but in most configurations, it helps speed things significantly.

Greytrapping

We know that spam senders rarely use a fully compliant SMTP implementation to send their messages, which is why greylisting works. We also know that spammers rarely check that the addresses they feed to their hijacked machines are actually deliverable. Combine these facts, and you see that if a greylisted machine tries to send a message to an invalid address in your domain, there's a good chance that the message is spam or malware.

This realization led to the next evolutionary step in spamd development—a technique dubbed *greytrapping*. When a greylisted host tries to deliver mail to a known bad address in our domains, the host is added to a locally maintained blacklist called spamd-greytrap. Members of the spamd-greytrap list are treated to the same 1-byte-per-second tarpitting as members of other blacklists.

Greytrapping as implemented in spamd is simple and elegant. The main thing you need as a starting point is spamd running in greylisting mode. The other crucial component is a list of addresses in domains your servers handle email for, but only ones that you're sure will never receive legitimate email. The number of addresses in your list is unimportant, but there must be at least one, and the upper limit is mainly defined by how many addresses you wish to add.

Next, you use `spamdb` to feed your list to the greytrapping feature and sit back to watch. First, a sender tries to send email to an address on your greytrap list and is simply greylisted, as with any sender you haven't exchanged email with before. If the same machine tries again, either to the same, invalid address or another address on your greytrapping list, the greytrap is triggered, and the offender is put into `spamd-greytrap` for 24 hours. For the next 24 hours, any SMTP traffic from the greytrapped host will be stuttered, with 1-byte-at-a-time replies.

That 24-hour period is short enough not to cause serious disruption of legitimate traffic because real SMTP implementations will keep trying to deliver for at least a few days. Experience from large-scale implementations of the technique shows that it rarely produces false positives. Machines that continue spamming after 24 hours will make it back to the tarpit soon enough.

To set up your traplist, use `spamdb`'s `-T` option. In my case, the strange address[6] I mentioned earlier in "Greylisting in Practice" on page 107 was a natural candidate for inclusion:

```
$ sudo spamdb -T -a wkitp98zpu.fsf@datadok.no
```

The command I actually entered was `$ sudo spamdb -T -a "<wkitp98zpu .fsf@datadok.no>"`. In OpenBSD 4.1 and newer, `spamdb` doesn't require the angle brackets or quotes, but it will accept them.

Add as many addresses as you like. I tend to find new additions for my local list of spamtrap addresses by looking in the greylist and mail server logs for failed attempts to deliver delivery failure reports to nonexistent addresses in my domains (yes, it really is as crazy as it sounds).

WARNING *Make sure that the addresses you add to your spamtrap lists are invalid and will stay invalid. There's nothing quite like the embarrassment of discovering that you made a valid address into a spamtrap, however temporarily.*

The following log fragment shows how a spam-sending machine is greylisted at first contact and then comes back and clumsily tries to deliver messages to the curious address I added to my traplist, only to end up in the `spamd-greytrap` blacklist after a few minutes. We know what it will be doing for the next 20-odd hours.

```
Nov  6 09:50:25 delilah spamd[23576]: 210.214.12.57: connected (1/0)
Nov  6 09:50:32 delilah spamd[23576]: 210.214.12.57: connected (2/0)
Nov  6 09:50:40 delilah spamd[23576]: (GREY) 210.214.12.57: <gilbert@keyholes.net> ->
<wkitp98zpu.fsf@datadok.no>
Nov  6 09:50:40 delilah spamd[23576]: 210.214.12.57: disconnected after 15 seconds.
Nov  6 09:50:42 delilah spamd[23576]: 210.214.12.57: connected (2/0)
```

6. Of course, this address is totally bogus. It looks like the kind of message ID the GNUS email and news client generates, and it was probably lifted from a news spool or some unfortunate malware victim's mailbox.

```
Nov  6 09:50:45 delilah spamd[23576]: (GREY) 210.214.12.57: <bounce-3C7E40A4B3@branch15.summer-
bargainz.com> -> <adm@dataped.no>
Nov  6 09:50:45 delilah spamd[23576]: 210.214.12.57: disconnected after 13 seconds.
Nov  6 09:50:50 delilah spamd[23576]: 210.214.12.57: connected (2/0)
Nov  6 09:51:00 delilah spamd[23576]: (GREY) 210.214.12.57: <gilbert@keyholes.net> ->
<wkitp98zpu.fsf@datadok.no>
Nov  6 09:51:00 delilah spamd[23576]: 210.214.12.57: disconnected after 18 seconds.
Nov  6 09:51:02 delilah spamd[23576]: 210.214.12.57: connected (2/0)
Nov  6 09:51:02 delilah spamd[23576]: 210.214.12.57: disconnected after 12 seconds.
Nov  6 09:51:02 delilah spamd[23576]: 210.214.12.57: connected (2/0)
Nov  6 09:51:18 delilah spamd[23576]: (GREY) 210.214.12.57: <gilbert@keyholes.net> ->
<wkitp98zpu.fsf@datadok.no>
Nov  6 09:51:18 delilah spamd[23576]: 210.214.12.57: disconnected after 16 seconds.
Nov  6 09:51:18 delilah spamd[23576]: (GREY) 210.214.12.57: <bounce-3C7E40A4B3@branch15.summer-
bargainz.com> -> <adm@dataped.no>
Nov  6 09:51:18 delilah spamd[23576]: 210.214.12.57: disconnected after 16 seconds.
Nov  6 09:51:20 delilah spamd[23576]: 210.214.12.57: connected (1/1), lists: spamd-greytrap
Nov  6 09:51:23 delilah spamd[23576]: 210.214.12.57: connected (2/2), lists: spamd-greytrap
Nov  6 09:55:33 delilah spamd[23576]: (BLACK) 210.214.12.57: <gilbert@keyholes.net> ->
<wkitp98zpu.fsf@datadok.no>
Nov  6 09:55:34 delilah spamd[23576]: (BLACK) 210.214.12.57: <bounce-3C7E40A4B3@branch15.
summer-bargainz.com> -> <adm@dataped.no>
```

As a side note, it looks like even though the spammer moved to send from a different machine, both the `From:` and `To:` addresses stayed the same. The fact that he's still trying to send to an address that's never been deliverable is a strong indicator that this spammer doesn't check his lists frequently.

Managing Lists with spamdb

There may be times when you need to view or change the contents of blacklists, whitelists, and greylists. These records are located in the */var/db/spamdb* database, and an administrator's main interface to managing those lists is `spamdb`.

Early versions of `spamdb` simply offered options to add whitelist entries to the database or update existing ones (`spamdb -a` *`nn.mm.nn.mm`*). You could delete whitelist entries (`spamdb -d` *`nn.mm.nn.mm`*) to compensate for shortcomings in either the blacklists used or the effects of the greylisting algorithms. Recent versions of `spamdb` offer some interesting features to support greytrapping.

Updating Lists

If you run `spamdb` without any parameters, it lists the contents of your `spamdb` database, and it lets you add or delete both spamtrap addresses and traplist entries. You can also add whitelist entries on the fly.

If you want to add a host to your whitelist without adding it to your permanent *nospamd* file and reloading your rule set or the table, you could do it from the command line instead, like this:

```
$ sudo spamdb -a 213.187.179.198
```

If a spam sender managed to get a message delivered despite your best efforts, you could correct the situation by adding the spam sender to the spamd-greytrap list like this:

```
$ sudo spamdb -a -t 192.168.2.128
```

Adding a new trap address is just as simple:

```
$ sudo spamdb -a -T _-medvetsky@ehtrib.org
```

If you want to reverse either of these decisions, you would simply substitute -d for the -a option in both these commands.

Keeping spamd Greylists in Sync

Beginning with OpenBSD 4.1, spamd can keep greylisting databases in sync across any number of cooperating greylisting gateways. The implementation is via a set of spamd command-line options:

- The -Y option specifies a *sync target*—that is, the IP address(es) of other spamd-running gateways you want to inform of updates to your greylisting information.
- On the receiving end, the -y option specifies a *sync listener*, which is the address or interface where this spamd instance is prepared to receive greylisting updates from other hosts.

For example, our main spamd gateway mainoffice-gw.example.com might have the following options added to its startup command line to establish a sync target and sync listener, respectively:

```
-Y minorbranch-gw.example.com -y mainoffice-gw.example.com
```

Conversely, minorbranch-gw.example.com at the branch office would have the hostnames reversed:

```
-Y mainoffice-gw.example.com -y minorbranch-gw.example.com
```

The spamd daemon also supports shared-secret authentication between the synchronization partners. Specifically, if you create the file */etc/mail/spamd.key* and distribute copies of it to all synchronization partners, it'll be used to calculate the necessary checksums for authentication. The *spamd.key* file itself can be any kind of data, such as random data harvested from */dev/arandom*, as suggested by the spamd man page.

NOTE *In situations where direct synchronization of* `spamd`*-related data isn't practical or if you simply want to share your* `spamd-greytrap` *with others, exporting the contents of your list of locally trapped spam senders to a text file may be desirable. The list format* `spamd-setup` *expects is one address per line, optionally with comment lines starting with one or more* `#` *characters. Exporting your list of currently trapped addresses in a usable format can be as simple as putting together a one-liner with* `spamdb`*,* `grep`*, and a little imagination.*

Detecting Out-of-Order MX Use

OpenBSD 4.1 gave `spamd` the ability to detect out-of-order MX use. Contacting a secondary mail exchanger first instead of trying the main one is a fairly well-known spammer trick and one that runs contrary to the behavior we expect from ordinary email transfer agents. In other words, if someone tries the email exchangers in the wrong order, we can be pretty sure that they're trying to deliver spam.

For our *example.com* domain with main mail server 192.0.2.225 and backup 192.0.2.224, adding `-M 192.0.2.224` to `spamd`'s startup options would mean that any host that tries to contact 192.0.2.224 via SMTP before contacting the main mail server at 192.0.2.225 will be added to the local `spamd-greytrap` list for the next 24 hours.

Handling Sites That Do Not Play Well with Greylisting

Unfortunately, there are situations where you'll need to compensate for the peculiarities of other sites' email setups.

The first email message sent from any site that hasn't contacted you for as long as the greylister keeps its data around will be delayed for some random amount of time, which depends mainly on the sender's retry interval. There are times when even a minimal delay is undesirable. If, for example, you have some infrequent customers who demand your immediate and urgent attention to their business when they do contact you, an initial delivery delay of what could be up to several hours may not be optimal. In addition, you are bound to encounter misconfigured mail servers that either don't retry at all or retry too quickly, perhaps stopping delivery retries after just one attempt.

Also, some sites are large enough to have several outgoing SMTP servers, and they don't play well with greylisting because they're not guaranteed to retry delivery of any given message from the same IP address used with the prior delivery attempt. Even though those sites comply with the retry requirements, it's obvious that this is one of the few remaining downsides of greylisting.

One way to compensate for such situations is to define a table for a local whitelist to be fed from a file in case of reboots. To make sure SMTP traffic from the addresses in the table is not fed to `spamd`, add a `pass` rule to allow the traffic to pass:

```
table <nospamd> persist file "/etc/mail/nospamd"
pass in log on egress proto tcp from <nospamd> to port smtp
```

In pre–OpenBSD 4.7 syntax, add a `no rdr` rule at the top of your redirection block and a matching `pass` rule to let SMTP traffic from the hosts in your `nospamd` table through, as shown here:

```
no rdr proto tcp from <nospamd> to $mailservers port smtp
pass in log on egress proto tcp from <nospamd> to port smtp
```

Once you've made these changes to your rule set, enter the addresses you need to protect from redirection into the */etc/mail/nospamd* file. Then reload your rule set using `pfctl -f /etc/pf.conf`. You can then use all the expected table tricks on the `<nospamd>` table, including replacing its content after editing the *nospamd* file. In fact, this approach is strongly hinted at in both man pages and sample configuration files distributed with recent versions of `spamd`.

At least some sites with many outgoing SMTP servers publish information about which hosts are allowed to send email for their domain via Sender Policy Framework (SPF) records as part of the domain's DNS information.[7] To retrieve the SPF records for our *example.com* domain, use the `host` command's `-ttxt` option as follows:

```
$ host -ttxt example.com
```

This command would produce an answer roughly like the following:

```
example.com descriptive text "v=spf1 ip4:192.0.2.128/25 -all"
```

Here, the text in quotes is the *example.com* domain's SPF record. If you want email from *example.com* to arrive quickly and you trust the people there not to send or relay spam, choose the address range from the SPF record, add it to your *nospamd* file, and reload the `<nospamd>` table contents from the updated file.

7. SPF records are stored in DNS zones as TXT records. See *http://www.openspf.org/* for details.

Spam-Fighting Tips

When used selectively, blacklists combined with `spamd` are powerful, precise, and efficient spam-fighting tools. The load on the `spamd` machine is minimal. On the other hand, `spamd` will never perform better than its weakest data source, which means you'll need to monitor your logs and use whitelisting when necessary.

It's also feasible to run `spamd` in a pure greylisting mode, with no blacklists. In fact, some users report that a purely greylisting `spamd` configuration is about as effective a spam-fighting tool as configurations with blacklists and sometimes significantly more effective than content filtering. One such report posted to *openbsd-misc* claimed that a pure greylisting configuration immediately rid the company of approximately 95 percent of its spam load. (This report is accessible via *http://marc.info/*, among other places; search for the subject "Followup – spamd greylisting results.")

I recommend two very good blacklists. One is Bob Beck's traplist based on "ghosts of usenet postings past." Generated automatically by computers running `spamd` at the University of Alberta, Bob's setup is a regular `spamd` system that removes trapped addresses automatically after 24 hours, which means that you get an extremely low number of false positives. The number of hosts varies widely and has been as high as 670,000. While still officially in testing, the list was made public in January 2006. The list is available from *http://www.openbsd.org/spamd/traplist.gz*. It's part of recent sample *spamd.conf* files as the `uatraps` blacklist.

The other list I recommend is *heise.de*'s `nixspam`, which has a 12-hour automatic expiry and extremely good accuracy. It's also in the sample *spamd.conf* file. Detailed information about this list is available from *http://www.heise.de/ix/nixspam/dnsbl_en/*.

Once you're happy with your setup, try introducing local greytrapping. This is likely to catch a few more undesirables, and it's good, clean fun. Some limited experiments—carried out while writing this chapter (chronicled at *http://bsdly.blogspot.com/* in entries starting with *http://bsdly.blogspot.com/2007/07/hey-spammer-heres-list-for-you.html*)—even suggest that harvesting the invalid addresses spammers use from your mail server logs, from `spamd` logs, or directly from your greylist to put in your traplist is extremely efficient. Publishing the list on a moderately visible Web page appears to ensure that the addresses you put there will be recorded over and over again by address-harvesting robots and will provide you with even better greytrapping material, as they're then more likely to be kept on the spammers' list of known good addresses.

7

TRAFFIC SHAPING WITH QUEUES AND PRIORITIES

In this chapter, we look at how to use traffic shaping to allocate bandwidth resources efficiently and according to a specified policy. If the term *traffic shaping* seems unfamiliar, rest assured it means what you think it means: that you'll be altering the way your network allocates resources in order to satisfy the requirements of your users and their applications. With a proper understanding of your network traffic and the applications and users that generate it, you can, in fact, go quite a bit of distance toward "bigger, better, faster, more" just by optimizing your network for the traffic that's actually supposed to pass there.

A small but powerful arsenal of traffic-shaping tools is at your disposal; all of them work by introducing nondefault behavior into your network setup to bend the realities of your network according to your wishes. Traffic shaping for PF contexts currently comes in two flavors: the once experimental

ALTQ (short for *alternate queuing*) framework, now considered old-style after some 15 years of service, and the newer OpenBSD *priorities and queuing* system introduced in OpenBSD 5.5.

In the first part of the chapter, we introduce traffic shaping by looking at the features of the new OpenBSD priority and queuing system. If you're about to set up on OpenBSD 5.5 or newer, you can jump right in, starting with the next section, "Always-On Priority and Queues for Traffic Shaping." This is also where the main traffic-shaping concepts are introduced with examples.

On OpenBSD 5.4 and earlier as well as other BSDs where the PF code wasn't current with OpenBSD 5.5, traffic shaping was the domain of the ALTQ system. On OpenBSD, ALTQ was removed after one transitional release, leaving only the newer traffic-shaping system in place from OpenBSD 5.6 onward. If you're interested in converting an existing ALTQ setup to the new system, you'll most likely find "Transitioning from ALTQ to Priorities and Queues" on page 131 useful; this section highlights the differences between the older ALTQ system and the new system.

If you're working with an operating system where the queues system introduced in OpenBSD 5.5 isn't yet available, you'll want to study the ALTQ traffic-shaping subsystem, which is described in "Directing Traffic with ALTQ" on page 133. If you're learning traffic-shaping concepts and want to apply them to an ALTQ setup, please read the first part of this chapter before diving into ALTQ-specific configuration details.

Always-On Priority and Queues for Traffic Shaping

Managing your bandwidth has a lot in common with balancing your checkbook or handling other resources that are either scarce or available in finite quantities. The resource is available in a constant supply with hard upper limits, and you need to allocate the resource with maximum *efficiency*, according to the *priorities* set out in your *policy* or *specification*.

OpenBSD 5.5 and newer offers several different options for managing your bandwidth resources via classification mechanisms in our PF rule sets. We'll take a look at what you can do with pure *traffic prioritization* first and then move on to how to subdivide your bandwidth resources by allocating defined subsets of your traffic to *queues*.

NOTE *The always-on priorities were introduced as a teaser of sorts in OpenBSD 5.0. After several years in development and testing, the new queuing system was finally committed in time to be included in OpenBSD 5.5, which was released on May 1, 2014. If you're starting your traffic shaping from scratch on OpenBSD 5.5 or newer or you're considering doing so, this section is the right place to start. If you're upgrading from an earlier OpenBSD version or transitioning from another ALTQ system to a recent OpenBSD, you'll most likely find the following section, "Transitioning from ALTQ to Priorities and Queues," useful.*

Shaping by Setting Traffic Priorities

If you're mainly interested in pushing certain kinds of traffic ahead of others, you may be able to achieve what you want by simply setting priorities: assigning a higher priority to some items so that they receive attention before others.

The prio Priority Scheme

Starting with OpenBSD 5.0, a priority scheme for classifying network traffic on a per-rule basis is available. The range of priorities is from 0 to 7, where 0 is lowest priority. Items assigned priority 7 will skip ahead of everything else, and the default value 3 is automatically assigned for most kinds of traffic. The priority scheme, which you'll most often hear referred to as `prio` after the PF syntax keyword, is always enabled, and you can tweak your traffic by setting priorities via your `match` or `pass` rules.

For example, to speed up your outgoing SSH traffic to the max, you could put a rule like this in your configuration:

```
pass proto tcp to port ssh set prio 7
```

Then your SSH traffic would be served before anything else.

You could then examine the rest of your rule set and decide what traffic is more or less important, what you would like always to reach its destination, and what parts of your traffic you feel matter less.

To push your Web traffic ahead of everything else and bump up the priority for network time and name services, you could amend your configuration with rules like these:

```
pass proto tcp to port { www https } set prio 7
pass proto { udp tcp } to port { domain ntp } set prio 6
```

Or if you have a rule set that already includes rules that match criteria other than just the port, you could achieve much the same effect by writing your priority traffic shaping as `match` rules instead:

```
match proto tcp to port { www https } set prio 7
match proto { udp tcp } to port { domain ntp } set prio 6
```

In some networks, time-sensitive traffic, like Voice over Internet Protocol (VoIP), may need special treatment. For VoIP, a priority setup like this may improve phone conversation quality:

```
voip_ports="{ 2027 4569 5036 5060 10000:20000 }"
match proto udp to port $voip_ports set prio 7
```

But do check your VoIP application's documentation for information on what specific ports it uses. In any case, using `match` rules like these can have a positive effect on your configuration in other ways, too: You can use `match` rules like the ones in the examples here to separate filtering

decisions—such as passing, blocking, or redirecting—from traffic-shaping decisions, and with that separation in place, you're likely to end up with a more readable and maintainable configuration.

It's also worth noting that parts of the OpenBSD network stack set default priorities for certain types of traffic that the developers decided was essential to a functional network. If you don't set any priorities, anything with `proto carp` and a few other management protocols and packet types will go by priority 6, and all types of traffic that don't receive a specific classification with a `set prio` rule will have a default priority of 3.

The Two-Priority Speedup Trick

In the examples just shown, we set different priorities for different types of traffic and managed to get specific types of traffic, such as VoIP and SSH, to move faster than others. But thanks to the design of TCP, which carries the bulk of your traffic, even a simple priority-shaping scheme has more to offer with only minor tweaks to the rule set.

As readers of RFCs and a few practitioners have discovered, the connection-oriented design of TCP means that for each packet sent, the sender will expect to receive an acknowledgment (ACK) packet back within a preset time or matching a defined "window" of sequence numbers. If the sender doesn't receive the acknowledgment within the expected limit, she assumes the packet was lost in transit and arranges to resend the data.

One other important factor to consider is that by default, packets are handled in the order they arrive. This is known as *first in, first out (FIFO)*, and it means that the essentially dataless ACK packets will be waiting their turn in between the larger data packets. On a busy or congested link, which is exactly where traffic shaping becomes interesting, waiting for ACKs and performing retransmissions can eat measurably into effective bandwidth and slow down all transfers. In fact, concurrent transfers in both directions can slow each other significantly more than the value of their expected data sizes.[1]

Fortunately, a simple and quite popular solution to this problem is at hand: You can use priorities to make sure those smaller packets skip ahead. If you assign two priorities in a `match` or `pass` rule, like this:

```
match out on egress set prio (5, 6)
```

The first priority will be assigned to the regular traffic, while ACK packets and other packets with a low delay type of service (ToS) will be assigned the second priority and will be served faster than the regular packets.

When a packet arrives, PF detects the ACK packets and puts them on the higher-priority queue. PF also inspects the ToS field on arriving packets. Packets that have the ToS set to low delay to indicate that the sender wants

1. Daniel Hartmeier, one of the original PF developers, wrote a nice article about this problem, which is available at *http://www.benzedrine.cx/ackpri.html*. Daniel's explanations use the older ALTQ priority queues syntax but include data that clearly illustrates the effect of assigning two different priorities to help ACKs along.

speedier delivery also get the high-priority treatment. When more than one priority is indicated, as in the preceding rule, PF assigns priority accordingly. Packets with other ToS values are processed in the order they arrive, but with ACK packets arriving faster, the sender spends less time waiting for ACKs and resending presumably lost data. The net result is that the available bandwidth is used more efficiently. (The `match` rule quoted here is the first one I wrote in order to get a feel for the new `prio` feature—on a test system, of course—soon after it was committed during the OpenBSD 5.0 development cycle. If you put that single `match` rule on top of an existing rule set, you'll probably see that the link can take more traffic and more simultaneous connections before noticeable symptoms of congestion turn up.)

See whether you can come up with a way to measure throughout before and after you introduce the two-priorities trick to your traffic shaping, and note the difference before you proceed to the more complex traffic-shaping options.

Introducing Queues for Bandwidth Allocation

We've seen that traffic shaping using only priorities can be quite effective, but there will be times when a priorities-only scheme will fall short of your goals. One such scenario occurs when you're faced with requirements that would be most usefully solved by assigning a higher priority, and perhaps a larger bandwidth share, to some kinds of traffic, such as email and other high-value services, and correspondingly less bandwidth to others. Another such scenario would be when you simply want to apportion your available bandwidth in different-sized chunks to specific services and perhaps set hard upper limits for some types of traffic, while at the same time wanting to ensure that all traffic that you care about gets at least its fair share of available bandwidth. In cases like these, you leave the pure-priority scheme behind, at least as the primary tool, and start doing actual traffic shaping using *queues*.

Unlike with the priority levels, which are always available and can be used without further preparations, in any rule, queues represent specific parts of your available bandwidth and can be used only after you've defined them in terms of available capacity. Queues are a kind of buffer for network packets. Queues are defined with a specific amount of bandwidth, or as a specific portion of available bandwidth, and you can allocate portions of each queue's bandwidth share to subqueues, or queues within queues, which share the parent queue's resources. The packets are held in a queue until they're either dropped or sent according to the queue's criteria and subject to the queue's available bandwidth. Queues are attached to specific interfaces, and bandwidth is managed on a per-interface basis, with available bandwidth on a given interface subdivided into the queues you define.

The basic syntax for defining a queue follows this pattern:

```
queue name on interface bandwidth number [ ,K,M,G]
     queue name1 parent name bandwidth number[ ,K,M,G] default
     queue name2 parent name bandwidth number[ ,K,M,G]
     queue name3 parent name bandwidth number[ ,K,M,G]
```

The letters following the bandwidth number denote the unit of measurement: `K` denotes kilobits; `M` megabits; and `G` gigabits. When you write only the bandwidth number, it's interpreted as the number of bits per second. It's possible to tack on other options to this basic syntax, as we'll see in later examples.

NOTE *Subqueue definitions name their parent queue, and one queue needs to be the default queue that receives any traffic not specifically assigned to other queues.*

Once queue definitions are in place, you integrate traffic shaping into your rule set by rewriting your `pass` or `match` rules to assign traffic to a specific queue.

WHAT'S YOUR TOTAL USABLE BANDWIDTH?

Once we start working with defined parts of total bandwidth rather than priorities that somehow share the whole, determining the exact value of your total usable bandwidth becomes interesting. It can be difficult to determine actual usable bandwidth on a specific interface for queuing. If you don't specify a total bandwidth, the total bandwidth available will be used to calculate the allocations, but some types of interfaces cannot reliably report the actual bandwidth value. One common example of this discrepancy is where your gateway's external interface is a 100 megabit (Mb) Ethernet interface, attached to a DSL line that offers only 8Mb download and 1Mb upload.* The Ethernet interface will then confidently report 100Mb bandwidth, not the actual value of the Internet-facing connection.

For this reason, it usually makes sense to set the total bandwidth to a fixed value. Unfortunately, the value to use may not be exactly what your bandwidth supplier tells you is available because there will always be some overhead due to various technologies and implementations. For example, in typical TCP/IP over wired Ethernet, overhead can be as low as single-digit percentages, but TCP/IP over ATM has been known to have overhead of almost 20 percent. If your bandwidth supplier doesn't provide the overhead information, you'll need to make an educated guess at the starting value. In any case, remember that the total bandwidth available is never greater than the bandwidth of the weakest link in your network path.

Queues are supported only for outbound connections relative to the system doing the queuing. When planning your bandwidth management, consider the actual usable bandwidth to be equal to the weakest (lowest bandwidth) link in the connection's path, even if your queues are set up on a different interface.

---

* This really dates the book, I know. In a few years, these numbers will seem quaint.

The HFSC Algorithm

Underlying any queue system you define using the queue system in OpenBSD 5.5 and later is the *Hierarchical Fair Service Curve (HFSC)* algorithm. HFSC was designed to allocate resources fairly among queues in a hierarchy. One of its interesting features is that it imposes no limits until some part of the traffic reaches a volume that's close to its preset limits. The algorithm starts shaping just before the traffic reaches a point where it deprives some other queue of its guaranteed minimum share.

NOTE *All sample configurations we present in this book assign traffic to queues in the outgoing direction because you can realistically control only traffic generated locally and, once limits are reached, any traffic-shaping system will eventually resort to dropping packets in order to make the endpoint back off. As we saw in the earlier examples, all well-behaved TCP stacks will respond to lost ACKs with slower packet rates.*

Now that you know at least the basics of the theory behind the OpenBSD queue system, let's see how queues work.

Splitting Your Bandwidth into Fixed-Size Chunks

You'll often find that certain traffic should receive a higher priority than other traffic. For example, you'll often want important traffic, such as mail and other vital services, to have a baseline amount of bandwidth available at all times, while other services, such as peer-to-peer file sharing, shouldn't be allowed to consume more than a certain amount. To address these kinds of issues, queues offer a wider range of options than the pure-priority scheme.

The first queue example builds on the rule sets from earlier chapters. The scenario is that we have a small local network, and we want to let the users on the local network connect to a predefined set of services outside their own network while also letting users from outside the local network access a Web server and an FTP server somewhere on the local network.

Queue Definition

In the following example, all queues are set up with the root queue, called `main`, on the external, Internet-facing interface. This approach makes sense mainly because bandwidth is more likely to be limited on the external link than on the local network. In principle, however, allocating queues and running traffic shaping can be done on any network interface.

This setup includes a queue for a total bandwidth of 20Mb with six subqueues.

```
queue main on $ext_if bandwidth 20M
      queue defq parent main bandwidth 3600K default
      queue ftp parent main bandwidth 2000K
      queue udp parent main bandwidth 6000K
      queue web parent main bandwidth 4000K
```

```
      queue ssh parent main bandwidth 4000K
        queue ssh_interactive parent ssh bandwidth 800K
        queue ssh_bulk parent ssh bandwidth 3200K
queue icmp parent main bandwidth 400K
```

The subqueue `defq`, shown in the preceding example, has a bandwidth allocation of 3600K, or 18 percent of the bandwidth, and is designated as the default queue. This means any traffic that matches a `pass` rule but that isn't explicitly assigned to some other queue ends up here.

The other queues follow more or less the same pattern, up to subqueue `ssh`, which itself has two subqueues (the two indented lines below it). Here, we see a variation on the trick of using two separate priorities to speed up ACK packets, and as we'll see shortly, the rule that assigns traffic to the two SSH subqueues assigns different priorities. Bulk SSH transfers, typically SCP file transfers, are transmitted with a ToS indicating throughput, while interactive SSH traffic has the ToS flag set to low delay and skips ahead of the bulk transfers. The interactive traffic is likely to be less bandwidth consuming and gets a smaller share of the bandwidth, but it receives preferential treatment because of the higher-priority value assigned to it. This scheme also helps the speed of SCP file transfers because the ACK packets for the SCP transfers will be assigned a higher priority.

Finally, we have the `icmp` queue, which is reserved for the remaining 400K, or 2 percent, of the bandwidth from the top level. This guarantees a minimum amount of bandwidth for ICMP traffic that we want to pass but that doesn't match the criteria that would have it assigned to the other queues.

Rule Set

To tie the queues into the rule set, we use the `pass` rules to indicate which traffic is assigned to the queues and their criteria.

```
set skip on { lo, $int_if }
pass log quick on $ext_if proto tcp to port ssh \
    queue (ssh_bulk, ssh_interactive) set prio (5,7)
pass in quick on $ext_if proto tcp to port ftp queue ftp
pass in quick on $ext_if proto tcp to port www queue http
pass out on $ext_if proto udp queue udp
pass out on $ext_if proto icmp queue icmp
pass out on $ext_if proto tcp from $localnet to port $client_out ❶
```

The rules for `ssh`, `ftp`, `www`, `udp`, and `icmp` assign traffic to their respective queues, and we note again that the `ssh` queue's subqueues are assigned traffic with two different priorities. The last catchall rule ❶ passes all other outgoing traffic from the local network, lumping it into the default `defq` queue.

You can always let a block of `match` rules do the queue assignment instead in order to make the configuration even more flexible. With match rules in place, you move the filtering decisions to block, pass, or even redirect to a set of rules elsewhere.

```
match log quick on $ext_if proto tcp to port ssh \
    queue (ssh_bulk, ssh_interactive) set prio (5,7)
match in quick on $ext_if proto tcp to port ftp queue ftp
match in quick on $ext_if proto tcp to port www queue http
match out on $ext_if proto udp queue udp
match out on $ext_if proto icmp queue icmp
```

Note that with `match` rules performing the queue assignment, there's no need for a final catchall to put the traffic that doesn't match the other rules into the default queue. Any traffic that doesn't match these rules and that's allowed to pass will end up in the default queue.

Upper and Lower Bounds with Bursts

Fixed bandwidth allocations are nice, but network admins with traffic-shaping ambitions tend to look for a little more flexibility once they've gotten their feet wet. Wouldn't it be nice if there were a regime with flexible bandwidth allocation, offering guaranteed lower and upper bounds for bandwidth available to each queue and variable allocations over time—and one that starts shaping only when there's an actual need to do so?

The good news is that the OpenBSD queues can do just that, courtesy of the underlying HFSC algorithm discussed earlier. HFSC makes it possible to set up queuing regimes with guaranteed minimum allocations and hard upper limits, and you can even have allocations that include `burst` values to let available capacity vary over time.

Queue Definition

Working from a typical gateway configuration like the ones we've altered incrementally over the earlier chapters, we insert this queue definition early in the *pf.conf* file:

```
queue rootq on $ext_if bandwidth 20M
        queue main parent rootq bandwidth 20479K min 1M max 20479K qlimit 100
             queue qdef parent main bandwidth 9600K min 6000K max 18M default
             queue qweb parent main bandwidth 9600K min 6000K max 18M
             queue qpri parent main bandwidth 700K min 100K max 1200K
             queue qdns parent main bandwidth 200K min 12K burst 600K for 3000ms
        queue spamd parent rootq bandwidth 1K min 0K max 1K qlimit 300
```

This definition has some characteristics that are markedly different from the previous one on page 121. We start with this rather small hierarchy by splitting the top-level queue, `rootq`, into two. Next, we subdivide the `main` queue into several subqueues, all of which have a `min` value set—the guaranteed minimum bandwidth allocated to the queue. (The `max` value would set a hard upper limit on the queue's allocation.) The `bandwidth` parameter also sets the allocation the queue will have available when it's backlogged—that is, when it's started to eat into its `qlimit`, or *queue limit*, allocation.

The queue limit parameter works like this: In case of congestion, each queue by default has a pool of 50 slots, the queue limit, to keep packets around when they can't be transmitted immediately. Here, the top-level queues, `main` and `spamd`, both have larger-than-default pools set by their `qlimit` setting: `100` for `main` and `300` for `spamd`. Cranking up these `qlimit` sizes means we're a little less likely to drop packets when the traffic approaches the set limits, but it also means that when the traffic shaping kicks in, we'll see increased latency for connections that end up in these larger pools.

Rule Set

The next step is to tie the newly created queues into the rule set. If you have a filtering regime in place already, the tie-in is simple—just add a few `match` rules:

```
match out on $ext_if proto tcp to port { www https } \
    set queue (qweb, qpri) set prio (5,6)
match out on $ext_if proto { tcp udp } to port domain \
    set queue (qdns, qpri) set prio (6,7)
match out on $ext_if proto icmp \
    set queue (qdns, qpri) set prio (6,7)
```

Here, the `match` rules once again do the ACK packet speedup trick with the high- and low-priority queue assignment, just as we saw earlier in the pure-priority-based system. The only exception is when we assign traffic to our lowest-priority queue (with a slight modification to an existing `pass` rule), where we really don't want any speedup.

```
pass in log on egress proto tcp to port smtp \
    rdr-to 127.0.0.1 port spamd set queue spamd set prio 0
```

Assigning the `spamd` traffic to a minimal-sized queue with 0 priority here is intended to slow down the spammers on their way to our `spamd`. (See Chapter 6 for more on `spamd` and related matters.)

With the queue assignment and priority setting in place, it should be clear that the queue hierarchy here uses two familiar tricks to make efficient use of available bandwidth. First, it uses a variation of the high- and low-priority mix demonstrated in the earlier pure-priority example. Second, we speed up almost all other traffic, especially the Web traffic, by allocating a small but guaranteed portion of bandwidth for name service lookups. For the `qdns` queue, we set the `burst` value with a time limit: After `3000` milliseconds, the allocation goes down to a minimum of `12K` to fit within the total `200K` quota. Short-lived `burst` values like this can be useful to speed connections that transfer most of their payload during the early phases.

It may not be immediately obvious from this example, but HFSC requires that traffic be assigned only to *leaf queues*, or queues without subqueues. That means it's possible to assign traffic to `main`'s subqueues—`qpri`, `qdef`, `qweb`, and `qdns`—as well as `rootq`'s subqueue—`spamd`—as we just did with the `match` and

pass rules, but not to rootq or main themselves. With all queue assignments in place, we can use systat queues to show the queues and their traffic:

```
    6 users    Load 0.31 0.28 0.34                  Tue May 19 21:31:54 2015

QUEUE               BW SCH  PR   PKTS BYTES DROP_P DROP_B QLEN BORR SUSP P/S  B/S
rootq              20M              0     0      0      0    0
 main              20M              0     0      0      0    0
  qdef              9M          48887   15M      0      0    0
  qweb              9M          18553 8135K      0      0    0
  qpri            600K          37549 2407K      0      0    0
  qdns            200K          15716 1568K      0      0    0
 spamd              1K          10590  661K    126   8772   47
```

The queues are shown indented to indicate their hierarchy, from root to leaf queues. The main queue and its subqueues—qpri, qdef, qweb, and qdns—are shown with their bandwidth allocations and number of bytes and packets passed. The DROP_P and DROP_B columns, which show the number of packets and bytes dropped, would appear if we had been forced to drop packets at this stage. QLEN is the number of packets waiting for processing, while the final two columns show live updates of packets and bytes per second.

For a more detailed view, use pfctl -vvsq to show the queues and their traffic:

```
queue rootq on xl0 bandwidth 20M qlimit 50
  [ pkts:          0  bytes:          0  dropped pkts:      0 bytes:      0 ]
  [ qlength:   0/ 50 ]
  [ measured:     0.0 packets/s, 0 b/s ]
queue main parent rootq on xl0 bandwidth 20M, min 1M, max 20M qlimit 100
  [ pkts:          0  bytes:          0  dropped pkts:      0 bytes:      0 ]
  [ qlength:   0/100 ]
  [ measured:     0.0 packets/s, 0 b/s ]
queue qdef parent main on xl0 bandwidth 9M, min 6M, max 18M default qlimit 50
  [ pkts:       1051  bytes:     302813  dropped pkts:      0 bytes:      0 ]
  [ qlength:   0/ 50 ]
  [ measured:     2.6 packets/s, 5.64Kb/s ]
queue qweb parent main on xl0 bandwidth 9M, min 6M, max 18M qlimit 50
  [ pkts:       1937  bytes:    1214950  dropped pkts:      0 bytes:      0 ]
  [ qlength:   0/ 50 ]
  [ measured:     3.6 packets/s, 13.65Kb/s ]
queue qpri parent main on xl0 bandwidth 600K, max 1M qlimit 50
  [ pkts:       2169  bytes:     143302  dropped pkts:      0 bytes:      0 ]
  [ qlength:   0/ 50 ]
  [ measured:     6.6 packets/s, 3.55Kb/s ]
queue qdns parent main on xl0 bandwidth 200K, min 12K burst 600K for 3000ms qlimit 50
  [ pkts:        604  bytes:      65091  dropped pkts:      0 bytes:      0 ]
  [ qlength:   0/ 50 ]
  [ measured:     1.6 packets/s, 1.31Kb/s ]
queue spamd parent rootq on xl0 bandwidth 1K, max 1K qlimit 300
  [ pkts:        884  bytes:      57388  dropped pkts:      0 bytes:      0 ]
  [ qlength: 176/300 ]
  [ measured:     1.9 packets/s, 1Kb/s ]
```

This view shows that the queues receive traffic roughly as expected with the site's typical workload. Notice that only a few moments after the rule set has been reloaded, the `spamd` queue is already backed up more than halfway to its `qlimit` setting, which seems to indicate that the queues are reasonably dimensioned to actual traffic.

NOTE *Pay attention to each queue's dropped packets (`dropped pkts:`) counter. If the number of packets dropped is high or increasing, then that could mean that one of the bandwidth allocation parameters needs adjusting or that some other network problem needs to be investigated.*

The DMZ Network, Now with Traffic Shaping

In Chapter 5, we set up a network with a single gateway and all externally visible services configured on a separate DMZ (demilitarized zone) network so that all traffic to the servers from both the Internet and the internal network had to pass through the gateway. That network schematic, illustrated in Chapter 5, is shown again in Figure 7-1. Using the rule set from Chapter 5 as the starting point, we'll add some queuing in order to optimize our network resources. The physical and logical layout of the network will not change.

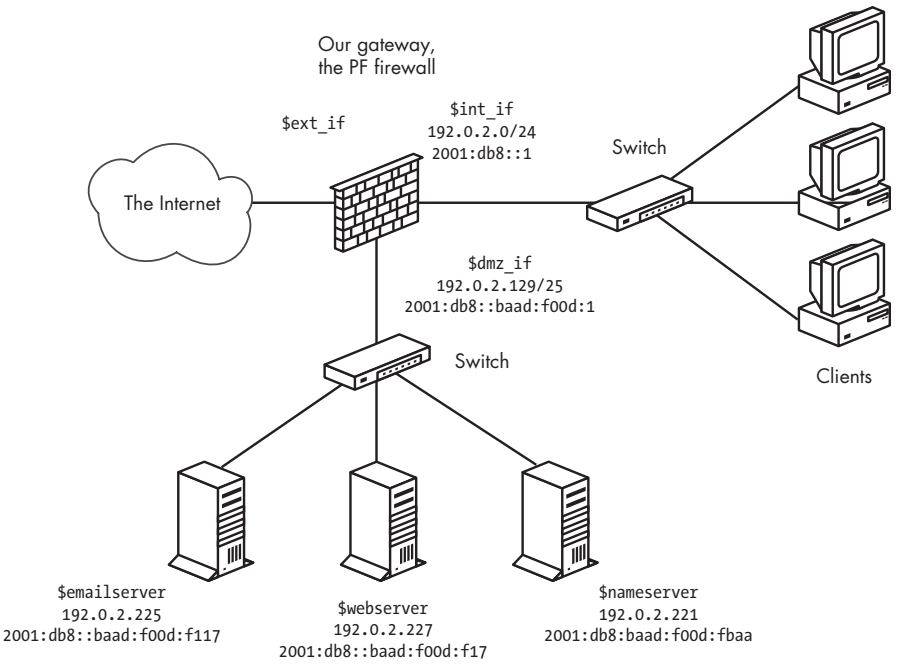

Figure 7-1: Network with DMZ

The most likely bottleneck for this network is the bandwidth for the connection between the gateway's external interface and the Internet. Although the bandwidth elsewhere in our setup isn't infinite, of course, the available bandwidth on any interface in the local network is likely to be

less limiting than the bandwidth actually available for communication with the outside world. In order to make services available with the best possible performance, we need to set up the queues so that the bandwidth available at the site is made available to the traffic we want to allow. The interface bandwidth on the DMZ interface is likely either 100Mb or 1Gb, while the *actual available bandwidth* for connections from outside the local network is considerably smaller. This consideration shows up in our queue definitions, where the actual bandwidth available for external traffic is the main limitation in the queue setup.

```
queue ext on $ext_if bandwidth 2M
        queue ext_main parent ext bandwidth 500K default
        queue ext_web parent ext bandwidth 500K
        queue ext_udp parent ext bandwidth 400K
        queue ext_mail parent ext bandwidth 600K

queue dmz on $dmz_if bandwidth 100M
        queue ext_dmz parent dmz bandwidth 2M
                queue ext_dmz_web parent ext_dmz bandwidth 800K default
                queue ext_dmz_udp parent ext_dmz bandwidth 200K
                queue ext_dmz_mail parent ext_dmz bandwidth 1M
        queue dmz_main parent dmz bandwidth 25M
        queue dmz_web parent dmz bandwidth 25M
        queue dmz_udp parent dmz bandwidth 20M
        queue dmz_mail parent dmz bandwidth 20M
```

Notice that for each interface, there's a root queue with a bandwidth limitation that determines the allocation for all queues attached to that interface. In order to use the new queuing infrastructure, we need to make some changes to the filtering rules, too.

NOTE *Because any traffic not explicitly assigned to a specific queue is assigned to the default queue for the interface, be sure to tune your filtering rules as well as your queue definitions to the actual traffic in your network.*

The main part of the filtering rules could end up looking like this after adding the queues:

```
pass in on $ext_if proto { tcp, udp } to $nameservers port domain \
    set queue ext_udp set prio (6,5)
pass in on $int_if proto { tcp, udp } from $localnet to $nameservers \
    port domain
pass out on $dmz_if proto { tcp, udp } to $nameservers port domain \
    set queue ext_dmz_udp set prio (6,5)
pass out on $dmz_if proto { tcp, udp } from $localnet to $nameservers \
    port domain  set queue dmz_udp
pass in on $ext_if proto tcp to $webserver port $webports set queue ext_web
pass in on $int_if proto tcp from $localnet to $webserver port $webports
pass out on $dmz_if proto tcp to $webserver port $webports \
    set queue ext_dmz_web
pass out on $dmz_if proto tcp from $localnet to $webserver port $webports \
    set queue dmz_web
```

```
pass in log on $ext_if proto tcp to $mailserver port smtp
pass in log on $ext_if proto tcp from $localnet to $mailserver port smtp
pass in log on $int_if proto tcp from $localnet to $mailserver port $email
pass out log on $dmz_if proto tcp to $mailserver port smtp set queue ext_mail
pass in on $dmz_if proto tcp from $mailserver to port smtp set queue dmz_mail
pass out log on $ext_if proto tcp from $mailserver to port smtp \
    set queue ext_dmz_mail
```

Notice that only traffic that will pass either the DMZ or the external interface is assigned to queues. In this configuration, with no externally accessible services on the internal network, queuing on the internal interface wouldn't make much sense because that's likely the part of the network with the least restricted available bandwidth. Also, as in earlier examples, there's a case to be made for separating the queue assignments from the filtering part of the rule set by making a block of `match` rules responsible for queue assignment.

Using Queues to Handle Unwanted Traffic

So far, we've focused on queuing as a way to make sure specific kinds of traffic are let through as efficiently as possible. Now, we'll look at two examples that present a slightly different way to identify and handle unwanted traffic using various queuing-related tricks to keep miscreants in line.

Overloading to a Tiny Queue

In "Turning Away the Brutes" on page 94, we used a combination of state-tracking options and `overload` rules to fill a table of addresses for special treatment. The special treatment we demonstrated in Chapter 6 was to cut all connections, but it's equally possible to assign `overload` traffic to a specific queue instead. For example, consider the rule from our first queue example, shown here.

```
pass log quick on $ext_if proto tcp to port ssh flags S/SA \
    keep state queue (ssh_bulk, ssh_interactive) set prio (5,7)
```

To create a variation of the overload table trick from Chapter 6, add state-tracking options, like this:

```
pass log quick on $ext_if proto tcp to port ssh flags S/SA \
    keep state (max-src-conn 15, max-src-conn-rate 5/3, \
    overload <bruteforce> flush global) queue (ssh_bulk, ssh_interactive) \
    set prio (5,7)
```

Then, make one of the queues slightly smaller:

```
queue smallpipe parent main bandwidth 512
```

And assign traffic from miscreants to the small-bandwidth queue with this rule:

```
pass inet proto tcp from <bruteforce> to port $tcp_services queue smallpipe
```

As a result, the traffic from the bruteforcers would pass, but with a hard upper limit of 512 bits per second. (It's worth noting that tiny bandwidth allocations may be hard to enforce on high-speed links due to the network stack's timer resolution. If the allocation is small enough relative to the capacity of the link, packets that exceed the stated per-second maximum allocation may be transferred anyway, before the bandwidth limit kicks in.) It might also be useful to supplement rules like these with table-entry expiry, as described in "Tidying Your Tables with pfctl" on page 97.

Queue Assignments Based on Operating System Fingerprint

Chapter 6 covered several ways to use `spamd` to cut down on spam. If running `spamd` isn't an option in your environment, you can use a queue and rule set based on the knowledge that machines that send spam are likely to run a particular operating system. (Let's call that operating system Windows.)

PF has a fairly reliable operating system fingerprinting mechanism, which detects the operating system at the other end of a network connection based on characteristics of the initial SYN packets at connection setup. The following may be a simple substitute for `spamd` if you've determined that legitimate mail is highly unlikely to be delivered from systems that run that particular operating system.

```
pass quick proto tcp from any os "Windows" to $ext_if \
    port smtp set queue smallpipe
```

Here, email traffic originating from hosts that run a particular operating system get no more than 512 bits per second of your bandwidth.

Transitioning from ALTQ to Priorities and Queues

If you already have configurations that use ALTQ for traffic shaping and you're planning a switch to OpenBSD 5.5 or newer, this section contains some pointers for how to manage the transition. The main points are these:

The rules after transition are likely simpler. The OpenBSD 5.5 and newer traffic-shaping system has done away with the somewhat arcane ALTQ syntax with its selection of queuing algorithms, and it distinguishes clearly between queues and pure-priority shuffling. In most cases, your configuration becomes significantly more readable and maintainable after a conversion to the new traffic-shaping system.

For simple configurations, `set prio` is enough. The simplest queue discipline in ALTQ was `priq`, or priority queues. The most common simple use

case was the two-priority speedup trick first illustrated by Daniel Hartmeier in the previously cited article. The basic two-priority configuration looks like this:

```
ext_if="kue0"

altq on $ext_if priq bandwidth 100Kb queue { q_pri, q_def }
      queue q_pri priority 7
      queue q_def priority 1 priq(default)

pass out on $ext_if proto tcp from $ext_if queue (q_def, q_pri)
pass in on $ext_if proto tcp to $ext_if queue (q_def, q_pri)
```

In OpenBSD 5.5 and newer, the equivalent effect can be achieved with no queue definitions. Instead, you assign two priorities in a `match` or `pass` rule, like this:

```
match out on egress set prio (5, 6)
```

Here, the first priority will be assigned to regular traffic, while ACK and other packets with a low-delay ToS will be assigned the second priority and will be served faster than the regular packets. The effect is the same as in the ALTQ example we just quoted, with the exception of defined bandwidth limits and the somewhat dubious effect of traffic shaping on incoming traffic.

Priority queues can for the most part be replaced by `set prio` constructs. For pure-priority differentiation, applying `set prio` on a per `pass` or `match` rule basis is simpler than defining queues and assigning traffic and affects only the packet priority. ALTQ allowed you to define CBQ or HFSC queues that also had a priority value as part of their definition. Under the new queuing system, assigning priority happens only in `match` or `pass` rules, but if your application calls for setting both priority and queue assignment in the same rule, the new syntax allows for that, too:

```
pass log quick on $ext_if proto tcp to port ssh \
      queue (ssh_bulk, ssh_interactive) set prio (5,7)
```

The effect is similar to the previous behavior shown in “Splitting Your Bandwidth into Fixed-Size Chunks” on page 123, and this variant may be particularly helpful during transition.

Priorities are now always important. Keep in mind that the default is 3. It’s important to be aware that traffic priorities are always enabled since OpenBSD 5.0, and they need to be taken into consideration even when you’re not actively assigning priorities. In old-style configurations that employed the two-priority trick to speed up ACKs and by extension all traffic, the only thing that was important was that there were two different priorities in play. The low-delay packets would be assigned to the higher-priority queue, and the net effect would be that traffic would likely pass faster, with more efficient bandwidth use than with the default FIFO

queue. Now the default priority is 3, and setting the priority for a queue to 0, as a few older examples do, will mean that the traffic assigned that priority will be considered ready to pass only when there's no higher-priority traffic left to handle.

For actual bandwidth shaping, HFSC works behind the scenes. Once you've determined that your specification calls for slicing available bandwidth into chunks, the underlying algorithm is always HFSC. The variety of syntaxes for different types of queues is gone. HFSC was chosen for its flexibility as well as the fact that it starts actively shaping traffic only once the traffic approaches one of the limits set by your queuing configuration. In addition, it's possible to create CBQ-like configurations by limiting the queue definitions to only bandwidth declarations. "Splitting Your Bandwidth into Fixed-Size Chunks" on page 123 (mentioned earlier) demonstrates a static configuration that implements CBQ as a subset of HFSC.

You can transition from ALTQ via the `oldqueue` mechanism. OpenBSD 5.5 supports legacy ALTQ configurations with only one minor change to configurations: The `queue` keyword was needed as a reserved word for the new queuing system, so ALTQ queues need to be declared as `oldqueue` instead. Following that one change (a pure search and replace operation that you can even perform just before starting your operating system upgrade), the configuration will work as expected.

If your setup is sufficiently complicated, go back to specifications and reimplement. The examples in this chapter are somewhat stylized and rather simple. If you have running configurations that have been built up incrementally over several years and have reached a complexity level, orders of magnitude larger than those described here, the new syntax may present an opportunity to define what your setup is for and produce a specification that is fit to reimplement in a cleaner and more maintainable configuration.

Going the `oldqueue` route and tweaking from there will work to some degree, but it may be easier to make the transition via a clean reimplementation from revised specification in a test environment where you can test whether your accumulated assumptions hold up in a the context of the new traffic-shaping system. Whatever route you choose for your transition, you're more or less certain to end up with a more readable and maintainable configuration after your switch to OpenBSD 5.5 or newer.

Directing Traffic with ALTQ

ALTQ is the very flexible legacy mechanism for network traffic shaping, which was integrated into PF on OpenBSD[2] in time for the OpenBSD 3.3 release by Henning Brauer, who's also the main developer of the priorities and queues system introduced in OpenBSD 5.5 (described in the previous sections of this chapter). OpenBSD 3.3 onward moved all ALTQ

2. The original research on ALTQ was presented in a paper for the USENIX 1999 conference. You can read Kenjiro Cho's paper "Managing Traffic with ALTQ" online at *http://www.usenix.org/publications/library/proceedings/usenix99/cho.html*. The code turned up in OpenBSD soon after through the efforts of Cho and Chris Cappucio.

configuration into *pf.conf* to ease the integration of traffic shaping and filtering. PF ports to other BSDs were quick to adopt at least some optional ALTQ integration.

NOTE *OpenBSD 5.5 introduced a new queue system for traffic shaping with a radically different (and more readable) syntax that complements the always-on priority system introduced in OpenBSD 5.0. The new system is intended to replace ALTQ entirely after one transitional release. The rest of this chapter is useful only if you're interested in learning about how to set up or maintain an ALTQ-based system.*

Basic ALTQ Concepts

As the name suggests, ALTQ configurations are totally queue-centric. As in the more recent traffic-shaping system, ALTQ queues are defined in terms of bandwidth and attached to interfaces. Queues can be assigned priority, and in some contexts, they can have subqueues that receive a share of the parent queue's bandwidth.

The general syntax for ALTQ queues looks like this:

```
altq on interface type [options ... ] main_queue { sub_q1, sub_q2 ..}
  queue sub_q1 [ options ... ]
  queue sub_q2 [ options ... ] { subA, subB, ... }
[...]
pass [ ... ] queue sub_q1
pass [ ... ] queue sub_q2
```

NOTE *On OpenBSD 5.5 and newer, ALTQ queues are denoted* `oldqueue` *instead of* `queue` *due to an irresolvable syntax conflict with the new queuing subsystem.*

Once queue definitions are in place, you integrate traffic shaping into your rule set by rewriting your `pass` or `match` rules to assign traffic to a specific queue. Any traffic that you don't explicitly assign to a specific queue gets lumped in with everything else in the default queue.

Queue Schedulers, aka Queue Disciplines

In the default networking setup, with no queuing, the TCP/IP stack and its filtering subsystem process the packets according to the FIFO discipline.

ALTQ offers three queue-scheduler algorithms, or *disciplines*, that can alter this behavior slightly. The types are `priq`, `cbq`, and `hfsc`. Of these, `cbq` and `hfsc` queues can have several levels of subqueues. The `priq` queues are essentially flat, with only one queue level. Each of the disciplines has its own syntax specifics, and we'll address those in the following sections.

priq

Priority-based queues are defined purely in terms of priority within the total declared bandwidth. For `priq` queues, the allowed priority range is

0 through 15, where a higher value earns preferential treatment. Packets that match the criteria for higher-priority queues are serviced before the ones matching lower-priority queues.

cbq

Class-based queues are defined as constant-sized bandwidth allocations, as a percentage of the total available or in units of kilobits, megabits, or gigabits per second. A `cbq` queue can be subdivided into queues that are also assigned priorities in the range 0 to 7, and again, a higher priority means preferential treatment.

hfsc

The `hfsc` discipline uses the HFSC algorithm to ensure a "fair" allocation of bandwidth among the queues in a hierarchy. HFSC comes with the possibility of setting up queuing regimes with guaranteed minimum allocations and hard upper limits. Allocations can even vary over time, and you can even have fine-grained priority with a 0 to 7 range.

Because both the algorithm and the corresponding setup with ALTQ are fairly complicated, with a number of tunable parameters, most ALTQ practitioners tend to stick with the simpler queue types. Yet the ones who claim to understand HFSC swear by it.

Setting Up ALTQ

Enabling ALTQ may require some extra steps, depending on your choice of operating system.

ALTQ on OpenBSD

On OpenBSD 5.5, all supported queue disciplines are compiled into the GENERIC and GENERIC.MP kernels. Check that your OpenBSD version still supports ALTQ. If so, the only configuration you need to do involves editing your *pf.conf*.

ALTQ on FreeBSD

On FreeBSD, make sure that your kernel has ALTQ and the ALTQ queue discipline options compiled in. The default FreeBSD GENERIC kernel doesn't have ALTQ options enabled, as you may have noticed from the messages you saw when running the */etc/rc.d/pf* script to enable PF. The relevant options are as follows:

```
options         ALTQ
options         ALTQ_CBQ        # Class Bases Queuing (CBQ)
options         ALTQ_RED        # Random Early Detection (RED)
options         ALTQ_RIO        # RED In/Out
options         ALTQ_HFSC       # Hierarchical Packet Scheduler (HFSC)
options         ALTQ_PRIQ       # Priority Queuing (PRIQ)
options         ALTQ_NOPCC      # Required for SMP build
```

The ALTQ option is needed to enable ALTQ in the kernel, but on SMP systems, you also need the ALTQ_NOPCC option. Depending on which types of queues you'll be using, you'll need to enable at least one of these: ALTQ_CBQ, ALTQ_PRIQ, or ALTQ_HFSC. Finally, you can enable the congestion-avoidance techniques *random early detection (RED)* and *RED In/Out* with the ALTQ_RED and ALTQ_RIO options, respectively. (See the *FreeBSD Handbook* for information on how to compile and install a custom kernel with these options.)

ALTQ on NetBSD

ALTQ was integrated into the NetBSD 4.0 PF implementation and is supported in NetBSD 4.0 and later releases. NetBSD's default GENERIC kernel configuration doesn't include the ALTQ-related options, but the GENERIC configuration file comes with all relevant options commented out for easy inclusion. The main kernel options are these:

```
options         ALTQ            # Manipulate network interfaces' output queues
options         ALTQ_CBQ        # Class-Based queuing
options         ALTQ_HFSC       # Hierarchical Fair Service Curve
options         ALTQ_PRIQ       # Priority queuing
options         ALTQ_RED        # Random Early Detection
```

The ALTQ option is needed to enable ALTQ in the kernel. Depending on the types of queues you'll be using, you must enable at least one of these: ALTQ_CBQ, ALTQ_PRIQ, or ALTQ_HFSC.

Using ALTQ requires you to compile PF into the kernel because the PF loadable module doesn't support ALTQ functionality. (See the NetBSD PF documentation at *http://www.netbsd.org/Documentation/network/pf.html* for the most up-to-date information.)

Priority-Based Queues

The basic concept behind priority-based queues (priq) is fairly straightforward. Within the total bandwidth allocated to the main queue, only traffic priority matters. You assign queues a priority value in the range 0 through 15, where a higher value means that the queue's requests for traffic are serviced sooner.

Using ALTQ Priority Queues to Improve Performance

Daniel Hartmeier discovered a simple yet effective way to improve the throughput for his home network by using ALTQ priority queues. Like many people, he had his home network on an asymmetric connection, with total usable bandwidth low enough that he wanted better bandwidth utilization. In addition, when the line was running at or near capacity, oddities started appearing. One symptom in particular seemed to suggest room for improvement: Incoming traffic (downloads, incoming mail, and such)

slowed down disproportionately whenever outgoing traffic started—more than could be explained by measuring the raw amount of data transferred. It all came back to a basic feature of TCP.

When a TCP packet is sent, the sender expects acknowledgment (in the form of an ACK packet) from the receiver and will wait a specified time for it to arrive. If the ACK doesn't arrive within that time, the sender assumes that the packet hasn't been received and resends it. And because in a default setup, packets are serviced sequentially by the interface as they arrive, ACK packets, with essentially no data payload, end up waiting in line while the larger data packets are transferred.

If ACK packets could slip in between the larger data packets, the result would be more efficient use of available bandwidth. The simplest practical way to implement such a system with ALTQ is to set up two queues with different priorities and integrate them into the rule set. Here are the relevant parts of the rule set.

```
ext_if="kue0"

altq on $ext_if priq bandwidth 100Kb queue { q_pri, q_def }
      queue q_pri priority 7
      queue q_def priority 1 priq(default)

pass out on $ext_if proto tcp from $ext_if queue (q_def, q_pri)

pass in on $ext_if proto tcp to $ext_if queue (q_def, q_pri)
```

Here, the priority-based queue is set up on the external interface with two subordinate queues. The first subqueue, `q_pri`, has a high-priority value of 7; the other subqueue, `q_def`, has a significantly lower-priority value of 1.

This seemingly simple rule set works by exploiting how ALTQ treats queues with different priorities. Once a connection is set up, ALTQ inspects each packet's ToS field. ACK packets have the ToS delay bit set to low, which indicates that the sender wanted the speediest delivery possible. When ALTQ sees a low-delay packet and queues of differing priorities are available, it assigns the packet to the higher-priority queue. This means that the ACK packets skip ahead of the lower-priority queue and are delivered more quickly, which in turn means that data packets are serviced more quickly. The net result is better performance than a pure FIFO configuration with the same hardware and available bandwidth. (Daniel Hartmeier's article about this version of his setup, cited previously, contains a more detailed analysis.)

Using a match Rule for Queue Assignment

In the previous example, the rule set was constructed the traditional way, with the queue assignment as part of the `pass` rules. However, this isn't the only way to do queue assignment. When you use `match` rules (available in OpenBSD 4.6 and later), it's incredibly easy to retrofit this simple priority-queuing regime onto an existing rule set.

If you worked through the examples in Chapters 3 and 4, your rule set probably has a `match` rule that applies `nat-to` on your outgoing traffic. To introduce priority-based queuing to your rule set, you first add the queue definitions and make some minor adjustments to your outgoing `match` rule.

Start with the queue definition from the preceding example and adjust the total bandwidth to local conditions, as shown in here.

```
altq on $ext_if priq bandwidth $ext_bw queue { q_pri, q_def }
      queue q_pri priority 7
      queue q_def priority 1 priq(default)
```

This gives the queues whatever bandwidth allocation you define with the `ext_bw` macro.

The simplest and quickest way to integrate the queues into your rule set is to edit your outgoing `match` rule to read something like this:

```
match out on $ext_if from $int_if:network nat-to ($ext_if) queue (q_def, q_pri)
```

Reload your rule set, and the priority-queuing regime is applied to all traffic that's initiated from your local network.

You can use the `systat` command to get a live view of how traffic is assigned to your queues.

```
$ sudo systat queues
```

This will give you a live display that looks something like this:

```
   2 users    Load 0.39 0.27 0.30                    Fri Apr  1 16:33:44 2015

QUEUE               BW SCH  PR   PKTS  BYTES  DROP_P  DROP_B QLEN BORRO SUSPE  P/S   B/S
q_pri                  priq  7  21705  1392K       0       0    0               12   803
q_def                  priq     12138  6759K       0       0    0                9  4620
```

Looking at the numbers in the `PKTS` (packets) and `BYTES` columns, you see a clear indication that the queuing is working as intended.

The `q_pri` queue has processed a rather large number of packets in relation to the amount of data, just as we expected. The ACK packets don't take up a lot of space. On the other hand, the traffic assigned to the `q_def` queue has more data in each packet, and the numbers show essentially the reverse packet numbers–to–data size ratio as in to the `q_pri` queue.

NOTE *`systat` is a rather capable program on all BSDs, and the OpenBSD version offers several views that are relevant to PF and that aren't found in the `systat` variants on the other systems as of this writing. We'll be looking at `systat` again in the next chapter. In the meantime, read the man pages and play with the program. It's a very useful tool for getting to know your system.*

Class-Based Bandwidth Allocation for Small Networks

Maximizing network performance generally feels nice. However, you may find that your network has other needs. For example, it might be important for some traffic—such as mail and other vital services—to have a baseline amount of bandwidth available at all times, while other services—peer-to-peer file sharing comes to mind—shouldn't be allowed to consume more than a certain amount. To address these kinds of requirements or concerns, ALTQ offers the class-based queue (`cbq`) discipline with a slightly larger set of options.

To illustrate how to use `cbq`, we'll build on the rule sets from previous chapters within a small local network. We want to let the users on the local network connect to a predefined set of services outside their own network and let users from outside the local network access a Web server and an FTP server somewhere on the local network.

Queue Definition

All queues are set up on the external, Internet-facing interface. This approach makes sense mainly because bandwidth is more likely to be limited on the external link than on the local network. In principle, however, allocating queues and running traffic shaping can be done on any network interface. The example setup shown here includes a `cbq` queue for a total bandwidth of 2Mb with six subqueues.

```
altq on $ext_if cbq bandwidth 2Mb queue { main, ftp, udp, web, ssh, icmp }
      queue main bandwidth 18% cbq(default borrow red)
      queue ftp bandwidth 10% cbq(borrow red)
      queue udp bandwidth 30% cbq(borrow red)
      queue web bandwidth 20% cbq(borrow red)
      queue ssh bandwidth 20% cbq(borrow red) { ssh_interactive, ssh_bulk }
            queue ssh_interactive priority 7 bandwidth 20%
            queue ssh_bulk priority 5 bandwidth 80%
      queue icmp bandwidth 2% cbq
```

The subqueue `main` has 18 percent of the bandwidth and is designated as the default queue. This means any traffic that matches a `pass` rule but isn't explicitly assigned to some other queue ends up here. The `borrow` and `red` keywords mean that the queue may "borrow" bandwidth from its parent queue, while the system attempts to avoid congestion by applying the RED algorithm.

The other queues follow more or less the same pattern up to the subqueue `ssh`, which itself has two subqueues with separate priorities. Here, we see a variation on the ACK priority example. Bulk SSH transfers, typically SCP file transfers, are transmitted with a ToS indicating throughput, while interactive SSH traffic has the ToS flag set to low delay and skips ahead of the bulk transfers. The interactive traffic is likely to be less bandwidth consuming and gets a smaller share of the bandwidth, but it receives

preferential treatment because of the higher-priority value assigned to it. This scheme also helps the speed of SCP file transfers because the ACK packets for the SCP transfers will be assigned to the higher-priority subqueue.

Finally, we have the `icmp` queue, which is reserved for the remaining 2 percent of the bandwidth from the top level. This guarantees a minimum amount of bandwidth for ICMP traffic that we want to pass but that doesn't match the criteria for being assigned to the other queues.

Rule Set

To make it all happen, we use these `pass` rules, which indicate which traffic is assigned to the queues and their criteria:

```
set skip on { lo, $int_if }
pass log quick on $ext_if proto tcp to port ssh queue (ssh_bulk, ssh_
interactive)
pass in quick on $ext_if proto tcp to port ftp queue ftp
pass in quick on $ext_if proto tcp to port www queue http
pass out on $ext_if proto udp queue udp
pass out on $ext_if proto icmp queue icmp
pass out on $ext_if proto tcp from $localnet to port $client_out
```

The rules for `ssh`, `ftp`, `www`, `udp`, and `icmp` assign traffic to their respective queues. The last catchall rule passes all other traffic from the local network, lumping it into the default `main` queue.

A Basic HFSC Traffic Shaper

The simple schedulers we have looked at so far can make for efficient setups, but network admins with traffic-shaping ambitions tend to look for a little more flexibility than can be found in the pure-priority-based queues or the simple class-based variety. The HFSC queuing algorithm (`hfsc` in *pf.conf* terminology) offers flexible bandwidth allocation, guaranteed lower and upper bounds for bandwidth available to each queue, and variable allocations over time, and it only starts shaping when there's an actual need. However, the added flexibility comes at a price: The setup is a tad more complex than the other ALTQ types, and tuning your setup for an optimal result can be quite an interesting process.

Queue Definition

First, working from the same configuration we altered slightly earlier, we insert this queue definition early in the *pf.conf* file:

```
altq on $ext_if bandwidth $ext_bw hfsc queue { main, spamd }
       queue main bandwidth 99% priority 7 qlimit 100 hfsc (realtime 20%, linkshare 99%) \
            { q_pri, q_def, q_web, q_dns }
          queue q_pri bandwidth 3% priority 7 hfsc (realtime 0, linkshare 3% red )
          queue q_def bandwidth 47% priority 1 hfsc (default realtime 30% linkshare 47% red)
          queue q_web bandwidth 47% priority 1 hfsc (realtime 30% linkshare 47% red)
```

```
    queue q_dns bandwidth 3% priority 7 qlimit 100 hfsc (realtime (30Kb 3000 12Kb), \
            linkshare 3%)
queue spamd bandwidth 0% priority 0 qlimit 300 hfsc (realtime 0, upperlimit 1%, \
        linkshare 1%)
```

The `hfsc` queue definitions take slightly different parameters than the simpler disciplines. We start off with this rather small hierarchy by splitting the top-level queue into two. At the next level, we subdivide the `main` queue into several subqueues, each with a defined priority. All the subqueues have a `realtime` value set—the guaranteed minimum bandwidth allocated to the queue. The optional `upperlimit` sets a hard upper limit on the queue's allocation. The `linkshare` parameter sets the allocation the queue will have available when it's backlogged—that is, when it's started to eat into its `qlimit` allocation.

In case of congestion, each queue by default has a pool of 50 slots, the queue limit (`qlimit`), to keep packets around when they can't be transmitted immediately. In this example, the top-level queues `main` and `spamd` both have larger-than-default pools set by their `qlimit` setting: `100` for `main` and `300` for `spamd`. Cranking up queue sizes here means we're a little less likely to drop packets when the traffic approaches the set limits, but it also means that when the traffic shaping kicks in, we'll see increased latency for connections that end up in these larger than default pools.

The queue hierarchy here uses two familiar tricks to make efficient use of available bandwidth:

- It uses a variation of the high- and low-priority mix demonstrated in the earlier pure-priority example.
- We speed up almost all other traffic (and most certainly the Web traffic that appears to be the main priority here) by allocating a small but guaranteed portion of bandwidth for name service lookups. For the `q_dns` queue, we set up the `realtime` value with a time limit—after `3000` milliseconds, the `realtime` allocation goes down to `12Kb`. This can be useful to speed connections that transfer most of their payload during the early phases.

Rule Set

Next, we tie the newly created queues into the rule set. If you have a filtering regime in place already, which we'll assume you do, the tie-in becomes amazingly simple, accomplished by adding a few `match` rules.

```
match out on $ext_if from $air_if:network nat-to ($ext_if) \
    queue (q_def, q_pri)
match out on $ext_if from $int_if:network nat-to ($ext_if) \
    queue (q_def, q_pri)
match out on $ext_if proto tcp to port { www https } queue (q_web, q_pri)
match out on $ext_if proto { tcp udp } to port domain queue (q_dns, q_pri)
match out on $ext_if proto icmp queue (q_dns, q_pri)
```

Here, the `match` rules once again do the ACK packet speedup trick with the high- and low-priority queue assignment, just as you saw earlier in the pure-priority-based system. The only exception is when we assign traffic to our lowest-priority queue, where we really don't care to have any speedup at all.

```
pass in log on egress proto tcp to port smtp rdr-to 127.0.0.1 port spamd queue spamd
```

This rule is intended to slow down the spammers a little more on their way to our `spamd`. With a hierarchical queue system in place, `systat queues` shows the queues and their traffic as a hierarchy, too.

```
   2 users    Load 0.22 0.25 0.25                  Fri Apr  3 16:43:37 2015

QUEUE          BW SCH  PRIO     PKTS     BYTES   DROP_P   DROP_B QLEN BORROW SUSPEN    P/S     B/S
root_nfe0      20M hfsc    0        0         0        0        0    0                      0       0
 main          19M hfsc    7        0         0        0        0    0                      0       0
  q_pri       594K hfsc    7     1360     82284        0        0    0                     11     770
  q_def      9306K hfsc          158     15816        0        0    0                    0.2      11
  q_web      9306K hfsc          914    709845        0        0    0                     50   61010
  q_dns       594K hfsc    7      196     17494        0        0    0                      3     277
 spamd          0 hfsc    0      431     24159        0        0    0                      2     174
```

The root queue is shown as attached to the physical interface—as `nfe0` and `root_nfe0`, in this case. `main` and its subqueues—`q_pri`, `q_def`, `q_web`, and `q_dns`—are shown with their bandwidth allocations and number of bytes and packets passed. The `DROP_P` and `DROP_B` columns are where number of packets and bytes dropped, respectively, would appear if we had been forced to drop packets at this stage. The final two columns show live updates of packets per second and bytes per second.

Queuing for Servers in a DMZ

In Chapter 5, we set up a network with a single gateway but with all externally visible services configured on a separate DMZ network. That way, all traffic to the servers from both the Internet and the internal network had to pass through the gateway (see Figure 7-1).

With the rule set from Chapter 5 as our starting point, we'll add some queuing in order to optimize our network resources. The physical and logical layout of the network will not change. The most likely bottleneck for this network is the bandwidth for the connection between the gateway's external interface and the Internet at large. The bandwidth elsewhere in our setup isn't infinite, of course, but the available bandwidth on any interface in the local network is likely to be less of a limiting factor than the bandwidth actually available for communication with the outside world. For services to be available with the best possible performance, we need to set up the queues so the bandwidth available at the site is made available to the traffic we want to allow.

In our example, it's likely that the interface bandwidth on the DMZ interface is either 100Mb or 1Gb, while the *actual available bandwidth* for connections from outside the local network is considerably smaller. This

consideration shows up in our queue definitions, where you clearly see that the bandwidth available for external traffic is the main limitation in the queue setup.

```
total_ext = 2Mb
total_dmz = 100Mb
altq on $ext_if cbq bandwidth $total_ext queue { ext_main, ext_web, ext_udp, \
    ext_mail, ext_ssh }
queue ext_main bandwidth 25% cbq(default borrow red) { ext_hi, ext_lo }
queue ext_hi priority 7 bandwidth 20%
queue ext_lo priority 0 bandwidth 80%
queue ext_web bandwidth 25% cbq(borrow red)
queue ext_udp bandwidth 20% cbq(borrow red)
queue ext_mail bandwidth 30% cbq(borrow red)
altq on $dmz_if cbq bandwidth $total_dmz queue { ext_dmz, dmz_main, dmz_web, \
    dmz_udp, dmz_mail }
queue ext_dmz bandwidth $total_ext cbq(borrow red) queue { ext_dmz_web, \
    ext_dmz_udp, ext_dmz_mail }
      queue ext_dmz_web bandwidth 40% priority 5
      queue ext_dmz_udp bandwidth 10% priority 7
      queue ext_dmz_mail bandwidth 50% priority 3
queue dmz_main bandwidth 25Mb cbq(default borrow red) queue { dmz_main_hi, \
    dmz_main_lo }
queue dmz_main_hi priority 7 bandwidth 20%
queue dmz_main_lo priority 0 bandwidth 80%
queue dmz_web bandwidth 25Mb cbq(borrow red)
queue dmz_udp bandwidth 20Mb cbq(borrow red)
queue dmz_mail bandwidth 20Mb cbq(borrow red)
```

Notice that the `total_ext` bandwidth limitation determines the allocation for all queues where the bandwidth for external connections is available. In order to use the new queuing infrastructure, we need to make some changes to the filtering rules, too. Keep in mind that any traffic you don't explicitly assign to a specific queue is assigned to the default queue for the interface. Thus, it's important to tune your filtering rules as well as your queue definitions to the actual traffic in your network.

With queue assignment, the main part of the filtering rules could end up looking like this:

```
pass in on $ext_if proto { tcp, udp } to $nameservers port domain \
    queue ext_udp
pass in on $int_if proto { tcp, udp } from $localnet to $nameservers \
    port domain
pass out on $dmz_if proto { tcp, udp } to $nameservers port domain \
    queue ext_dmz_udp
pass out on $dmz_if proto { tcp, udp } from $localnet to $nameservers \
    port domain queue dmz_udp
pass in on $ext_if proto tcp to $webserver port $webports queue ext_web
pass in on $int_if proto tcp from $localnet to $webserver port $webports
pass out on $dmz_if proto tcp to $webserver port $webports queue ext_dmz_web
pass out on $dmz_if proto tcp from $localnet to $webserver port $webports \
    queue dmz_web
pass in log on $ext_if proto tcp to $mailserver port smtp
```

```
pass in log on $ext_if proto tcp from $localnet to $mailserver port smtp
pass in log on $int_if proto tcp from $localnet to $mailserver port $email
pass out log on $dmz_if proto tcp to $mailserver port smtp queue ext_mail
pass in on $dmz_if from $mailserver to port smtp queue dmz_mail
pass out log on $ext_if proto tcp from $mailserver to port smtp \
    queue ext_dmz_mail
```

Notice that only traffic that will pass either the DMZ interface or the external interface is assigned to queues. In this configuration, with no externally accessible services on the internal network, queuing on the internal interface wouldn't make much sense because it's likely the part of our network with the least restrictions on available bandwidth.

Using ALTQ to Handle Unwanted Traffic

So far, we've focused on queuing as a method to make sure specific kinds of traffic are let through as efficiently as possible given the conditions that exist in and around your network. Now, we'll look at two examples that present a slightly different approach to identify and handle unwanted traffic in order to demonstrate some queuing-related tricks you can use to keep miscreants in line.

Overloading to a Tiny Queue

Think back to "Turning Away the Brutes" on page 94, where we used a combination of state-tracking options and `overload` rules to fill up a table of addresses for special treatment. The special treatment we demonstrated in Chapter 6 was to cut all connections, but it's equally possible to assign `overload` traffic to a specific queue instead.

Consider this rule from our class-based bandwidth example in "Class-Based Bandwidth Allocation for Small Networks" on page 139.

```
pass log quick on $ext_if proto tcp to port ssh flags S/SA \
    keep state queue (ssh_bulk, ssh_interactive)
```

We could add state-tracking options, as shown in here.

```
pass log quick on $ext_if proto tcp to port ssh flags S/SA \
    keep state (max-src-conn 15, max-src-conn-rate 5/3, \
    overload <bruteforce> flush global) queue (ssh_bulk, ssh_interactive)
```

Then, we could make one of the queues slightly smaller.

```
queue smallpipe bandwidth 1kb cbq
```

Next, we could assign traffic from miscreants to the small-bandwidth queue with the following rule.

```
pass inet proto tcp from <bruteforce> to port $tcp_services queue smallpipe
```

It might also be useful to supplement rules like these with table-entry expiry, as described in “Tidying Your Tables with pfctl” on page 97.

Queue Assignments Based on Operating System Fingerprint

Chapter 6 covered several ways to use `spamd` to cut down on spam. If running `spamd` isn't an option in your environment, you can use a queue and rule set based on the common knowledge that machines that send spam are likely to run a particular operating system.

PF has a fairly reliable operating system fingerprinting mechanism, which detects the operating system at the other end of a network connection based on characteristics of the initial SYN packets at connection setup. The following may be a simple substitute for `spamd` if you've determined that legitimate mail is highly unlikely to be delivered from systems that run that particular operating system.

```
pass quick proto tcp from any os "Windows" to $ext_if port smtp queue smallpipe
```

Here, email traffic originating from hosts that run a particular operating system get no more than 1KB of your bandwidth, with no borrowing.

Conclusion: Traffic Shaping for Fun, and Perhaps Even Profit

This chapter has dealt with traffic-shaping techniques that can make your traffic move faster, or at least make preferred traffic pass more efficiently and according to your specifications. By now you should have at least a basic understanding of traffic-shaping concepts and how they apply to the traffic-shaping tool set you'll be using on your systems.

I hope that the somewhat stylized (but functional) examples in this chapter have given you a taste of what's possible with traffic shaping and that the material has inspired you to play with some of your own ideas of how you can use the traffic-shaping tools in your networks. If you pay attention to your network traffic and the underlying needs it expresses (see Chapters 9 and 10 for more on studying network traffic in detail), you can use the traffic-shaping tools to improve the way your network serves its users. With a bit of luck, your users will appreciate your efforts and you may even enjoy the experience.

8

REDUNDANCY AND RESOURCE AVAILABILITY

High availability and *uninterrupted service* have been both marketing buzzwords and coveted goals for real-world IT professionals and network administrators as long as most of us can remember. To meet this perceived need and solve a few related problems, *CARP* and *pfsync* were added as two highly anticipated features in OpenBSD 3.5. With these tools, OpenBSD and the other operating systems that adopted them came a long way toward offering what other operating systems refer to as general purpose *clustering* functionality. The terminology used by OpenBSD and its sister BSDs differs from what other products use, but as you will see in this chapter, CARP, pfsync, and related tools offer high availability functionality equivalent to what a variety of proprietary systems tend to offer only as costly optional extras.

This chapter covers how to use these tools as found in your base system to manage resource availability—or, in other words, how to use them to make sure resources and services in your care stay available even in adverse conditions.

Redundancy and Failover: CARP and pfsync

The Common Address Redundancy Protocol (CARP) was developed as a non-patent-encumbered alternative to the Virtual Router Redundancy Protocol (VRRP), which was far along the track to becoming an IETF-sanctioned standard, even though possible patent issues haven't been resolved.[1] One of the main purposes of CARP is to ensure that the network will keep functioning as usual, even when a firewall or other service goes down due to errors or planned maintenance activities, such as upgrades. Not content to just make a clone of the patent-encumbered protocol, the OpenBSD developers decided to go one better on several fronts. CARP features authenticated redundancy—it's address-family independent and comes with state synchronization features. Complementing CARP, the pfsync protocol is designed to handle synchronization of PF states between redundant packet-filtering nodes or gateways. Both protocols are intended to ensure redundancy for essential network features with automatic failover.

CARP is based on setting up a group of machines as one *master* and one or more redundant *backups*, all equipped to handle a common IP address. If the master goes down, one of the backups will inherit the IP address. The handover from one CARP host to another may be authenticated, essentially by setting a shared secret (in practice, much like a password).

In the case of PF firewalls, pfsync can be set up to handle the synchronization, and if the synchronization via pfsync has been properly set up, active connections will be handed over without noticeable interruption. In essence, pfsync is a type of virtual network interface specially designed to synchronize state information between PF firewalls. Its interfaces are assigned to physical interfaces with `ifconfig`.

Even if it's technically possible to lump pfsync traffic together with other traffic on a regular interface, it's strongly recommended that you set up pfsync on a separate network, or even VLAN. pfsync does no authentication on its synchronization partners, so the only way to guarantee correct synchronization is to use dedicated interfaces for your pfsync traffic.

The Project Specification: A Redundant Pair of Gateways

To illustrate a useful failover setup with CARP and pfsync, we'll examine a network with one gateway to the world. Our goals for the reconfigured network are as follows:

- The network should keep functioning much the same way it did before we introduced redundancy.
- We should have better availability without noticeable downtime.
- The network should experience graceful failover with no interruption of active connections.

1. VRRP is described in RFC 2281 and RFC 3768. The patents involved are held by Cisco, IBM, and Nokia. See the RFCs for details.

We'll begin with the relatively simple network from Chapter 3, as shown in Figure 8-1.

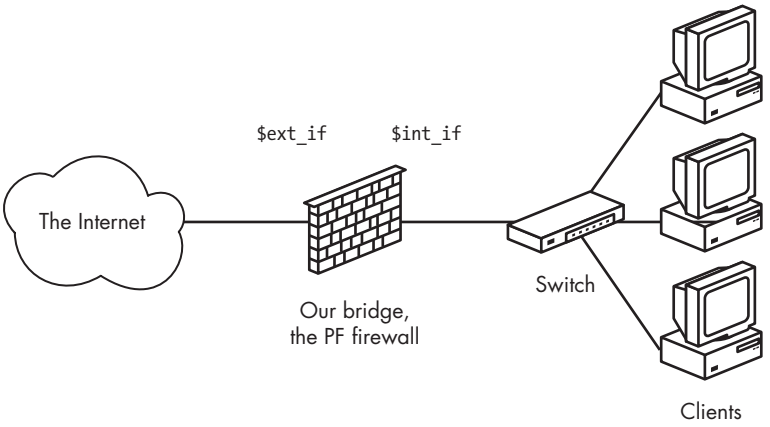

Figure 8-1: Network with a single gateway

We replace the single gateway with a redundant pair of gateways that share a private network for state-information updates over pfsync. The result is shown in Figure 8-2.

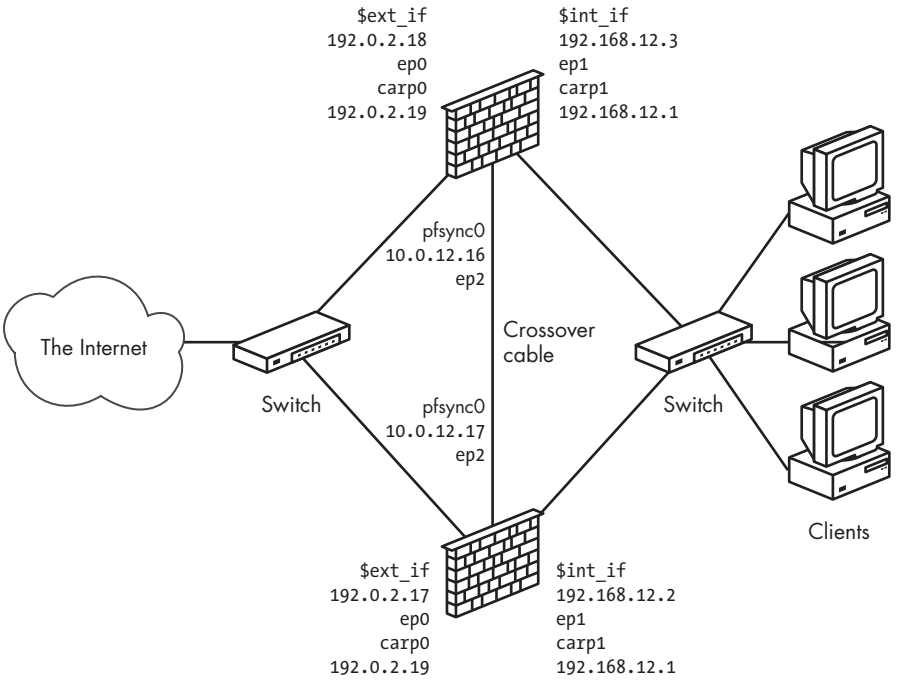

Figure 8-2: Network with redundant gateways

CARP addresses are virtual addresses, and unless you have console access to all machines in your CARP group, you should almost always assign an IP address to the physical interfaces. With a unique IP address for each physical interface, you'll be able to communicate with the host and be sure of which machine you're interacting with. Without IP addresses assigned to physical interfaces, you could find yourself with a setup where the backup gateways are unable to communicate (except with hosts in networks where the physical interfaces have addresses assigned) until they become the master in the redundancy group and take over the virtual IP addresses.

It's reasonable to assume that the IP address assigned to the physical interface will belong in the same subnet as the virtual, shared IP address. It's also important to be aware that this is, in fact, not a requirement—it's even possible to configure CARP where the physical interface hasn't been assigned an address. If you don't specify a specific physical interface for the CARP interface, the kernel will try to assign the CARP address to a physical interface that's already configured with an address in the same subnet as the CARP address. Even if it may not be required in simpler configurations, it's generally useful to make the interface selection explicit via the `carpdev` option in the `ifconfig` command string that you use to set up the CARP interface.

WARNING *If when you reconfigure your network, the default gateway address goes from fixed to a specific interface and from host to a virtual address, it's nearly impossible to avoid a temporary loss of connectivity.*

Setting Up CARP

Most CARP setup lies in cabling (according to the schematic for your network), setting `sysctl` values, and issuing `ifconfig` commands. Also, on some systems, you'll need to make sure that your kernel is set up with the required devices compiled in.

Checking Kernel Options

On OpenBSD, both the CARP and pfsync devices are in the default GENERIC and GENERIC.MP kernel configurations. Unless you're running a custom kernel without these options, no kernel reconfiguration is necessary. If you're running FreeBSD, make sure that the kernel has the CARP and pfsync devices compiled in because the default GENERIC kernel lacks these options. (See the *FreeBSD Handbook* to learn how to compile and install a custom kernel with these options.)

NetBSD should check that the kernel has pseudo-device CARP compiled in because NetBSD's default GENERIC kernel configuration doesn't have it. (You'll find the relevant line commented out in the GENERIC configuration file.) As of this writing, NetBSD doesn't support pfsync due to claimed protocol-numbering issues.

Setting sysctl Values

On all CARP-capable systems, the basic functions are governed by a handful of `sysctl` variables. The main one is `net.inet.carp.allow`, and it's enabled by default. On a typical OpenBSD system, you'll see:

```
$ sysctl net.inet.carp.allow
net.inet.carp.allow=1
```

This means that your system comes equipped for CARP.

If your kernel isn't configured with a CARP device, this command should produce something like the following on FreeBSD:

```
sysctl: unknown oid 'net.inet.carp.allow'
```

Or it could produce something like this on NetBSD:

```
sysctl: third level name 'carp' in 'net.inet.carp.allow' is invalid
```

Use this `sysctl` command to view all CARP-related variables:

```
$ sysctl net.inet.carp
net.inet.carp.allow=1
net.inet.carp.preempt=0
net.inet.carp.log=2
```

NOTE *On FreeBSD, you'll also encounter the read-only status variable `net.inet.carp.suppress_preempt`, which indicates whether preemption is possible. On systems with CARP code based on OpenBSD 4.2 or earlier, you'll also see `net.inet.carp.arpbalance`, which is used to enable CARP ARP balancing to offer some limited load balancing for hosts on a local network.*

To enable the graceful failover between the gateways in our setup, we need to set the `net.inet.carp.preempt` variable so that on hosts with more than one network interface (like our gateways), all CARP interfaces will move between master and backup status concurrently. This setting must be identical on all hosts in the CARP group, and it should be repeated on all hosts during setup.

```
$ sudo sysctl net.inet.carp.preempt=1
```

The `net.inet.carp.log` variable sets the debug level for CARP logging between 0 and 7. The default of 2 means only CARP state changes are logged.

Setting Up Network Interfaces with ifconfig

Notice in the network diagram shown in Figure 8-2 that the local network uses addresses in the 192.168.12.0 network, while the Internet-facing

interface is in the 192.0.2.0 network. With these address ranges and the CARP interface's default behavior in mind, the commands for setting up the virtual interfaces are actually quite straightforward.

In addition to the usual network parameters, CARP interfaces require one additional parameter: the *virtual host ID (`vhid`)*, which uniquely identifies the interfaces that will share the virtual IP address.

WARNING *The `vhid` is an 8-bit value that must be set uniquely within the network's broadcast domain. Setting the `vhid` to the wrong value can lead to network problems that can be hard to debug, and there's even anecdotal evidence that ID collisions with otherwise unrelated systems can occur and cause disruption on redundancy and load-balancing systems based on VRRP, which uses a virtual node identification scheme similar to CARP's.*

Run these commands on the machine that will be the initial master for the group:

```
$ sudo ifconfig carp0 192.0.2.19 vhid 1
$ sudo ifconfig carp1 192.168.1.1 vhid 2
```

We don't need to explicitly set the physical interface because the `carp0` and `carp1` virtual interfaces will bind themselves to the physical interfaces that are already configured with addresses in the same subnets as the assigned CARP address.

NOTE *On systems that offer the `carpdev` option to `ifconfig`, it's recommended to use the `carpdev` option for all CARP interface setups, even if it isn't strictly required. The `carpdev` option becomes indispensable in cases where the choice of physical network device for the CARP interface isn't obvious from the existing network configuration, and adding a `carpdev interface` string to the `ifconfig` commands can make the difference between a nonfunctional setup and a working one. This can be particularly useful in some nonintuitive configurations and where the number of free IP addresses in the relevant network is severely limited. The FreeBSD port of CARP offers the `carpdev` option starting with FreeBSD 10.0.*

Use `ifconfig` to make sure that each CARP interface is properly configured and pay particular attention to the `carp:` line, which indicates `MASTER` status, as shown here:

```
$ ifconfig carp0
carp0: flags=8843<UP,BROADCAST,RUNNING,SIMPLEX,MULTICAST> mtu 1500
        lladdr 00:00:5e:00:01:01
        carp: MASTER carpdev ep0 vhid 1 advbase 1 advskew 0
        groups: carp
        inet 192.0.2.19 netmask 0xffffff00 broadcast 192.0.2.255
        inet6 fe80::200:5eff:fe00:101%carp0 prefixlen 64 scopeid 0x5
```

The setup is almost identical on the backup except that you add the `advskew` parameter, which indicates how much *less preferred* it is for the specified machine to take over than the current master.

```
$ sudo ifconfig carp0 192.0.2.19 vhid 1 advskew 100
$ sudo ifconfig carp1 192.168.1.1 vhid 2 advskew 100
```

The `advskew` parameter and its companion value, `advbase`, are used to calculate the interval between the current host's announcements of its master status once it's taken over. The default value for `advbase` is 1, and the default for `advskew` is 0. In the preceding example, the master would announce every second (1 + 0/256), while the backup would wait for 1 + 100/256 seconds.

With `net.inet.carp.preempt=1` on all hosts in the failover group, when the master stops announcing or announces that it isn't available, the backups take over, and the new master starts announcing at its configured rate. Smaller `advskew` values mean shorter announcement intervals and a higher likelihood that the host becomes the new master. If more hosts have the same `advskew`, the one that's already master will keep its master status.

On OpenBSD 4.1 and higher, one more factor in the equation determines which host takes over CARP master duty. The *demotion counter* is a value each CARP host announces for its interface group as a measure of readiness for its CARP interfaces. When the demotion counter value is 0, the host is in complete readiness; higher values indicate measures of degradation. You can set the demotion counter from the command line using `ifconfig -g`, but the value is usually set by the system itself, with higher values typically during the boot process. All other things being equal, the host with the lowest demotion counter will win the contest to take over as the CARP master.

NOTE *As of this writing, FreeBSD CARP versions earlier than FreeBSD 10 don't support setting the demotion counter.*

On the backup, use `ifconfig` once again to check that each CARP interface is properly configured:

```
$ ifconfig carp0
carp0: flags=8843<UP,BROADCAST,RUNNING,SIMPLEX,MULTICAST> mtu 1500
        lladdr 00:00:5e:00:01:01
        carp: BACKUP carpdev em0 vhid 1 advbase 1 advskew 100
        groups: carp
        inet 192.0.2.19 netmask 0xffffff00 broadcast 192.0.2.255
        inet6 fe80::200:5eff:fe00:101%carp0 prefixlen 64 scopeid 0x5
```

The output here is only slightly different from what you've just seen on the master. Notice that the `carp:` line indicates `BACKUP` status along with the `advbase` and `advskew` parameters.

For actual production use, you should add a measure of security against unauthorized CARP activity by configuring the members of the CARP group with a shared, secret passphrase, such as the following:[2]

```
$ sudo ifconfig carp0 pass mekmitasdigoat 192.0.2.19 vhid 1
$ sudo ifconfig carp1 pass mekmitasdigoat 192.168.1.1 vhid 2
```

NOTE *As with any other password, the passphrase will become a required ingredient in all CARP traffic in your setup. Be sure to configure all CARP interfaces in a failover group with the same passphrase (or none).*

Once you've figured out the appropriate settings, preserve them through future system reboots by putting them in the proper files in */etc*:

- On OpenBSD, put the proper `ifconfig` parameters into *hostname.carp0* and *hostname.carp1*.
- On FreeBSD and NetBSD, put the relevant lines in your *rc.conf* file as contents of the `ifconfig_carp0=` and `ifconfig_carp1=` variables.

Keeping States Synchronized: Adding pfsync

As the final piece of configuration, set up state-table synchronization between the hosts in your redundancy group to prevent traffic disruption during failover. This feat is accomplished through a set of pfsync interfaces. (As noted earlier, as of this writing, NetBSD doesn't support pfsync.)

Configuring pfsync interfaces requires planning and a few `ifconfig` commands. You can set up pfsync on any configured network interface, but it's best to set up a separate network for the synchronization. The sample configuration in Figure 8-2 shows a tiny network set aside for the purpose. A crossover cable connects the two Ethernet interfaces, but in configurations with more than two hosts in the failover group, you may want a setup with a separate switch, hub, or VLAN. The interfaces to be used for the synchronization have been assigned the IP addresses 10.0.12.16 and 10.0.12.17, respectively.

With the basic TCP/IP configuration in place, the complete pfsync setup for each synchronization partner interface is

```
$ sudo ifconfig pfsync0 syncdev ep2
```

2. This particular passphrase has a very specific meaning. A Web search will reveal its significance and why it's *de rigeur* for modern networking documentation. The definitive answer can be found via the *openbsd-misc* mailing list archives.

The pfsync protocol itself offers little in the way of security features: It has no authentication mechanism and, by default, communicates via IP multicast traffic. However, in cases where a physically separate network isn't feasible, you can tighten up your pfsync security by setting up pfsync to synchronize only with a specified `syncpeer`:

```
$ sudo ifconfig pfsync0 syncpeer 10.0.12.16 syncdev ep2
```

This produces a configured interface that shows up in `ifconfig` output like this:

```
pfsync0: flags=41<UP,RUNNING> mtu 1500
        priority: 0
        pfsync: syncdev: ep2 syncpeer: 10.0.12.16 maxupd: 128 defer: off
        groups: carp pfsync
```

Another option is to set up an IPsec tunnel and use that to protect the sync traffic. In this case, the `ifconfig` command is

```
$ sudo ifconfig pfsync0 syncpeer 10.0.12.16 syncdev enc0
```

This means that the `syncdev` device becomes the `enc0` encapsulating interface instead of the physical interface.

NOTE *If possible, set up synchronization across a physically separate, dedicated network or a separate VLAN because any lost pfsync updates could lead to less than clean failover.*

One very useful way to check that your PF state synchronization is running properly is to watch the state table on your synchronized hosts using **`systat states`** on each machine. The command gives you a live display of states, showing updates happening in bulk on the sync targets. Between the synchronizations, states should display identically on all hosts. (Traffic counters—such as the number of packets and bytes passed—are the exception; they display updates only on the host that handles the actual connection.)

This takes us to the end of the basic network configuration for CARP-based failover. In the next section, we'll discuss what to keep in mind when writing rule sets for redundant configurations.

Putting Together a Rule Set

After all the contortions we've been through in order to configure basic networking, you may be wondering what it will take to migrate the rules you use in your current *pf.conf* to the new setup. Fortunately, not much. The main change we've introduced is essentially invisible to the rest of the world, and a well-designed rule set for a single gateway configuration will generally work well for a redundant setup, too.

That said, we've introduced two additional protocols (CARP and pfsync), and you'll probably need to make some relatively minor changes to your rule set in order for the failover to work properly. Basically, you need to pass the CARP and pfsync traffic to the appropriate interfaces. The simplest way to handle the CARP traffic is to introduce a macro definition for your `carpdevs` that includes all physical interfaces that will handle CARP traffic. You'll also introduce an accompanying `pass` rule, like the following one, in order to pass CARP traffic on the appropriate interfaces:

```
pass on $carpdevs proto carp
```

Similarly, for pfsync traffic, you can introduce a macro definition for your `syncdev` and an accompanying `pass` rule:

```
pass on $syncdev proto pfsync
```

Skipping the pfsync interfaces entirely for filtering is cheaper performance-wise than filtering and passing. To take the pfsync device out of the filtering equation altogether, use this rule:

```
set skip on $syncdev
```

You should also consider the roles of the virtual CARP interface and its address versus the physical interface. As far as PF is concerned, all traffic will pass through the physical interfaces, but the traffic may have the CARP interface's IP addresses as source or destination addresses.

You may find that you have rules in your configuration that you don't want to bother to synchronize in case of a failover, such as connections to services that run on the gateway itself. One prime example is the typical rule to allow SSH in for the administrator:

```
pass in on $int_if from $ssh_allowed to self
```

For rules like these, you could use the state option `no-sync` to prevent synchronizing state changes for connections that really aren't relevant once failover has occurred:

```
pass in on $int_if from $ssh_allowed to self keep state (no-sync)
```

With this configuration, you'll be able to schedule operating system upgrades and formerly downtime-producing activities on members of your CARPed group of systems at times when they're most convenient, with no noticeable downtime for the users of your services.

IFSTATED, THE INTERFACE STATE DAEMON

In properly CARPed setups, basic networking functionality is well provided for, but your setup may include elements that need special attention when the network configuration changes on a host. For example, some services might need to be started or stopped when a specific interface goes down or restarts, or you may want to run specific commands or scripts in response to interface state changes. If this sounds familiar, `ifstated` is for you.

The `ifstated` tool was introduced in OpenBSD 3.5 to trigger actions based on changes in the state of network interfaces. You'll find it in the base system on OpenBSD and via the ports system as *net/ifstated* on FreeBSD. On OpenBSD, the file */etc/ifstated.conf* (or */usr/local/etc/ifstated.conf* if you installed the port on FreeBSD) contains an almost-ready-to-run configuration with a few pointers on how to set up `ifstated` for a CARPed environment.

The main controlling objects are interfaces and their states—for example, `carp0.link.up` is the state where the `carp0` interface has become master—and you perform actions in response to state changes.

The states and actions to perform whenever the state of an interface changes are specified in a straightforward scripting language with basic features like variables, macros, and simple logical conditionals. (See `man ifstated` and `man ifstated.conf` as well as the default *ifstated.conf* sample file supplied in your base system install for more on this topic and on implementing CARP-based clustering features in your environment.)

CARP for Load Balancing

Redundancy by failover is nice, but sometimes it's less attractive to have hardware sitting around in case of failure and better to create a configuration that spreads the network load over several hosts.

In addition to ARP balancing (which works by calculating hashes based on the source MAC address on incoming connections), CARP in OpenBSD 4.3 and higher supports several varieties of IP-based load balancing, with traffic allocated based on hashes calculated from the connections' source and destination IP addresses. Because ARP balancing is based on the source MAC address, it'll work only for hosts in the directly connected network segment. On the other hand, the IP-based methods are appropriate for load-balancing connections to and from the Internet at large.

The choice of method for your application will depend on the specifications of the rest of the network equipment you need to work with. The basic `ip` balancing mode uses a multicast MAC address to have the directly connected switch forward traffic to all hosts in the load-balancing cluster.

Unfortunately, the combination of a unicast IP address and a multicast MAC address isn't supported by some systems. In those cases, you may need to configure your load balancing in `ip-unicast` mode, which uses a unicast MAC address, and configure your switch to forward to the appropriate hosts. Or you may need to configure your load balancing in `ip-stealth` mode, which doesn't use the multicast MAC address at all. As usual, the devil is in the details, and the answers are found in man pages and other documentation, most likely with a bit of experimentation thrown in.

NOTE *Traditionally, `relayd` has been used to do intelligent load balancing as the frontend for servers that offer services to the rest of the world. In OpenBSD 4.7, `relayd` acquired the ability to track available uplinks and alter the system's routing tables based on link health, with the functionality wrapped in a bundle with the `router` keyword. For setups with several possible uplinks or various routing tables, you can set up `relayd` to choose your uplink or, with a little help from the `sysctl` variables `net.inet.ip.multipath` and `net.inet6.ip6.multipath`, perform load balancing across available routes and uplinks. The specifics will vary with your networking environment. The `relayd.conf` man page contains a complete example to get you started.*

CARP in Load-Balancing Mode

In load-balancing mode, the CARP concept is extended by letting each CARP interface be a member of multiple failover groups and as many load-balancing groups as there are physical hosts that will share the virtual address. In contrast with the failover case, where there can be only one master, each node in a load-balancing cluster *must* be the master of its own group so that it can receive traffic. The choice of group—and by extension, physical host—that ends up handling a given connection is determined by CARP via a hash value calculation. This calculation is based on the connection's source MAC address in the ARP-balancing case and on the source and destination IP address in the IP-balancing case as well as actual availability. The downside to this scheme is that each group consumes one virtual host ID, so you'll run out of these IDs quite a bit more quickly in a load-balancing configuration than when using failover only. In fact, there's a hard upper limit to the number of CARP-based load-balancing *clusters* of 32 virtual host IDs.

The `advskew` parameter plays a similar role in load-balancing configurations as in the failover ones, but the `ifconfig` (and *hostname.carpN*) syntax for CARP load balancing is slightly different from that of the failover case.

Setting Up CARP Load Balancing

Changing the CARP failover group built over the previous sections to a load-balancing cluster is as simple as editing the configuration files and reloading. In the following example, we choose an IP load-balancing scheme. If you choose a different scheme, the configuration itself differs only in the keyword for mode selection.

On the first host, we change */etc/hostname.carp0* to

```
pass mekmitasdigoat 192.0.2.19 balancing ip carpnodes 5:100,6:0
```

This says that on this host, the `carp0` interface is a member of the group with `vhid 5` (with an `advskew` of `100`) as well as the interface with `vhid 6`, where it's the prime candidate for becoming initial master (with an `advskew` set to `0`).

Next, we change */etc/hostname.carp1* to this:

```
pass mekmitasdigoat 192.168.12.1 balancing ip carpnodes 3:100,4:0
```

For `carp1`, the memberships are `vhids 3` and `4`, with `advskew` values of `100` and `0`, respectively.

For the other host, the `advskew` values are reversed, but the configuration is otherwise predictably similar. Here, */etc/hostname.carp0* reads:

```
pass mekmitasdigoat 192.0.2.19 balancing ip carpnodes 5:0,6:100
```

This means that the `carp0` interface is a member of `vhid 5` with `advskew 0` and a member of `vhid 6` with `advskew 100`. Complementing this is the */etc/hostname.carp1* file that reads:

```
pass mekmitasdigoat 192.168.12.1 balancing ip carpnodes 3:0,4:100
```

Again, `carp1` is a member of `vhid 3` and `4`, with `advskew 0` in the first and `100` in the other.

The `ifconfig` output for the `carp` interface group on the first host looks like this:

```
$ ifconfig carp
carp0: flags=8843<UP,BROADCAST,RUNNING,SIMPLEX,MULTICAST> mtu 1500
        lladdr 01:00:5e:00:01:05
        priority: 0
        carp: carpdev vr0 advbase 1 balancing ip
                state MASTER vhid 5 advskew 0
                state BACKUP vhid 6 advskew 100
        groups: carp
        inet 192.0.2.19 netmask 0xffffff00 broadcast 192.0.2.255
        inet6 fe80::200:24ff:fecb:1c10%carp0 prefixlen 64 scopeid 0x7
carp1: flags=8843<UP,BROADCAST,RUNNING,SIMPLEX,MULTICAST> mtu 1500
        lladdr 01:00:5e:00:01:03
        priority: 0
        carp: carpdev vr1 advbase 1 balancing ip
                state MASTER vhid 3 advskew 0
                state BACKUP vhid 4 advskew 100
        groups: carp
        inet 192.168.12.1 netmask 0xffffff00 broadcast 192.168.12.255
        inet6 fe80::200:24ff:fecb:1c10%carp1 prefixlen 64 scopeid 0x8
pfsync0: flags=41<UP,RUNNING> mtu 1500
        priority: 0
        pfsync: syncdev: vr2 syncpeer: 10.0.12.17 maxupd: 128 defer: off
        groups: carp pfsync
```

The other host has this `ifconfig` output:

```
$ ifconfig carp
carp0: flags=8843<UP,BROADCAST,RUNNING,SIMPLEX,MULTICAST> mtu 1500
        lladdr 01:00:5e:00:01:05
        priority: 0
        carp: carpdev vr0 advbase 1 balancing ip
                state BACKUP vhid 5 advskew 100
                state MASTER vhid 6 advskew 0
        groups: carp
        inet 192.0.2.19 netmask 0xffffff00 broadcast 192.0.2.255
        inet6 fe80::200:24ff:fecb:1c18%carp0 prefixlen 64 scopeid 0x7
carp1: flags=8843<UP,BROADCAST,RUNNING,SIMPLEX,MULTICAST> mtu 1500
        lladdr 01:00:5e:00:01:03
        priority: 0
        carp: carpdev vr1 advbase 1 balancing ip
                state BACKUP vhid 3 advskew 100
                state MASTER vhid 4 advskew 0
        groups: carp
        inet 192.168.12.1 netmask 0xffffff00 broadcast 192.168.12.255
        inet6 fe80::200:24ff:fecb:1c18%carp1 prefixlen 64 scopeid 0x8
pfsync0: flags=41<UP,RUNNING> mtu 1500
        priority: 0
        pfsync: syncdev: vr2 syncpeer: 10.0.12.16 maxupd: 128 defer: off
        groups: carp pfsync
```

If we had three nodes in our load-balancing scheme, each `carp` interface would need to be a member of an additional group, for a total of three groups. In short, for each physical host you introduce in the load-balancing group, each `carp` interface becomes the member of an additional group.

Once you've set up the load-balancing cluster, check the flow of connections by running **`systat states`** on each of the hosts in your load-balancing cluster for a few minutes to make sure that the system works as expected and to see that all the effort you put in has been worth it.

9

LOGGING, MONITORING, AND STATISTICS

Exercising control over a network—whether for your home networking needs or in a professional context—is likely to be a main objective for anyone who reads this book. One necessary element of keeping control is having access to all relevant information about what happens in your network. Fortunately for us, PF—like most components of Unix-like systems—is able to generate log data for network activity.

PF offers a wealth of options for setting the level of logging detail, processing log files, and extracting specific kinds of data. You can already do a lot with the tools that are in your base system, and several other tools are available via your package system to collect, study, and view log data in a number of useful ways. In this chapter, we take a closer look at PF logs in general and some of the tools you can use to extract and present information.

PF Logs: The Basics

The information that PF logs and the level of logging detail are up to you, as determined by your rule set. Basic logging is simple: For each rule that you want to log data for, add the `log` keyword. When you load the rule set with `log` added to one or more rules, any packet that starts a connection matching the logging rule (blocked, passed, or matched) is copied to a `pflog` device. *The packet is logged as soon as it's seen by PF and at the same time that the logging rule is evaluated.*

NOTE *In complicated rule sets, a packet may go through several transformations due to `match` or `pass` rules, and criteria that matched a packet when it entered the host might not match after a transformation.*

PF will also store certain additional data, such as the timestamp, interface, original source and destination IP addresses, whether the packet was blocked or passed, and the associated rule number from the loaded rule set.

PF log data is collected by the `pflogd` logging daemon, which starts by default when PF is enabled at system startup. The default location for storing the log data is */var/log/pflog*. The log is written in a binary format, usually called *packet capture format (pcap)*, that's intended to be read and processed by `tcpdump`. We'll discuss additional tools to extract and display information from your log file later. The log file format is a well-documented and widely supported binary format.

To get started, here's a basic log example. Start with the rules you want to log and add the `log` keyword:

```
block log
pass log quick proto { tcp, udp } to port ssh
```

Reload the rule set, and you should see the timestamp on your */var/log/pflog* file change as the file starts growing. To see what's being stored there, use `tcpdump` with the `-r` option to read the file.

If logging has been going on for a while, entering the following on a command line can produce large amounts of output:

```
$ sudo tcpdump -n -ttt -r /var/log/pflog
```

For example, the following are just the first lines from a file several screens long, with almost all lines long enough to wrap:

```
$ sudo tcpdump -n -ttt -r /var/log/pflog
tcpdump: WARNING: snaplen raised from 116 to 160
Sep 13 13:00:30.556038 rule 10/(match) pass in on epic0: 194.54.107.19.34834 >
194.54.103.66.113: S 3097635127:3097635127(0) win 16384 <mss 1460,nop,nop,sackOK,nop,wscale
0,[|tcp]> (DF)
Sep 13 13:00:30.556063 rule 10/(match) pass out on fxp0: 194.54.107.19.34834 >
194.54.103.66.113: S 3097635127:3097635127(0) win 16384 <mss 1460,nop,nop,sackOK,nop,wscale
0,[|tcp]> (DF)
```

```
Sep 13 13:01:07.796096 rule 10/(match) pass in on epic0: 194.54.107.19.29572 >
194.54.103.66.113: S 2345499144:2345499144(0) win 16384 <mss 1460,nop,nop,sackOK,nop,wscale
0,[|tcp]> (DF)
Sep 13 13:01:07.796120 rule 10/(match) pass out on fxp0: 194.54.107.19.29572 >
194.54.103.66.113: S 2345499144:2345499144(0) win 16384 <mss 1460,nop,nop,sackOK,nop,wscale
0,[|tcp]> (DF)
Sep 13 13:01:15.096643 rule 10/(match) pass in on epic0: 194.54.107.19.29774 >
194.54.103.65.53: 49442 [1au][|domain]
Sep 13 13:01:15.607619 rule 12/(match) pass in on epic0: 194.54.107.19.29774 >
194.54.107.18.53: 34932 [1au][|domain]
```

The `tcpdump` program is very flexible, especially when it comes to output, and it offers a number of display choices. The format in this example follows from the options we fed to `tcpdump`. The program almost always displays the date and time the packet arrived (the `-ttt` option specifies this long format). Next, `tcpdump` lists the rule number in the loaded rule set, the interface on which the packet appeared, the source and target address and ports (the `-n` option tells `tcpdump` to display IP addresses, not hostnames), and the various packet properties.

NOTE *The rule numbers in your log files refer to the* loaded, in-memory *rule set. Your rule set goes through some automatic steps during the loading process, such as macro expansion and optimizations, which make it likely that the rule number as stored in the logs will not quite match what you'd find by counting from the top of your* pf.conf *file. If it isn't immediately obvious to you which rule matched, use* `pfctl -vvs rules` *and study the output.*

In our `tcpdump` output example, we see that the tenth rule (`rule 10`) in the loaded rule set seems to be a catchall that matches both IDENT requests and domain name lookups. This is the kind of output you'll find invaluable when debugging, and it's essential to have this kind of data available in order to stay on top of your network. With a little effort and careful reading of the `tcpdump` man pages, you should be able to extract useful information from your log data.

For a live display of the traffic you log, use `tcpdump` to read log information directly from the log device. To do so, use the `-i` option to specify which interface you want `tcpdump` to read from, as follows. (The `-l` option, which enables line buffering on the output, is useful if you want to look at what you're capturing.)

```
$ sudo tcpdump -lnettti pflog0
Apr 29 22:07:36.097434 rule 16/(match) pass in on xl0: 85.19.150.98.53 > 213.187.179.198.41101:
63267*- 1/0/2 (68)
Apr 29 22:07:36.097760 rule def/(match) pass out on em0: 213.187.179.198.22 >
192.168.103.44.30827: P 1825500807:1825500883(76) ack 884130750 win 17520 [tos 0x10]
Apr 29 22:07:36.098386 rule def/(match) pass in on em0: 192.168.103.44.30827 >
213.187.179.198.22: . ack 76 win 16308 (DF) [tos 0x10]
Apr 29 22:07:36.099544 rule 442/(match) pass in on xl0: 93.57.15.161.4487 > 213.187.179.198.80:
P ack 3570451894 win 65535 <nop,nop,timestamp 4170023961 0>
```

```
Apr 29 22:07:36.108037 rule 25/(match) pass out on xl0: 213.187.179.198.25 >
213.236.166.45.65106: P 2038177705:2038177719(14) ack 149019161 win 17424 (DF)
Apr 29 22:07:36.108240 rule def/(match) pass out on em0: 213.187.179.198.22 >
192.168.103.44.30827: P 76:232(156) ack 1 win 17520 [tos 0x10]
```

This sequence begins with a domain name lookup answer, followed by two packets from an open SSH connection, which tells us that the site's administrator probably enabled `log (all)` on the matching rules (see "Logging All Packets: log (all)" on page 165). The fourth packet belongs to a website connection, the fifth is part of an outgoing SMTP connection, and finally there's another SSH packet. If you were to leave this command running, the displayed lines would eventually scroll off the top of your screen, but you could redirect the data to a file or to a separate program for further processing.

NOTE *Sometimes you'll be interested mainly in traffic between specific hosts or in traffic matching specific criteria. For these cases, `tcpdump`'s filtering features can be useful. See `man tcpdump` for details.*

Logging the Packet's Path Through Your Rule Set: log (matches)

Early versions of the PF logging code didn't feature an easy way to track all rules that a packet would match during rule-set traversal. This omission became more evident than before when `match` rules were introduced in OpenBSD 4.6 and PF users were offered a more convenient and slightly easier way to subject packets and connections to transformations, such as address rewriting. `match` rules allow you to perform actions on a packet or connection independently of the eventual `pass` or `block` decision. The specified actions—such as `nat-to`, `rdr-to`, and a few others—are performed immediately. This can lead to situations in which a packet has been transformed by a `match` rule and it no longer matches criteria in a filtering rule that appears later in the rule set that it otherwise would have matched if the transformation hadn't already occurred. One fairly basic example is a `match` rule that applies `nat-to` on the external interface, placed before any `pass` rules in the rule set. Once the `nat-to` action has been applied, any filtering criteria that would have matched the packet's original source address will no longer match the packet.

This greater versatility made some rule sets harder to debug (typically those with several `match` rules that perform transformations), and it became clear that a new logging option was needed.

The PF developers had been eyeing the logging code for a rewrite for some time, and by the time the logging system was rewritten for the OpenBSD 4.9 release, the restructured code made it easy to introduce the log option `matches` to help debug such rule sets and to help track a packet's path through rule sets where several sets of `match` or `pass` rules could transform the packet.

Adding `log (matches)` to a rule forces the logging of all matched rules once a packet matches a rule containing a `log (matches)` clause. Once such a

match occurs, all subsequent rules will also be logged. As a result, you can use targeted `log (matches)` statements to trace a packet's path through your loaded rule set, making it much easier to untangle complicated rule sets.

For example, consider this simple rule set with NAT. The `log (matches)` rule is as follows:

```
match in log (matches) on $int_if from $testhost tag localnet
```

Our test host is a workstation in the local network with the IP address 192.168.103.44. When the test host looks up a website somewhere on the Internet, the logged information looks like this:

```
Apr 29 21:08:24.386474 rule 3/(match) match in on em0: 192.168.103.44.14054 > 81.93.163.115.80:
S 1381487359:1381487359(0) win 16384 <mss 1460,nop,nop,sackOK,nop,wscale 3,nop,nop,timestamp
735353043[|tcp]> (DF) ❶
Apr 29 21:08:24.386487 rule 11/(match) block in on em0: 192.168.103.44.14054 >
81.93.163.115.80: S 1381487359:1381487359(0) win 16384 <mss 1460,nop,nop,sackOK,nop,wscale
3,nop,nop,timestamp 735353043[|tcp]> (DF) ❷
Apr 29 21:08:24.386497 rule 17/(match) pass in on em0: 192.168.103.44.14054 > 81.93.163.115.80:
S 1381487359:1381487359(0) win 16384 <mss 1460,nop,nop,sackOK,nop,wscale 3,nop,nop,timestamp
735353043[|tcp]> (DF) ❸
Apr 29 21:08:24.386513 rule 17/(match) pass in on em0: 192.168.103.44.14054 > 81.93.163.115.80:
S 1381487359:1381487359(0) win 16384 <mss 1460,nop,nop,sackOK,nop,wscale 3,nop,nop,timestamp
735353043[|tcp]> (DF)
Apr 29 21:08:24.386553 rule 5/(match) match out on xl0: 213.187.179.198.14054 >
81.93.163.115.80: S 1381487359:1381487359(0) win 16384 <mss 1460,nop,nop,sackOK,nop,wscale
3,nop,nop,timestamp 735353043[|tcp]> (DF) ❹
Apr 29 21:08:24.386568 rule 16/(match) pass out on xl0: 213.187.179.198.14054 >
81.93.163.115.80: S 1381487359:1381487359(0) win 16384 <mss 1460,nop,nop,sackOK,nop,wscale
3,nop,nop,timestamp 735353043[|tcp]> (DF) ❺
```

The initial packet first matches `rule 3`, the `match log (matches)` rule quoted above the log fragment ❶. The next match is `rule 11` in our loaded rule set ❷, the initial `block all`, but the packet also matches `rule 17`, which lets it `pass in on em0` ❸. The next matching `rule 5` at ❹ is apparently a `match` rule that applies `nat-to` (note the changed source address). Finally, the packet passes `out on xl0` thanks to `rule 16` ❺, a matching `pass` rule.

This example really has only one transformation (the `nat-to`), but the `log (matches)` feature allows us to follow the connection's initial packet through all matching rules in the rule set, including the source address substitution.

Logging All Packets: log (all)

For most debugging and lightweight monitoring purposes, logging the first packet in a connection provides enough information. However, sometimes you may want to log all packets that match certain rules. To do so, use the `(all)` logging option in the rules you want to monitor. After making this change to our minimal rule set, we have the following:

```
block log (all)
pass log (all) quick proto tcp to port ssh keep state
```

This option makes the logs quite a bit more verbose. To illustrate just how much more data `log (all)` generates, we'll use the following rule set fragment, which passes domain name lookups and network time synchronizations:

```
udp_services = "{ domain, ntp }"
pass log (all) inet proto udp to port $udp_services
```

With these rules in place, here's an example of what happens when a Russian name server sends a domain name request to a server in our network:

```
$ sudo tcpdump -lnttti pflog0 port domain
tcpdump: WARNING: snaplen raised from 116 to 160
tcpdump: listening on pflog0, link-type PFLOG
Sep 30 14:27:41.260190 212.5.66.14.53 > 194.54.107.19.53:[|domain]
Sep 30 14:27:41.260253 212.5.66.14.53 > 194.54.107.19.53:[|domain]
Sep 30 14:27:41.260267 212.5.66.14.53 > 194.54.107.19.53:[|domain]
Sep 30 14:27:41.260638 194.54.107.19.53 > 212.5.66.14.53:[|domain]
Sep 30 14:27:41.260798 194.54.107.19.53 > 212.5.66.14.53:[|domain]
Sep 30 14:27:41.260923 194.54.107.19.53 > 212.5.66.14.53:[|domain]
```

We now have six entries instead of just one.

Even with all but `port domain` filtered out by `tcpdump`, adding `log (all)` to one or more rules considerably increases the amount of data in your logs. If you need to log all traffic but your gateway's storage capacity is limited, you may find yourself shopping for additional storage, and the added I/O activity may in fact have a negative impact on performance. Also, recording and storing traffic logs with this level of detail is likely to have legal implications.

LOG RESPONSIBLY!

Creating logs of any kind could have surprising consequences, including some legal implications. Once you start storing log data generated by your network traffic, you're creating a store of information about your users. There may be good technical and business reasons to store logs for extended periods, but logging just enough data and storing it for just the right amount of time can be a fine art.

You probably have some idea of the practical issues related to generating log data, such as arranging for sufficient storage to retain enough log data long enough to be useful. The legal implications will vary according to your location. Some countries and territories have specific requirements for handling log data, along with restrictions on how that data may be used and how long logs can be retained. Others require service providers to retain traffic logs for a specific period of time, in some cases with a requirement to deliver any such data to law enforcement upon request. Make sure you understand the legal issues before you build a logging infrastructure.

Logging to Several pflog Interfaces

Versions of PF newer than OpenBSD 4.1 make it possible to direct your log data to more than one `pflog` interface. In OpenBSD 4.1, the `pflog` interface became a *cloneable* device, meaning that you can use `ifconfig` commands to create several `pflog` interfaces, in addition to the default `pflog0`. This makes it possible to record the log data for different parts of your rule set to separate `pflog` interfaces, and it makes it easier to process the resulting data separately if necessary.

Moving from the default single `pflog0` interface to several `pflog` interfaces requires some changes to your setup that are subtle but effective. To log to several interfaces, make sure that all the log interfaces your rule set uses are created. You don't need to create the devices before the rule set is loaded; if your rule set logs to a nonexistent interface, the log data is simply discarded.

When tuning your setup to use several `pflog` interfaces, you'll most likely add the required interfaces from the command line, like so:

```
$ sudo ifconfig create pflog1
```

Specify the log device when you add the `log` keyword to your rule set, as follows:

```
pass log (to pflog1) proto tcp to $emailserver port $email
pass log (to pflog1) proto tcp from $emailserver to port smtp
```

For a more permanent configuration on OpenBSD, create a *hostname.pflog1* file containing only `up` and similar *hostname.pflogN* files for any additional logging interfaces.

On FreeBSD, the configuration of the cloned `pflog` interfaces belongs in your *rc.conf* file in the following form:

```
ifconfig_pflog1="up"
```

As of this writing, cloning `pflog` interfaces on NetBSD isn't an option.

As you saw in Chapter 6, directing log information for different parts of your rule set to separate interfaces makes it possible to feed different parts of the log data PF produces to separate applications. This makes it easier to have programs like `spamlogd` process only the relevant information, while you feed other parts of your PF log data to other log-processing programs.

Logging to syslog, Local or Remote

One way to avoid storing PF log data on the gateway itself is to instruct your gateway to log to another machine. If you already have a centralized logging infrastructure in place, this is a fairly logical thing to do, even if PF's ordinary logging mechanisms weren't really designed with traditional `syslog`-style logging in mind.

As any old BSD hand will tell you, the traditional `syslog` system log facility is a bit naive about managing the data it receives over UDP from other hosts, with denial-of-service attacks involving full disks one frequently mentioned danger. There's also the ever-present risk that log information will be lost under high load on either individual systems or the network. Therefore, consider setting up remote logging *only* if all hosts involved communicate over a well-secured and properly dimensioned network. On most BSDs, `syslogd` isn't set up by default to accept log data from other hosts. (See the `syslogd` man page for information about how to enable listening for log data from remote hosts if you plan to use remote `syslog` logging.)

If you'd still like to do your PF logging via `syslog`, the following is a short recipe for how to accomplish this. In ordinary PF setups, `pflogd` copies the log data to the log file. When you want to store the log data on a remote system, you should disable `pflog`'s data accumulation by changing daemon's startup options in *rc.conf.local* (on OpenBSD), like so:

```
pflogd_flags="NO"
```

On FreeBSD and NetBSD, change the `pflog_flats=` setting line in *rc.conf*. Then kill the `pflogd` process. Next, make sure that the log data, now no longer collected by `pflogd`, is transmitted in a meaningful way to your log-processing system instead. This step has two parts: First, set up your system logger to transmit data to the log-processing system, and then use `tcpdump` with `logger` to convert the data and inject it into the `syslog` system.

To set up `syslogd` to process the data, choose your *log facility*, *log level*, and *action* and put the resulting line in */etc/syslog.conf*. These concepts are very well explained in `man syslog.conf`, which is required reading if you want to understand system logs. The *action* part is usually a file in a local filesystem. For example, if you've already set up the system logger at *loghost.example.com* to receive your data, choose log facility `local2` with log level `info` and enter this line:

```
local2.info                    @loghost.example.com
```

Once you've made this change, restart `syslogd` to make it read the new settings.

Next, set `tcpdump` to convert the log data from the `pflog` device and feed it to `logger`, which will then send it to the system logger. Here, we reuse the `tcpdump` command from the basic examples earlier in this chapter, with some useful additions:

```
$ sudo nohup tcpdump -lnettti pflog0 | logger -t pf -p local2.info &
```

The `nohup` command makes sure the process keeps running even if it doesn't have a controlling terminal or it's put in the background (as we do here with the trailing `&`). The `-l` option to the `tcpdump` command specifies line-buffered output, which is useful for redirecting to other programs.

The `logger` option adds the tag `pf` to identify the PF data in the stream and specifies log priority with the `-p` option as `local2.info`. The result is logged to the file you specify on the logging host, with entries that will look something like this:

```
pf: Sep 21 14:05:11.492590 rule 93/(match) pass in on ath0:
10.168.103.11.15842 > 82.117.50.17.80: [|tcp] (DF)
pf: Sep 21 14:05:11.492648 rule 93/(match) pass out on xl0:
194.54.107.19.15842 > 82.117.50.17.80: [|tcp] (DF)
pf: Sep 21 14:05:11.506289 rule 93/(match) pass in on ath0:
10.168.103.11.27984 > 82.117.50.17.80: [|tcp] (DF)
pf: Sep 21 14:05:11.506330 rule 93/(match) pass out on xl0:
194.54.107.19.27984 > 82.117.50.17.80: [|tcp] (DF)
pf: Sep 21 14:05:11.573561 rule 136/(match) pass in on ath0:
10.168.103.11.6430 > 10.168.103.1.53:[|domain]
pf: Sep 21 14:05:11.574276 rule 136/(match) pass out on xl0:
194.54.107.19.26281 > 209.62.178.21.53:[|domain]
```

This log fragment shows mainly Web-browsing activities from a client in a NATed local network, as seen from the gateway's perspective, with accompanying domain name lookups.

Tracking Statistics for Each Rule with Labels

The sequential information you get from retrieving log data basically tracks packet movements over time. In other contexts, the sequence or history of connections is less important than aggregates, such as the number of packets or bytes that have matched a rule since the counters were last cleared.

At the end of Chapter 2, you saw how to use `pfctl -s info` to view the global aggregate counters, along with other data. For a more detailed breakdown of the data, track traffic totals on a per-rule basis with a slightly different form of `pfctl` command, such as `pfctl -vs rules`, to display statistics along with the rule, as shown here:

```
$ pfctl -vs rules
pass inet proto tcp from any to 192.0.2.225 port = smtp flags S/SA keep state label "mail-in"
  [ Evaluations: 1664158   Packets: 1601986   Bytes: 763762591   States: 0     ]
  [ Inserted: uid 0 pid 24490 ]
pass inet proto tcp from 192.0.2.225 to any port = smtp flags S/SA keep state label "mail-out"
  [ Evaluations: 2814933   Packets: 2711211   Bytes: 492510664   States: 0     ]
  [ Inserted: uid 0 pid 24490 ]
```

The format of this output is easy to read, and it's obviously designed for contexts in which you want to get an idea of what's going on at a glance. If you specify even more verbose output with `pfctl -vvs rules`, you'll see essentially the same display, with rule numbers added. On the other hand, the output from this command isn't very well suited for feeding to a script or other program for further processing. To extract these statistics and a few more items in a script-friendly format—and to make your own decisions about which rules are worth tracking)—use rule *labels*.

Labels do more than identify rules for processing specific kinds of traffic; they also make it easier to extract the traffic statistics. By attaching labels to rules, you can store certain extra data about parts of your rule set. For example, you could use labeling to measure bandwidth use for accounting purposes.

In the following example, we attach the labels `mail-in` and `mail-out` to our `pass` rules for incoming and outgoing mail traffic, respectively.

```
pass log proto { tcp, udp } to $emailserver port smtp label "mail-in"
pass log proto { tcp, udp } from $emailserver to port smtp label "mail-out"
```

Once you've loaded the rule set with labels, check the data using `pfctl -vsl`:

```
$ sudo pfctl -vsl
    ❶      ❷       ❸        ❹       ❺      ❻        ❼       ❽
mail-in 1664158 1601986 763762591 887895 682427415 714091 81335176
mail-out 2814933 2711211 492510664 1407278 239776267 1303933 252734397
```

This output contains the following information:

❶ The label
❷ The number of times the rule has been evaluated
❸ The total number of packets passed
❹ The total number of bytes passed
❺ The number of packets passed in
❻ The number of bytes passed in
❼ The number of packets passed out
❾ The number of bytes passed out

The format of this list makes it very well suited for parsing by scripts and applications.

The labels accumulate data from the time the rule set is loaded until their counters are reset. And, in many contexts, it makes sense to set up a `cron` job that reads label values at fixed intervals and then puts those values into permanent storage.

If you choose to run the data collection at fixed intervals, consider collecting the data using `pfctl -vsl -z`. The `z` option resets the counters once `pfctl` has read them, with the result that your data collector will then fetch *periodic data*, accumulated since the command or the script was last run.

NOTE *Rules with macros and lists expand to several distinct rules. If your rule set contains rules with lists and macros that have a label attached, the in-memory result will be a number of rules, each with a separate, identically named label attached to it. While this may lead to confusing* `sudo pfctl -vsl` *output, it shouldn't be a problem as long as the application or script that receives the data can interpret the data correctly by adding up the totals for the identical labels.*

If this type of data collection sounds useful to you, it's also worth noting that recent PF versions offer the option of collecting traffic metadata as NetFlow or IPFIX data. See"Collecting NetFlow Data with pflow(4)" on page 176 for details.

Additional Tools for PF Logs and Statistics

One other important component of staying in control of your network is having the ability to keep an updated view of your system's status. In this section, we'll examine a selection of monitoring tools that you may find useful. All the tools presented here are available either in the base system or via the package system on OpenBSD and FreeBSD (and, with some exceptions, on NetBSD).

Keeping an Eye on Things with systat

If you're interested in seeing an instant snapshot of the traffic passing through your systems right now, the `systat` program on OpenBSD offers several useful views. In Chapter 7, we looked briefly at `systat queues` to see how traffic was assigned to queues in our traffic-shaping rule sets. Here, we'll review some additional useful options.

The `systat` program is available on all BSD operating systems, in slightly different versions. On all systems, `systat` offers views of system statistics, with some minor variations in syntax and output. For example, the `queues` view is one of several `systat` views available in recent OpenBSD versions, but not in FreeBSD or NetBSD as of this writing.

For a more general view of the current state table than that offered by `queues`, try `systat states`, which gives a listing very similar to the `top(1)` process listing. Here's an example of typical `systat states` output:

```
   2 users    Load 0.24 0.28 0.27  (1-16 of 895)       Wed Apr  1 14:00:04 2015

PR   D SRC                  DEST                 STATE   AGE   EXP  PKTS BYTES  RATE  PEAK   AVG RU G
udp  O 192.168.103.1:56729  192.168.103.9:12345    1:0  8340m    25  372K  542M  1492  4774  1137  *
tcp  I 10.168.103.15:47185  213.187.179.198:22     4:4  62377 86398  2954  613K 13264 23654    10 18
tcp  I 10.168.103.15:2796   213.187.179.198:22     4:4  62368 86219  4014  679K     0     0    11 18
tcp  I 10.168.103.15:15599  129.240.64.10:6667     4:4  61998 86375  9266  849K     0    58    14  *
tcp  O 213.187.179.198:1559 129.240.64.10:6667     4:4  61998 86375  9266  849K     0    58    14  * 1
tcp  I 10.168.103.15:8923   140.211.166.4:6667     4:4  61843 86385 15677 4794K     0   299    79  *
tcp  O 213.187.179.198:8923 140.211.166.4:6667     4:4  61843 86385 15677 4794K     0   299    79  * 1
tcp  I 10.168.103.15:47047  217.17.33.10:6667      4:4  61808 86385  7093  556K     0    88     9  *
tcp  O 213.187.179.198:4704 217.17.33.10:6667      4:4  61808 86385  7093  556K     0    88     9  * 1
tcp  I 10.168.103.15:30006  203.27.221.42:6667     4:4  61744 86375  6000  487K     0    49     8  *
tcp  O 213.187.179.198:3000 203.27.221.42:6667     4:4  61744 86375  6000  487K     0    49     8  * 1
tcp  I 10.168.103.15:31709  209.250.145.51:6667    4:4  61744 86385  6646  613K     0   114    10  *
tcp  O 213.187.179.198:3170 209.250.145.51:6667    4:4  61744 86385  6646  613K     0   114    10  * 1
tcp  I 192.168.103.254:5386 69.90.74.197:80        4:4  56718 29844    10  3282     0     0     0  *
tcp  O 213.187.179.198:5386 69.90.74.197:80        4:4  56718 29844    10  3282     0     0     0  * 1
tcp  I 10.168.103.15:33241  192.168.103.84:22      4:4  46916 82678  7555  897K     0     0    19  *
```

If your states don't fit on one screen, just page through the live display.

Similarly, `systat rules` displays a live view of packets, bytes, and other statistics for your loaded rule set, as in this example:

```
   2 users    Load 1.25 0.87 0.52  (1-16 of 239)       Fri Apr  3 14:01:59 2015

RUL ANCHOR      A DIR L Q IF    PR   K  PKTS BYTES STATE MAX INFO
  0             M In                    26M   12G 4946K     all  max-mss 1440
  1             M Out     nfe0         4853K 3162M 94858     inet from 10.0.0.0/8 to any  queue(q_def
  2             M Out     nfe0         3318K 2430M 61672     inet from 192.168.103.0/24 to any  queue
  3             M Out     nfe0  tcp    6404K 4341M  134K     from any to any port = www  queue(q_web,
  4             M Out     nfe0  tcp    84298   43M  1594     from any to any port = https  queue(q_we
  5             M Out     nfe0  tcp      502 34677    63     from any to any port = domain  queue(q_d
  6             M Out     nfe0  udp     512K   64M  257K     from any to any port = domain  queue(q_d
  7             M Out     nfe0  icmp     11  1008     3     all  queue(q_dns, q_pri)
  8             B Any L                14638 1346K     0     return all
  9             B Any   Q                95  5628     0     return from <bruteforce> to any
 10             P Any                  1139K 1005M   757     all flags any
 11             P In    Q       tcp  K 18538 1350K   708     inet from any to any port = ftp
 12             P Out           tcp  K     0     0     0     inet from 127.0.0.1/32 to any port = ftp
 13             P Any                  1421  128K   134     all flags any
 14             P In  L   egres tcp  K 1830K   87M 18933     inet from any to any port = smtp  queue
 15             P In  L   egres tcp  K    31  5240     2     from <nospamd> to any port = smtp
```

The `systat rules` view is especially useful because it offers a live view into the fully parsed and loaded rule set. For example, if your rule set behaves oddly, the `rules` view can point you in the right direction and show you the flow of packets.

The `systat` program also offers a view that presents the same data you'd get via `pfctl -s status` on the command line. The following example shows part of the output of `systat pf`. The `systat pf` view offers more information than will fit on most screens, but you can page through the live display of the data.

```
   2 users    Load 0.34 0.64 0.47  (1-16 of 51)        Fri Apr  3 14:04:04 2015

          TYPE NAME                         VALUE       RATE NOTES
            pf Status                     Enabled
            pf Since                   139:05:08
            pf Debug                         err
            pf Hostid                 0x82aea702

          nfe0 Bytes In               6217042900          IPv4
          nfe0 Bytes In                        0          IPv6
          nfe0 Bytes Out              5993394114          IPv4
          nfe0 Bytes Out                      64          IPv6
          nfe0 Packets In               12782504          IPv4, Passed
          nfe0 Packets In                      0          IPv6, Passed
          nfe0 Packets In                  11096          IPv4, Blocked
          nfe0 Packets In                      0          IPv6, Blocked
          nfe0 Packets Out              12551463          IPv4, Passed
          nfe0 Packets Out                     1          IPv6, Passed
          nfe0 Packets Out                   167          IPv4, Blocked
```

The systat program offers quite a few other views, including network-related ones, such as netstat, vmstat for virtual memory statistics, and iostat for input/output statistics by device. You can cycle through all systat views using the left and right cursor keys. (See man systat for full details.)

Keeping an Eye on Things with pftop

If your system doesn't have a systat version with the PF-related views, you can still keep an eye on what's passing into and out of your network in real time using Can Erkin Acar's pftop. This command shows a running snapshot of your traffic. pftop isn't included in the base system, but it's available as a package—in ports on OpenBSD and FreeBSD as *sysutils/pftop*[1] and on NetBSD via pkgsrc as *sysutils/pftop*. Here's an example of its output:

```
pfTop: Up State 1-17/771, View: default, Order: none, Cache: 10000                14:05:42

PR    DIR SRC                  DEST                    STATE            AGE   EXP  PKTS BYTES
udp   Out 192.168.103.1:56729  192.168.103.9:12345      SINGLE:NO_TRAFFIC 8346m   22  373K  543M
tcp   In  10.168.103.15:47185  213.187.179.198:22  ESTABLISHED:ESTABLISHED 62715 86395  3232  667K
tcp   In  10.168.103.15:2796   213.187.179.198:22  ESTABLISHED:ESTABLISHED 62706 86369  4071  686K
tcp   In  10.168.103.15:15599  129.240.64.10:6667  ESTABLISHED:ESTABLISHED 62336 86379  9318  854K
tcp   Out 213.187.179.198:15599 129.240.64.10:6667 ESTABLISHED:ESTABLISHED 62336 86379  9318  854K
tcp   In  10.168.103.15:8923   140.211.166.4:6667  ESTABLISHED:ESTABLISHED 62181 86380 15755 4821K
tcp   Out 213.187.179.198:8923 140.211.166.4:6667  ESTABLISHED:ESTABLISHED 62181 86380 15755 4821K
tcp   In  10.168.103.15:47047  217.17.33.10:6667   ESTABLISHED:ESTABLISHED 62146 86379  7132  559K
tcp   Out 213.187.179.198:47047 217.17.33.10:6667  ESTABLISHED:ESTABLISHED 62146 86379  7132  559K
tcp   In  10.168.103.15:30006  203.27.221.42:6667  ESTABLISHED:ESTABLISHED 62082 86380  6034  489K
tcp   Out 213.187.179.198:30006 203.27.221.42:6667 ESTABLISHED:ESTABLISHED 62082 86380  6034  489K
tcp   In  10.168.103.15:31709  209.250.145.51:6667 ESTABLISHED:ESTABLISHED 62082 86379  6685  617K
tcp   Out 213.187.179.198:31709 209.250.145.51:6667 ESTABLISHED:ESTABLISHED 62082 86379  6685  617K
tcp   In  192.168.103.254:53863 69.90.74.197:80    ESTABLISHED:ESTABLISHED 57056 29506    10  3282
tcp   Out 213.187.179.198:53863 69.90.74.197:80    ESTABLISHED:ESTABLISHED 57056 29506    10  3282
tcp   In  10.168.103.15:33241  192.168.103.84:22   ESTABLISHED:ESTABLISHED 47254 82340  7555  897K
tcp   Out 10.168.103.15:33241  192.168.103.84:22   ESTABLISHED:ESTABLISHED 47254 82340  7555  897K
```

You can use pftop to sort your connections by a number of different criteria, including by PF rule, volume, age, and source and destination addresses.

Graphing Your Traffic with pfstat

Once you have a system up and running and producing data, a graphical representation of traffic data is a useful way to view and analyze your data. One way to graph your PF data is with pfstat, a utility developed by Daniel Hartmeier to extract and present the statistical data that's automatically generated by PF. The pfstat tool is available via the OpenBSD package system or as the port *net/pfstat*, via the FreeBSD ports system as *sysutils/pfstat*, and via NetBSD pkgsrc as *sysutils/pfstat*.

1. On OpenBSD, all pftop functionality is included in various systat views, as described in the previous section.

The pfstat program collects the data you specify in the configuration file and presents that data as JPG or PNG graphics files. The data source can be either PF running on the local system via the */dev/pf* device or data collected from a remote computer running the companion pfstatd daemon.

To set up pfstat, you simply decide which parts of your PF data you want to graph and how, and then you write the configuration file and start cron jobs to collect the data and generate your graphs. The program comes with a well-annotated sample configuration file and a useful man page. The sample configuration is a useful starting point for writing your own configuration file. For example, the following *pfstat.conf* fragment is very close to one you'll find in the sample configuration:[2]

```
collect  8 = global states inserts  diff
collect  9 = global states removals diff
collect 10 = global states searches diff

image "/var/www/users/peter/bsdly.net/pfstat-states.jpg" {
        from 1 days to now
        width 980 height 300
        left
                graph 8 "inserts" "states/s" color 0 192 0 filled,
                graph 9 "removals" "states/s" color 0 0 255
        right
                graph 10 "searches" "states/s" color 255 0 0
}
```

The configuration here starts off with three collect statements, where each of the data series is assigned a unique numeric identifier. Here, we capture the number of insertions, removals, and searches in the state table. Next up is the image definition, which specifies the data that is to be graphed. The from line specifies the period to display (from 1 days to now means that only data collected during the last 24 hours is to be displayed). width and height specify the graph size measured in number of pixels in each direction. The graph statements specify how the data series are displayed as well as the graph legends. Collecting state insertions, removals, and searches once a minute and then graphing the data collected over one day produces a graph roughly like the one in Figure 9-1.

2. The color values listed in the configuration example would give you a graph with red, blue, and green lines. For the print version of this book, we changed the colors to grayscale values: 0 192 0 became 105 105 105, 0 0 255 became 192 192 192, and 255 0 0 became 0 0 0.

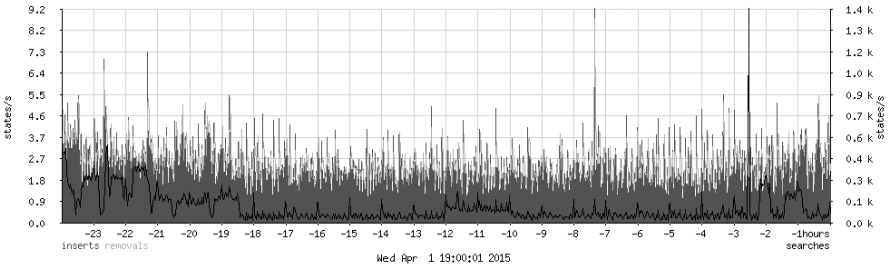

Figure 9-1: State table statistics, 24-hour time scale

The graph can be tweaked to provide a more detailed view of the same data. For example, to see the data for the last hour in a slightly higher resolution, change the period to `from 1 hours to now` and the dimensions to `width 600 height 300`. The result is something like the graph in Figure 9-2.

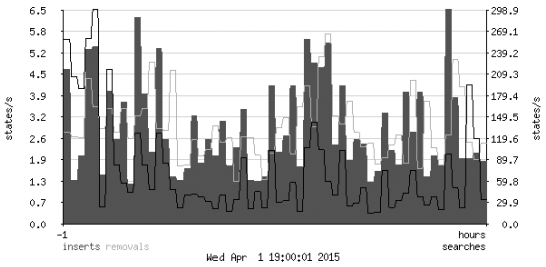

Figure 9-2: State table statistics, 1-hour time scale

The `pfstat` home page at *http://www.benzedrine.cx/pfstat.html* contains several examples, with demonstrations in the form of live graphs of the data from the *benzedrine.cx* domain's gateways. By reading the examples and tapping your own knowledge of your traffic, you should be able to create `pfstat` configurations that are well suited to your site's needs.

NOTE *In addition to `pfstat`, other system-monitoring packages offer at least some PF-monitoring features. One such package is the popular `symon` utility, which is usually configured with the `symon` data gatherer on all monitored systems and at least one host with `symux` and the optional `syweb` Web interface. Based on round-robin database tool (RRDtool), `symon` has a useful interface for recording PF data and offers a useful graphical interface for displaying PF statistics via the `syweb` Web interface. `symon` is available as a port or package on OpenBSD and FreeBSD as `sysutils/symon`, and the `syweb` Web interface is available as `www/syweb`.*

Collecting NetFlow Data with pflow(4)

NetFlow is a network data collection and analysis method that has spawned many supporting tools for recording and analyzing data about TCP/IP connections. NetFlow originated at Cisco and over time has become an essential feature in various network equipment as a tool for network management and analysis.

The NetFlow data model defines a network *flow* as a unidirectional sequence of packets with the same source and destination IP address and protocol. For example, a TCP connection will appear in NetFlow data as two flows: one in each direction.

PF data can be made available to NetFlow tools via the `pflow(4)` pseudo-interface that was introduced in OpenBSD 4.5 along with the `pflow` state option. Essentially, all the information you'd expect to find in a NetFlow-style flow record is easily derived from the data PF keeps in the state table, and the `pflow` interface offers a straightforward way to export PF state-table data in this processing-friendly and well-documented format. As with other logging, you enable NetFlow data collection in your PF rule set on a per-rule basis.

A complete NetFlow-based network-monitoring system consists of several distinct parts. The NetFlow data originates at one or more *sensors* that generate data about network traffic. The sensors forward data about the flows to a *collector*, which stores the data it receives. Finally, a *reporting* or *analysis* system lets you extract and process the data.[3]

Setting Up the NetFlow Sensor

The NetFlow sensor requires two components: one or more configured `pflow(4)` devices and at least one `pass` rule in your rule set with the `pflow` state option enabled. The `pflow` interfaces are created with two required parameters: the flow source IP address and flow destination's IP address and port. Here's an example of the `ifconfig` command for the */etc/hostname.pflow0* file:

```
flowsrc 192.0.2.1 flowdst 192.0.2.105:3001
```

From the command line, use this command:

```
$ sudo ifconfig pflow0 create flowsrc 192.0.2.1 flowdst 192.0.2.105:3001
```

In both cases, this command sets up the host to send NetFlow data with a flow source address 192.0.2.1 to a collector that should listen for NetFlow data at 192.0.2.105, UDP port 3001.

NOTE *It's possible to set up several `pflow` devices with separate flow destinations. It's not currently possible, however, to specify on a per-rule basis which `pflow` device should receive the generated data.*

3. For a more in-depth treatment of network analysis with NetFlow-based tools, see *Network Flow Analysis* by Michael W. Lucas (No Starch Press, 2010).

After enabling the pflow device, specify in */etc/pf.conf* which pass rules should provide NetFlow data to the sensor. For example, if your main concern is to collect data on your clients' email traffic to IPv4 hosts, this rule would set up the necessary sensor:

```
pass out log inet proto tcp from <client> to port $email \
      label client-email keep state (pflow)
```

When pflow was first introduced to PF, the immediate reaction from early adopters was that more likely than not, they'd want to add the pflow option to most pass rules in their rule sets. This led PF developer Henning Brauer to introduce another useful PF feature—the ability to set *state defaults* that apply to all rules unless otherwise specified. For example, if you add the following line at the start of your rule set, all pass rules in the configuration will generate NetFlow data to be exported via the pflow device.

```
set state-defaults pflow
```

With at least one pflow device configured and at least one rule in your *pf.conf* that generates data for export via the pflow device, you're almost finished setting up the sensor. You may still need to add a rule, however, that allows the UDP data to flow from the IP address you specified as the flow data source to the collector's IP address and target port at the flow destination. Once you've completed this last step, you should be ready to turn your attention to collecting the data for further processing.

NetFlow Data Collecting, Reporting, and Analysis

If your site has a NetFlow-based collection and analysis infrastructure in place, you may already have added the necessary configuration to feed the PF-originated data into the data collection and analysis system. If you haven't yet set up a flow-analysis environment, there are a number of options available.

The OpenBSD packages system offers three NetFlow collector and analysis packages: flow-tools, flowd, and nfdump.[4] All three systems have a dedicated and competent developer and user community as well as various add-ons, including graphical Web interfaces. flow-tools is the main component in many sites' flow-analysis setups. The nfdump fans point to the nfsen analysis package that integrates the nfdump tools in a powerful and flexible Web-based analysis frontend that will, among other things, display the command-line equivalent of your GUI selections. You'll find the command-line display useful when you need to drill down further into the data than the selections in the GUI allow. You can copy the command displayed in the GUI and make any further adjustments you need on the nfdump command line in a shell session or script to extract the exact data you want.

4. The actively maintained project home pages for flow-tools and nfdump are *http://code.google.com/p/flow-tools/* and *http://nfdump.sourceforge.net/*. (The older versions should still be available from *http://www.splintered.net/sw/flow-tools/*.) The nfsen Web frontend has a project page at *http://nfsen.sourceforge.net/*. For the latest information about flowd, visit *http://www.mindrot.org/flowd.html*.

CHOOSING A COLLECTOR

The choice of collector is somewhat tied to the choice of analysis package. Perhaps because the collectors tend to store flow data in their own unique formats, most reporting and analysis backends are developed with a distinctive bias for one or the other collector.

Regardless of your choice of NetFlow collector, the familiar logging caveats apply: Detailed traffic log information will require storage. In the case of NetFlow, each flow will generate a record of fairly fixed size, and anecdotal evidence indicates that even modest collection profiles on busy sites can generate gigabytes of NetFlow data per day. The amount of storage you'll need is directly proportional to the number of connections and how long you keep the original NetFlow data. Finally, recording and storing traffic logs with this level of detail is likely to have legal implications.

Collectors generally offer filtering features that let you discard data about specific hosts or networks or even discard some parts of the NetFlow records themselves, either globally or for data about specific hosts or networks.

To illustrate some basic NetFlow collection and how to extract a subset of the collected data for further analysis, we'll use `flowd`, developed by longtime OpenBSD developer Damien Miller and available via the package systems (on OpenBSD as *net/flowd* and on FreeBSD as *net-mgmt/flowd*).

I've chosen to use `flowd` here mainly because it was developed to be small, simple, and secure. As you'll see, `flowd` still manages to be quite useful and flexible. Flow data operations with other tools will differ in some details, but the underlying principles remain the same.

When compared to other NetFlow collector suites, `flowd` is very compact, with only two executable programs—the collector daemon `flowd` and the flow-filtering and presentation program `flowd-reader`—as well as the supporting library and controlling configuration file. The documentation is adequate, if a bit terse, and the sample */etc/flowd.conf* file contains a generous number of comments. Based on the man pages and the comments in the sample configuration file, it shouldn't take you long to create a useful collector configuration.

After stripping out any comment lines—using `grep -v \# /etc/flowd.conf` or similar—a very basic `flowd` configuration could look like this:

```
logfile "/var/log/flowd"
listen on 192.0.2.105:3001
flow source 192.0.2.1
store ALL
```

While this configuration barely contains more information than the `pflow` interface's configuration in the earlier description of setting up the sensor, it does include two important items:

- The `logfile` line tells us where the collected data is to be stored (and reveals that `flowd` tends to store all data in a single file).
- The final line tells us that `flowd` will store all fields in the data it receives from the designated flow source.

With this configuration in place, start up the `flowd` daemon, and almost immediately you should see the */var/log/flowd* file grow as network traffic passes through your gateway and flow records are collected. After a while, you should be able to look at the data using `flowd`'s companion program `flowd-reader`. For example, with all fields stored, the data for one name lookup from a host on the NATed local network looks like this in `flowd-reader`'s default view:

```
$ sudo flowd-reader /var/log/flowd
FLOW recv_time 2011-04-01T21:15:53.607179 proto 17 tcpflags 00 tos 00 agent
[213.187.179.198] src [192.0.2.254]:55108 dst [192.0.2.1]:53 packets 1 octets
62
FLOW recv_time 2011-04-01T21:15:53.607179 proto 17 tcpflags 00 tos 00 agent
[213.187.179.198] src [192.0.2.1]:53 dst [192.0.2.254]:55108 packets 1 octets
129
```

Notice that the lookup generates two flows: one in each direction.

The first flow is identified mainly by the time it was received, followed by the protocol used (protocol 17 is UDP, as */etc/protocols* will tell you). The connection had both TCP and TOS flags unset, and the collector received the data from our gateway at 192.0.2.1. The flow's source address was 192.0.2.254, source port 55108, and the destination address was 192.0.2.1, source port 53, conventionally the DNS port. The flow consisted of 1 packet with a payload of 62 octets. The return flow was received by the collector at the same time, and we see that this flow has the source and destination reversed, with a slightly larger payload of 129 octets. `flowd-reader`'s output format lends itself to parsing by regular expressions for postprocessing in reporting tools or plotting software.

You might think that this data is all anyone would ever want to know about any particular set of network flows, but it's possible to extract even more detailed information. For example, using the `flowd-reader -v` option for verbose output, you might see something like this:

```
FLOW recv_time 2011-04-01T21:15:53.607179 proto 17 tcpflags 00 tos 00
agent [213.187.179.198] src [192.0.2.254]:55108 dst [192.0.2.1]:53 gateway
[0.0.0.0] packets 1 octets 62 in_if 0 out_if 0 sys_uptime_ms 1w5d19m59s.000
time_sec 2011-04-01T21:15:53 time_nanosec 103798508 netflow ver 5 flow_start
1w5d19m24s.000 flow_finish 1w5d19m29s.000 src_AS 0 src_masklen 0 dst_AS 0
dst_masklen 0 engine_type 10752 engine_id 10752 seq 5184351 source 0 crc32
759adcbd
```

```
FLOW recv_time 2011-04-01T21:15:53.607179 proto 17 tcpflags 00 tos 00
agent [213.187.179.198] src [192.0.2.1]:53 dst [192.0.2.254]:55108 gateway
[0.0.0.0] packets 1 octets 129 in_if 0 out_if 0 sys_uptime_ms 1w5d19m59s.000
time_sec 2011-04-01T21:15:53 time_nanosec 103798508 netflow ver 5 flow_start
1w5d19m24s.000 flow_finish 1w5d19m29s.000 src_AS 0 src_masklen 0 dst_AS 0
dst_masklen 0 engine_type 10752 engine_id 10752 seq 5184351 source 0 crc32
f43cbb22
```

The `gateway` field indicates that the sensor itself served as the gateway for this connection. You see a list of the interfaces involved (the `in_if` and `out_if` values), the sensor's system uptime (`sys_uptime_ms`), and a host of other parameters—such as `AS` numbers (`src_AS` and `dst_AS`)—that may be useful for statistics or filtering purposes in various contexts. Once again, the output is ideally suited to filtering via regular expressions.

You don't need to rely on external software for the initial filtering on the data you collect from your `pflow` sensor. `flowd` itself offers a range of filtering features that make it possible to store only the data you need. One approach is to put the filtering expressions in the *flowd.conf*, as in the following example (with the comments stripped to save space):

```
logfile "/var/log/flowd.compact"
listen on 192.0.2.105:3001
flow source 192.0.2.1
store SRC_ADDR
store DST_ADDR
store SRCDST_PORT
store PACKETS
store OCTETS
internalnet = "192.0.2.0/24"
unwired = "10.168.103.0/24"
discard src $internalnet
discard dst $internalnet
discard src $unwired
discard dst $unwired
```

You can choose to store only certain fields in the flow records. For example, in configurations where there's only one collector or agent, the `agent` field serves no useful purpose and doesn't need to be stored. In this configuration, we choose to store only the source and destination address and port, the number of packets, and the number of octets.

You can limit the data you store even further. The macros `internalnet` and `unwired` expand to two NATed local networks, and the four `discard` lines following the macro definitions mean that `flowd` discards any data it receives about flows with either source or destination addresses in either of those local networks. The result is a more compact set of data, tailored to your specific needs, and you see only routable addresses and the address of the sensor gateway's external interface:

```
$ sudo flowd-reader /var/log/flowd.compact | head
FLOW src [193.213.112.71]:38468 dst [192.0.2.1]:53 packets 1 octets 79
FLOW src [192.0.2.1]:53 dst [193.213.112.71]:38468 packets 1 octets 126
```

```
FLOW src [200.91.75.5]:33773 dst [192.0.2.1]:53 packets 1 octets 66
FLOW src [192.0.2.1]:53 dst [200.91.75.5]:33773 packets 1 octets 245
FLOW src [200.91.75.5]:3310 dst [192.0.2.1]:53 packets 1 octets 75
FLOW src [192.0.2.1]:53 dst [200.91.75.5]:3310 packets 1 octets 199
FLOW src [200.91.75.5]:2874 dst [192.0.2.1]:53 packets 1 octets 75
FLOW src [192.0.2.1]:53 dst [200.91.75.5]:2874 packets 1 octets 122
FLOW src [192.0.2.1]:15393 dst [158.37.91.134]:123 packets 1 octets 76
FLOW src [158.37.91.134]:123 dst [192.0.2.1]:15393 packets 1 octets 76
```

Even with the verbose option, `flowd-reader`'s display reveals only what you explicitly specify in the filtering configuration:

```
$ sudo flowd-reader -v /var/log/flowd.compact | head
LOGFILE /var/log/flowd.compact
FLOW src [193.213.112.71]:38468 dst [192.0.2.1]:53 packets 1 octets 79
FLOW src [192.0.2.1]:53 dst [193.213.112.71]:38468 packets 1 octets 126
FLOW src [200.91.75.5]:33773 dst [192.0.2.1]:53 packets 1 octets 66
FLOW src [192.0.2.1]:53 dst [200.91.75.5]:33773 packets 1 octets 245
FLOW src [200.91.75.5]:3310 dst [192.0.2.1]:53 packets 1 octets 75
FLOW src [192.0.2.1]:53 dst [200.91.75.5]:3310 packets 1 octets 199
FLOW src [200.91.75.5]:2874 dst [192.0.2.1]:53 packets 1 octets 75
FLOW src [192.0.2.1]:53 dst [200.91.75.5]:2874 packets 1 octets 122
FLOW src [192.0.2.1]:15393 dst [158.37.91.134]:123 packets 1 octets 76
```

Fortunately, `flowd` doesn't force you to make all your filtering decisions when your collector receives the flow data from the sensor. Using the `-f` flag, you can specify a separate file with filtering statements to extract specific data from a larger set of collected flow data. For example, to see HTTP traffic to your Web server, you could write a filter that stores only flows with your Web server's address and TCP port 80 as the destination or flows with your Web server and TCP port 80 as the source:

```
webserver = 192.0.2.227
discard all
accept dst $webserver port 80 proto tcp
accept src $webserver port 80 proto tcp
store RECV_TIME
store SRC_ADDR
store DST_ADDR
store PACKETS
store OCTETS
```

Assuming you stored the filter in *towebserver.flowdfilter*, you could then extract traffic matching your filtering criteria from */var/log/flowd*, like this:

```
$ sudo flowd-reader -v -f towebserver.flowdfilter /var/log/flowd | tail
FLOW recv_time 2011-04-01T21:13:15.505524 src [89.250.115.174] dst
[192.0.2.227] packets 6 octets 414
FLOW recv_time 2011-04-01T21:13:15.505524 src [192.0.2.227] dst
[89.250.115.174] packets 4 octets 725
FLOW recv_time 2011-04-01T21:13:49.605833 src [216.99.96.53] dst [192.0.2.227]
packets 141 octets 7481
```

```
FLOW recv_time 2011-04-01T21:13:49.605833 src [192.0.2.227] dst [216.99.96.53]
packets 212 octets 308264
FLOW recv_time 2011-04-01T21:14:04.606002 src [91.121.94.14] dst [192.0.2.227]
packets 125 octets 6634
FLOW recv_time 2011-04-01T21:14:04.606002 src [192.0.2.227] dst [91.121.94.14]
packets 213 octets 308316
FLOW recv_time 2011-04-01T21:14:38.606384 src [207.46.199.44] dst
[192.0.2.227] packets 10 octets 642
FLOW recv_time 2011-04-01T21:14:38.606384 src [192.0.2.227] dst
[207.46.199.44] packets 13 octets 16438
FLOW recv_time 2011-04-01T21:15:14.606768 src [213.187.176.94] dst
[192.0.2.227] packets 141 octets 7469
FLOW recv_time 2011-04-01T21:15:14.606768 src [192.0.2.227] dst
[213.187.176.94] packets 213 octets 308278
```

In addition to the filtering options demonstrated here, the `flowd` filtering functions take a number of other options. Some of those options will be familiar from other filtering contexts such as PF, including a range of network-oriented parameters; others are more oriented to extracting data on flows originating at specific dates or time periods and other storage-oriented parameters. The full story, as always, is found in `man flowd.conf`.

Once you've extracted the data you need, you have several tools available for processing and presenting your data.

Collecting NetFlow Data with pfflowd

For systems that don't support NetFlow data export via `pflow`, NetFlow support is available via the `pfflowd` package. As we already saw in the previous section, PF state table data maps very well to the NetFlow data model, and `pfflowd` is intended to record state changes from the local system's `pfsync` device. Once enabled, `pfflowd` acts as a NetFlow sensor that converts `pfsync` data to NetFlow format for transmission to a NetFlow collector on the network.

The `pfflowd` tool was written and is maintained by Damien Miller and is available from *http://www.mindrot.org/projects/pfflowd/* as well as through the package systems on OpenBSD and FreeBSD as *net/pfflowd*. The lack of `pfsync` support on NetBSD means that `pfflowd` isn't available on that platform as of this writing.

SNMP Tools and PF-Related SNMP MIBs

Simple Network Management Protocol (SNMP) was designed to let network administrators collect and monitor key data about how their systems run and change configurations on multiple network nodes from a centralized system.[5] The SNMP protocol comes with a well-defined interface and a method for extending the *management information base (MIB)*, which defines the managed devices and objects.

5. The protocol debuted with RFC 1067 in August 1988 and is now in its third major version as defined in RFCs 3411 through 3418.

Both proprietary and open source network management and monitoring systems generally have SNMP support in one form or the other, and in some products, it's a core feature. On the BSDs, SNMP support has generally come in the form of the `net-snmp` package, which provides the tools you need to retrieve SNMP data and to collect data for retrieval by management systems. The package is available on OpenBSD as *net/net-snmp*, on FreeBSD as *net-mgmt/net-snmp*, and on NetBSD as *net/net-snmp*. OpenBSD's `snmpd` (written mainly by Reyk Floeter) debuted as part of the base system in OpenBSD 4.3 and implements all required SNMP functionality. (See `man snmpd` and `man snmpd.conf` for details.)

There are MIBs to make PF data available to SNMP monitoring. Joel Knight maintains the MIBs for retrieving data on PF, CARP, and OpenBSD kernel sensors, and he offers them for download from *http://www.packetmischief.ca/openbsd/snmp/*. The site also offers patches to the `net-snmp` package to integrate the OpenBSD MIBs.

After installing the package and the extension, your SNMP-capable monitoring systems will be able to watch PF data in any detail you desire. (FreeBSD's `bsnmpd` includes a PF module. See the `bsnmpd` man page for details.)

Log Data as the Basis for Effective Debugging

In this chapter, we walked through the basics of collecting, displaying, and interpreting data about a running system with PF enabled. Knowing how to find and use information about how your system behaves is useful for several purposes.

Keeping track of the status of a running system is useful in itself, but the ability to read and interpret log data is even more essential when testing your setup. Another prime use for log data is to track the effect of changes you make in the configuration, such as when tuning your system to give optimal performance. In the next chapter, we'll focus on checking your configuration and tuning it for optimal performance, based on log data and other observations.

10

GETTING YOUR SETUP JUST RIGHT

By now, you've spent significant time designing your network and implementing that design in your PF configuration. Getting your setup just right—that is, removing any remaining setup bugs and inefficiencies—can be quite challenging at times.

This chapter describes options and methods that will help you get the setup you need. First, we'll take a look at global options and settings that can have a profound influence on how your configuration behaves.

Things You Can Tweak and What You Probably Should Leave Alone

Network configurations are inherently very tweakable. While browsing the `pf.conf` man page or other reference documentation, it's easy to be overwhelmed by the number of options and settings that you could conceivably adjust in order to get that perfectly optimized setup.

Keep in mind that for PF in general, *the defaults* are sane for most setups. Some settings and variables lend themselves to tuning; others should come with a big warning that they should be adjusted only in highly unusual circumstances, if at all.

Here, we'll look at some of the global settings that you should know about, although you won't need to change them in most circumstances.

These options are written as `set option setting` and go *after* any macro definitions in your *pf.conf* file but *before* translation or filtering rules.

NOTE *If you read the `pf.conf` man page, you'll discover that a few other options are available. However, most of those aren't relevant in a network-testing and performance-tuning context.*

Block Policy

The `block-policy` option determines which feedback, if any, PF will give to hosts that try to create connections that are subsequently blocked. The option has two possible values:

- `drop` drops blocked packets with no feedback.
- `return` returns with status codes, such as `Connection refused` or similar.

The correct strategy for block policies has been the subject of considerable discussion over the years. The default setting for `block-policy` is `drop`, which means that the packet is silently dropped without any feedback. Silently dropping packets, however, makes it likely that the sender will resend the unacknowledged packets rather than drop the connection. Thus, the sender may keep up the effort until the relevant timeout counter expires. If you don't want this behavior to be the default in your setup, set the block policy to `return`:

```
set block-policy return
```

This setting means that the sender's networking stack will receive an unambiguous signal indicating that the connection was refused.

Whichever `block-policy` option you use will specify the *global* default for your block policy. If necessary, however, you can still vary the blocking type for specific rules. For example, you could change the brute-force protection rule set from Chapter 6 to set `block-policy` to `return` but also use `block drop quick from <bruteforce>` to make the brute forcers waste time if they stick around once they've been added to the `<bruteforce>` table. You could also specify `drop` for traffic from nonroutable addresses coming in

on your Internet-facing interface or other clearly nondesirable traffic, such as attempts to enlist your gear in amplifying a distributed denial-of-service (DDoS) attack.[1]

Skip Interfaces

The `skip` option lets you exclude specific interfaces from all PF processing. The net effect is like a `pass-all` rule for the interface, but it actually disables all PF processing on the interface. For example, you can use this option to disable filtering on the loopback interface group, where filtering in most configurations adds little in terms of security or convenience:

```
set skip on lo
```

In fact, filtering on the loopback interface is almost never useful, and it can lead to odd results with a number of common programs and services. The default is that `skip` is unset, which means that all configured interfaces can take part in PF processing. In addition to making your rule set slightly simpler, setting `skip` on interfaces where you don't want to perform filtering results in a slight performance gain.

State Policy

The `state-policy` option specifies how PF matches packets to the state table. It has two possible values:

- With the default `floating` state policy, traffic can match state on all interfaces, not just the one where the state was created.
- With an `if-bound` policy, traffic will match only on the interface where the state is created; traffic on other interfaces will not match the existing state.

Like the `block-policy` option, this option specifies the global state-matching policy, but you can override the state-matching policy on a per-rule basis if needed. For example, in a rule set with the default `floating` policy, you could have a rule like this:

```
pass out on egress inet proto tcp to any port $allowed modulate state (if-bound)
```

With this rule, any return traffic trying to pass back in would need to pass on the same interface where the state was created in order to match the state-table entry.

1. If you've yet to be hit by this particular kind of nastiness, you will be. Here's a writeup about a DDOS situation where the hamfistedness was about equally distributed between both sides—the attacker and the attacked: *http://bsdly.blogspot.com/2012/12/ddos-bots-are-people-or-manned-by-some.html*. Your attackers will likely be smarter and better equipped than these.

The situations in which an `if-bound` policy is useful are rare enough that you should leave this setting at the default.

State Defaults

Introduced in OpenBSD 4.5, the `state-defaults` option enables you to set specific state options as the default options for all rules in the rule set—unless those state options are specifically overridden by other options in individual rules.

Here's a common example:

```
set state-defaults pflow
```

This option sets up all `pass` rules in the configuration to generate NetFlow data to be exported via a `pflow` device.

In some contexts, it makes sense to apply state-tracking options, such as connection limits, as a global state default for the entire rule set. Here's an example:

```
set state-defaults max 1500, max-src-conn 100, source-track rule
```

This option sets the default maximum number of state entries per rule to 1,500, with a maximum of 100 simultaneous connections from any one host and with separate limits for each rule in the loaded rule set.

Any option that's valid inside parentheses for `keep state` in an individual rule can also be included in a `set state-defaults` statement. Setting state defaults in this way is useful if there are state options that aren't already system defaults that you want to apply to all rules in your configuration.

Timeouts

The `timeout` option sets the timeouts and related options for various interactions with the state-table entries. The majority of the available parameters are protocol-specific values stored in seconds and prefixed `tcp.`, `udp.`, `icmp.`, and `other.`. However, `adaptive.start` and `adaptive.end` denote the number of state-table entries.

The following `timeout` options affect state-table memory use and, to some extent, lookup speed:

- The `adaptive.start` and `adaptive.end` values set the limits for scaling down timeout values once the number of state entries reaches the `adaptive.start` value. When the number of states reaches `adaptive.end`, all timeouts are set to 0, essentially expiring all states immediately. The defaults are 6,000 and 12,000 (calculated as 60 percent and 120 percent of the state limit, respectively). These settings are intimately related to the memory-pool limit parameters you set via the `limit` option.
- The `interval` value denotes the number of seconds between purges of expired states and fragments. The default is 10 seconds.

- The `frag` value denotes the number of seconds a fragment will be kept in an unassembled state before it's discarded. The default is 30 seconds.
- When set, `src.track` denotes the number of seconds source-tracking data will be kept after the last state has expired. The default is 0 seconds.

You can inspect the current settings for all `timeout` parameters with `pfctl -s timeouts`. For example, the following display shows a system running with default values:

```
$ sudo pfctl -s timeouts
tcp.first                  120s
tcp.opening                 30s
tcp.established          86400s
tcp.closing                900s
tcp.finwait                 45s
tcp.closed                  90s
tcp.tsdiff                  30s
udp.first                   60s
udp.single                  30s
udp.multiple                60s
icmp.first                  20s
icmp.error                  10s
other.first                 60s
other.single                30s
other.multiple              60s
frag                        30s
interval                    10s
adaptive.start            6000 states
adaptive.end             12000 states
src.track                    0s
```

These options can be used to tweak your setup for performance. However, changing the protocol-specific settings from the default values creates a significant risk that valid but idle connections might be dropped prematurely or blocked outright.

Limits

The `limit` option sets the size of the memory pools PF uses for state tables and address tables. These are hard limits, so you may need to increase or tune the values for various reasons. If your network is a busy one with larger numbers than the default values allow for, or if your setup requires large address tables or a large number of tables, then this section will be very relevant to you.

Keep in mind that the total amount of memory available through memory pools is taken from the *kernel memory space*, and the total available is a function of total available kernel memory. Kernel memory is to some extent dynamic, but the amount of memory allocated to the kernel can never equal or exceed all physical memory in the system. (If that happened, there would be no space for user-mode programs to run.)

The amount of available pool memory depends on which hardware platform you use as well as on a number of hard-to-predict variables specific to the local system. On the i386 architecture, the maximum kernel memory is in the 768MB to 1GB range, depending on a number of factors, including the number and kind of hardware devices in the system. The amount actually available for allocation to memory pools comes out of this total, again depending on a number of system-specific variables.

To inspect the current `limit` settings, use `pfctl -sm`. Typical output looks like this:

```
$ sudo pfctl -sm
states        hard limit    10000
src-nodes     hard limit    10000
frags         hard limit     5000
tables        hard limit     1000
table-entries hard limit   200000
```

To change these values, edit *pf.conf* to include one or more lines with new `limit` values. For example, you could use the following lines to raise the hard limit for the number of states to 25,000 and for the number of table entries to 300,000:

```
set limit states 25000
set limit table-entries 300000
```

You can also set several `limit` parameters at the same time in a single line by enclosing them in brackets:

```
set limit { states 25000, src-nodes 25000, table-entries 300000 }
```

In the end, other than possibly increasing these three parameters for larger installations, you almost certainly shouldn't change the limits at all. If you do, however, it's important to watch your system logs for any indication that your changed limits have undesirable side effects or don't fit in available memory. Setting the `debug` level to a higher value is potentially quite useful for watching the effects of tuning `limit` parameters.

Debug

The `debug` option determines what, if any, error information PF will generate at the *kern.debug* log level. The default value is `err`, which means that only serious errors will be logged. Since OpenBSD 4.7, the log levels here correspond to the ordinary `syslog` levels, which range from `emerg` (panics are logged), `alert` (correctable but very serious errors are logged), `crit` (critical conditions are logged), and `err` (errors are logged) to `warning` (warnings are logged), `notice` (unusual conditions are logged), `info` (informational messages are logged), and `debug` (full debugging information, likely only useful to developers, is logged).

NOTE *In pre–OpenBSD 4.7 versions, PF used its own log-level system, with a default of* `urgent` *(equivalent to* `err` *in the new system). The other possible settings were* `none` *(no messages),* `misc` *(reporting slightly more than* `urgent`*), and* `loud` *(producing status messages for most operations). The* `pfctl` *parser still accepts the older-style debug levels for compatibility.*

After one of my gateways ran at the `debug` level for a while, this is what a typical chunk of the */var/log/messages* file looked like:

```
$ tail -f /var/log/messages
Oct  4 11:41:11 skapet /bsd: pf_map_addr: selected address 194.54.107.19
Oct  4 11:41:15 skapet /bsd: pf: loose state match: TCP 194.54.107.19:25
194.54.107.19:25 158.36.191.135:62458 [lo=3178647045 high=3178664421 win=33304
modulator=0 wscale=1] [lo=3111401744 high=3111468309 win=17376 modulator=0
wscale=0] 9:9 R seq=3178647045 (3178647044) ack=3111401744 len=0 ackskew=0
pkts=9:12
Oct  4 11:41:15 skapet /bsd: pf: loose state match: TCP 194.54.107.19:25
194.54.107.19:25 158.36.191.135:62458 [lo=3178647045 high=3178664421 win=33304
modulator=0 wscale=1] [lo=3111401744 high=3111468309 win=17376 modulator=0
wscale=0] 10:10 R seq=3178647045 (3178647044) ack=3111401744 len=0 ackskew=0
pkts=10:12
Oct  4 11:42:24 skapet /bsd: pf_map_addr: selected address 194.54.107.19
```

At the `debug` level, PF repeatedly reports the IP address for the interface it's currently handling. In between the selected address messages, PF warns twice for the same packet that the sequence number is at the very edge of the expected range. This level of detail seems a bit overwhelming at first glance, but in some circumstances, studying this kind of output is the best way to diagnose a problem and later to check to see whether your solution helped.

NOTE *This option can be set from the command line with* `pfctl -x`*, followed by the debug level you want. The command* `pfctl -x debug` *gives you maximum debugging information;* `pfctl -x none` *turns off debug messages entirely.*

Keep in mind that some `debug` settings can produce large amounts of log data and, in extreme cases, could impact performance all the way to self-denial-of-service level.

Rule Set Optimization

The `ruleset-optimization` option enables or sets the mode for the rule set optimizer. The default setting for `ruleset-optimization` in OpenBSD 4.1 and equivalents is `none`, which means that no rule set optimization is performed at load time. From OpenBSD 4.2 onward, the default is `basic`, which means that when the rule set loads, the optimizer performs the following actions:

- Removes duplicate rules
- Removes rules that are subsets of other rules

- Merges rules into tables if appropriate (typical rule-to-table optimizations are rules that pass, redirect, or block based on identical criteria, except source and/or target addresses)
- Changes the order of rules to improve performance

For example, say you have the macro `tcp_services = { ssh, www, https }` combined with the rule `pass proto tcp from any to self port $tcp_services`. Elsewhere in your rule set, you have a different rule that says `pass proto tcp from any to self port ssh`. The second rule is clearly a subset of the first, and they can be merged into one. Another common combination is having a `pass` rule like `pass proto tcp from any to int_if:network port $tcp_services` with otherwise identical `pass` rules, where the target addresses are all in the `int_if:network` range.

With `ruleset-optimization` set to `profile`, the optimizer analyzes the loaded rule set relative to network traffic in order to determine the optimal order of `quick` rules.

You can also set the value of the optimization option from the command line with `pfctl`:

```
$ sudo pfctl -o basic
```

This example enables the rule set optimization in `basic` mode.

Because the optimization may remove or reorder rules, the meaning of some statistics—mainly the number of evaluations per rule—may change in ways that are hard to predict. In most cases, however, the effect is negligible.

Optimization

The `optimization` option specifies profiles for state-timeout handling. The possible values are `normal`, `high-latency`, `satellite`, `aggressive`, and `conservative`. The recommendation is to keep the default `normal` setting unless you have very specific needs.

The values `high-latency` and `satellite` are synonyms; with these values, states expire more slowly in order to compensate for potential high latency.

The `aggressive` setting expires states early in order to save memory. This could, in principle, increase the risk of dropping idle-but-valid connections if your system is already close to its load and traffic limits, but anecdotal evidence indicates that the `aggressive` optimization setting rarely, if ever, interferes with valid traffic.

The `conservative` setting goes to great lengths to preserve states and idle connections, at the cost of some additional memory use.

Fragment Reassembly

The fragment reassembly options tied to `scrub` were significantly reworked in OpenBSD 4.6, which introduced the new `set reassemble` option to turn reassembly of fragmented packets on or off. If `reassemble` is set to `off`, fragmented packets are simply dropped unless they match a rule with the

fragment option. The default is set reassemble on, which means that fragments are reassembled and that reassembled packets in which the do-not-fragment bit was set on individual fragments will have the bit cleared.

Cleaning Up Your Traffic

The next two features we'll discuss, scrub and antispoof, share a common theme: They provide automated protection against potentially dangerous clutter in your network traffic. Together, they're commonly referred to as tools for "network hygiene" because they sanitize your networking considerably.

Packet Normalization with scrub: OpenBSD 4.5 and Earlier

In PF versions up to and including OpenBSD 4.5, the scrub keyword enables network traffic normalization. With scrub, fragmented packets are reassembled, and invalid fragments—such as overlapping fragments—are discarded, so the resulting packet is complete and unambiguous.

Enabling scrub provides a measure of protection against certain kinds of attacks based on incorrect handling of packet fragments.[2] A number of supplementing options are available, but the simplest form is suitable for most configurations:

```
scrub in
```

In order for certain services to work with scrub, specific options must be set. For example, some NFS implementations won't work with scrub at all unless you use the no-df parameter to clear the do-not-fragment bit on any packets that have the bit set. Certain combinations of services, operating systems, and network configurations may require some of the more exotic scrub options.

Packet Normalization with scrub: OpenBSD 4.6 Onward

In OpenBSD 4.6, scrub was demoted from stand-alone rule material to become an action you could attach to pass or match rules (the introduction of match rules being one of the main new PF features in OpenBSD 4.6). One other important development in the same rewrite of the scrub code was that the numerous packet-reassembly options were eliminated in favor of the new reassemble option, which simply turns reassembly on or off.

With the new scrub syntax, you need to supply at least one option in parentheses. The following works quite well for several networks in my care:

```
match in all scrub (no-df max-mss 1440)
```

2. Some notable attack techniques, including several historical denial-of-service setups, have exploited bugs in fragment handling that could lead to out-of-memory conditions or other resource exhaustion. One such exploit, which was aimed at Cisco's PIX firewall series, is described in the advisory at *http://www.cisco.com/en/US/products/products_security_advisory09186a008011e78d.shtml*.

This option clears the do-not-fragment bit and sets the maximum segment size to 1,440 bytes.

Other variations are possible, and even though the list of `scrub` options shrank somewhat for the OpenBSD 4.6 version, you should be able to cater to specific needs by consulting the man pages and doing some experimentation. For most setups, a global match rule like the one quoted earlier is appropriate, but keep in mind that you can vary `scrub` options on a per-rule basis if needed.

If you find yourself needing to debug a `scrub`-related problem, study the `pf.conf` man page and consult the gurus on the relevant mailing lists.

Protecting Against Spoofing with antispoof

Some very useful and common packet-handling actions could be written as PF rules, but not without becoming long, complicated, and error-prone rule set boilerplate. Thus, `antispoof` was implemented for a common special case of filtering and blocking. This mechanism protects against activity from spoofed or forged IP addresses, mainly by blocking packets that appear on interfaces traveling in directions that aren't logically possible.

With `antispoof`, you can specify that you want to weed out spoofed traffic coming in from the rest of the world as well as any spoofed packets that might originate in your own network. Figure 10-1 illustrates the concept.

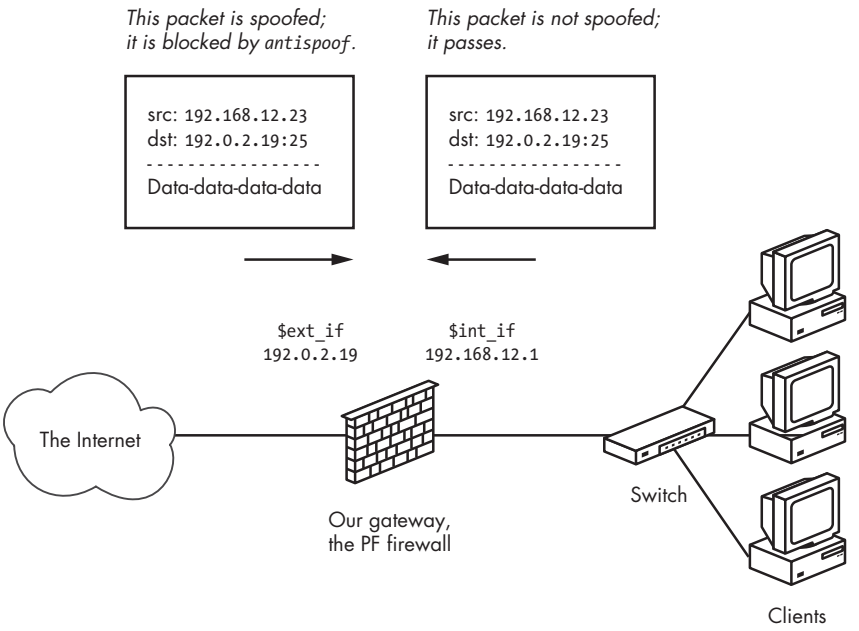

Figure 10-1: `antispoof` drops packets that come in from the wrong network.

To establish the kind of protection depicted in the diagram, specify `antispoof` for both interfaces in the illustrated network with these two lines:

```
antispoof for $ext_if
antispoof for $int_if
```

These lines expand to complex rules. The first one blocks incoming traffic when the source address appears to be part of the network directly connected to the antispoofed interface but arrives on a different interface. The second rule performs the same functions for the internal interface, blocking any traffic with apparently local network addresses that arrive on interfaces other than `$int_if`. Keep in mind, however, that `antispoof` isn't designed to detect address spoofing for remote networks that aren't directly connected to the machine running PF.

Testing Your Setup

Now it's time to dust off the precise specification that describes how your setup *should* work.

The physical layout of our sample network is centered on a *gateway* connected to the Internet via `$ext_if`. Attached to the gateway via `$int_if` is a *local network* with workstations and possibly one or more servers for local use. Finally, we have a *DMZ* connected to `$dmz_if`, populated with servers offering services to the local network and the Internet. Figure 10-2 shows the logical layout of the network.

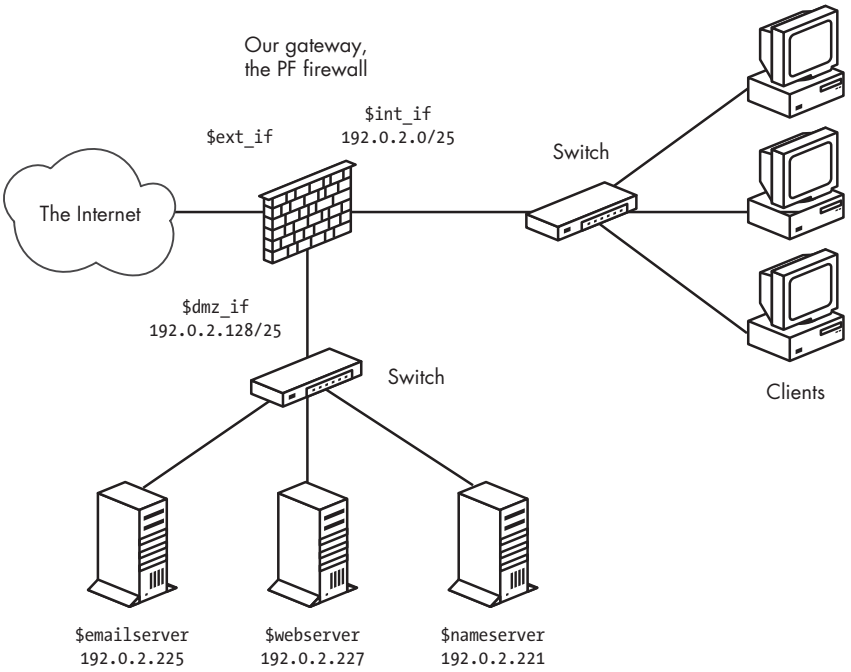

Figure 10-2: Network with servers in a DMZ

The corresponding rule set specification looks something like this:

- Machines outside our network should have access to the services offered by our servers in the DMZ and should not have access to the local network.
- The machines in our local network, attached to `$int_if`, should have access to the services offered by the servers in the DMZ and access to a defined list of services outside our network.
- The machines in the DMZ should have access to some network services in the outside world.

The task at hand is to make sure the rule set we have in place actually implements the specification. We need to test the setup. A useful test would be to try the sequence in Table 10-1.

Your configuration may call for other tests or could differ in some particulars, but your real-life test scenario should specify how packets and connections should be logged. The main point is that you should decide what the expected and desired result for each of your test cases should be before you start testing.

In general, you should test using the applications you expect the typical user to have, such as Web browsers or mail clients on various operating systems. The connections should simply succeed or fail, according to specifications. If one or more of your basic tests gives an unexpected result, move on to debugging your rule set.

Table 10-1: Sample Rule Set Test Case Sequence

Test Action	Expected Result
Try a connection from the local network to each allowed port on the servers in the DMZ.	The connection should pass.
Try a connection from the local network to each allowed port on servers outside your network.	The connection should pass.
Try a connection on any port from the DMZ to the local network.	The connection should be blocked.
Try a connection from the DMZ to each allowed port on servers outside your network.	The connection should pass.
Try a connection from outside your network to `$webserver` in the DMZ on each port in `$webports`.	The connection should pass.
Try a connection from outside your network to `$webserver` in the DMZ on port 25 (SMTP).	The connection should be blocked.
Try a connection from outside your network to `$emailserver` in the DMZ on port 80 (HTTP).	The connection should be blocked.
Try a connection from outside your network to `$emailserver` in the DMZ on port 25 (SMTP).	The connection should pass.
Try a connection from outside your network to one or more machines in the local network.	The connection should be blocked.

Debugging Your Rule Set

When your configuration doesn't behave as expected, there may be an error in the rule set logic, so you need to find the error and correct it. Tracking down logic errors in your rule set can be time-consuming and could involve manually evaluating your rule set—both as it's stored in the *pf.conf* file and as the loaded version after macro expansions and any optimizations.

Users often initially blame PF for issues that turn out to be basic network problems. Network interfaces set to wrong duplex settings, bad netmasks, and faulty network hardware are common culprits.

Before diving into the rule set itself, you can easily determine whether the PF configuration is causing the problem. To do so, disable PF with `pfctl -d` to see whether the problem disappears. If the problem persists when PF is disabled, you should turn to debugging other parts of your network configuration instead. If the problem disappears upon disabling PF and you're about to start adjusting your PF configuration, make sure that PF is enabled and that your rule set is loaded with this command:

```
$ sudo pfctl -si | grep Status
Status: Enabled for 20 days 06:28:24            Debug: err
```

`Status: Enabled` tells us that PF is enabled, so we try viewing the loaded rules with a different `pfctl` command:

```
$ sudo pfctl -sr
match in all scrub (no-df max-mss 1440)
block return log all
block return log quick from <bruteforce> to any
anchor "ftp-proxy/*" all
```

Here, `pfctl -sr` is equivalent to `pfctl -s rules`. The output is likely to be a bit longer than that shown here, but this is a good example of what you should expect to see when a rule set is loaded.

For debugging purposes, consider adding the `-vv` flag to the `pfctl` command line to see rule numbers and some additional debug information, like this:

```
$ sudo pfctl -vvsr
@0 match in all scrub (no-df max-mss 1440)
  [ Evaluations: 341770    Packets: 3417668   Bytes: 2112276585  States: 125   ]
  [ Inserted: uid 0 pid 14717 State Creations: 92254 ]
@1 match out on nfe0 inet from 10.0.0.0/8 to any queue(q_def, q_pri) nat-to
(nfe0:1) round-robin static-port
  [ Evaluations: 341770    Packets: 0         Bytes: 0           States: 0     ]
  [ Inserted: uid 0 pid 14717 State Creations: 0     ]
@2 match out on nfe0 inet from 192.168.103.0/24 to any queue(q_def, q_pri)
nat-to (nfe0:1) round-robin static-port
  [ Evaluations: 68623     Packets: 2138128   Bytes: 1431276138  States: 103   ]
  [ Inserted: uid 0 pid 14717 State Creations: 39109 ]
```

```
@3 block return log all
  [ Evaluations: 341770    Packets: 114929    Bytes: 62705138    States: 0     ]
  [ Inserted: uid 0 pid 14717 State Creations: 0     ]
@4 block return log (all) quick from <bruteforce:0> to any
  [ Evaluations: 341770    Packets: 2         Bytes: 104         States: 0     ]
  [ Inserted: uid 0 pid 14717 State Creations: 0     ]
@5 anchor "ftp-proxy/*" all
  [ Evaluations: 341768    Packets: 319954    Bytes: 263432399   States: 0     ]
  [ Inserted: uid 0 pid 14717 State Creations: 70    ]
```

Now you should perform a structured walk-through of the loaded rule set. Find the rules that match the packets you're investigating. What's the last matching rule? If more than one rule matches, is one of the matching rules a `quick` rule? (As you probably recall from earlier chapters, when a packet matches a `quick` rule, evaluation stops, and whatever the `quick` rule specifies is what happens to the packet.) If so, you'll need to trace the evaluation until you hit the end of the rule set or the packet matches a `quick` rule, which then ends the process. If your rule set walk-through ends somewhere other than the rule you were expecting to match your packet, you've found your logic error. Be sure to watch out for `match` rules. If you can't determine why a specific packet matched a particular `block` or `pass` rule, the reason could be that a `match` rule applied an action that made the packet or connection match filtering criteria other than the expected ones.

Rule set logic errors tend to fall into three types:

- Your rule doesn't match because it's never evaluated. A `quick` rule earlier in the rule set matched, and the evaluation stopped.
- Your rule is evaluated but doesn't match the packet after all, due to the rule's criteria.
- Your rule is evaluated and the rule matches, but the packet also matches another rule later in the rule set. The last matching rule is the one that determines what happens to your connection.

Chapter 9 introduced `tcpdump` as a valuable tool for reading and interpreting PF logs. The program is also very well suited for viewing the traffic that passes on a specific interface. What you learned about PF's logs and how to use `tcpdump`'s filtering features will come in handy when you want to track down exactly which packets reach which interface.

Here's an example of using `tcpdump` to watch for TCP traffic (but not SSH or SMTP traffic) on the `xl0` interface and to print the result in very verbose mode (`vvv`):

```
$ sudo tcpdump -nvvvpi xl0 tcp and not port ssh and not port smtp
tcpdump: listening on xl0, link-type EN10MB
21:41:42.395178 194.54.107.19.22418 > 137.217.190.41.80: S [tcp sum ok]
3304153886:3304153886(0) win 16384 <mss 1460,nop,nop,sackOK,nop,wscale
0,nop,nop,timestamp 1308370594 0> (DF) (ttl 63, id 30934, len 64)
21:41:42.424368 137.217.190.41.80 > 194.54.107.19.22418: S [tcp sum ok]
1753576798:1753576798(0) ack 3304153887 win 5792 <mss 1460,sackOK,timestamp
168899231 1308370594,nop,wscale 9> (DF) (ttl 53, id 0, len 60)
```

The connection shown here is a successful connection to a website.

There are more interesting things to look for, though, such as connections that fail when they shouldn't according to your specifications or connections that succeed when your specification says they clearly shouldn't.

The test in these cases involves tracking the packets' path through your configuration. Once more, it's useful to check whether PF is enabled or whether disabling PF makes a difference. Building on the result from that initial test, you then perform the same kind of analysis of the rule set as described previously:

- Once you have a reasonable theory of how the packets should traverse your rule set and your network interfaces, use `tcpdump` to see the traffic on each of the interfaces in turn.
- Use `tcpdump`'s filtering features to extract only the information you need—that is, to see only the packets that should match your specific case, such as `port smtp and dst 192.0.2.19`.
- Find the place where your assumptions no longer match the reality of your network traffic.
- Turn on logging for the rules that may be involved and turn `tcpdump` loose on the relevant `pflog` interface to see which rule the packets actually match.

The main outline for the test procedure is fairly fixed. If you've narrowed down the cause to your PF configuration, again, it's a case of finding out which rules match and which rule ends up determining whether the packet passes or is blocked.

Know Your Network and Stay in Control

The recurring theme in this book has been how PF and related tools make it relatively easy for you, as the network administrator, to take control of your network and to make it behave the way you want it to behave—in other words, how PF allows you to build the network you need.

Running a network can be fun, and I hope you've enjoyed this tour of what I consider to be the best tool available for network security. In presenting PF, I made a conscious decision early on to introduce you to the methods and ways of thinking via interesting and useful configurations, rather than offering a full catalog of available features or, for that matter, making this book the complete reference. The complete PF reference already exists in the man pages, which are updated every six months with the new OpenBSD releases. You can also find further information in the resources I've listed in Appendix A.

Now that you have a broad, basic knowledge of what PF can do, you can start building the network according to your own ideas of what you need. You've reached the point where you can find your way around the man pages and locate the exact information you need. This is when the fun part starts!

A

RESOURCES

Though I may have wanted to, it proved impossible to cover all possible wrinkles of PF configuration within these pages. I hope that the resources listed here fill in some details or present a slightly different perspective. Some of them are even quite enjoyable reads for their own sake.

General Networking and BSD Resources on the Internet

The following are the general web-accessible resources cited throughout the book. It's worth looking at the various BSD projects' websites for the most up-to-date information.

- Of particular interest for OpenBSD users is the online *OpenBSD Journal (http://undeadly.org/)*. It offers news and articles about OpenBSD and related issues.

- OpenBSD's website, *http://www.openbsd.org/*, is the main reference for OpenBSD information. If you're using OpenBSD, you'll be visiting this site every now and then.
- You'll find a collection of presentations and papers by OpenBSD developers at *http://www.openbsd.org/papers/*. This site is a good source of information about ongoing developments in OpenBSD.
- *OpenBSD's Frequently Asked Questions (http://www.openbsd.org/faq/index.html)* is more of a user guide than a traditional question-and-answer document. This is where you'll find a generous helping of background information and step-by-step instructions on how to set up and run your OpenBSD system.
- Henning Brauer's presentation "Faster Packets—Performance Tuning in the Network Stack and PF" *(http://quigon.bsws.de/papers/2009/eurobsdcon-faster_packets/)* is the current main PF developer's overview of the work done in recent OpenBSD releases to improve network performance, with PF as a main component.
- *PF: The OpenBSD Packet Filter (http://www.openbsd.org/faq/pf/index.html)*, also known as the *PF User Guide* or the *PF FAQ*, is the official PF documentation maintained by the OpenBSD team. This guide is updated for each release, and it's an extremely valuable reference resource for PF practitioners.
- Bob Beck's "pf. It's not just for firewalls anymore" *(http://www.ualberta.ca/~beck/nycbug06/pf/)* is an NYCBUG 2006 presentation that covers PF's redundancy and reliability features, illustrated by real-world examples taken from the University of Alberta network.
- Daniel Hartmeier's PF pages *(http://www.benzedrine.cx/pf.html)* are his collection of PF-related material with links to resources around the Web.
- Daniel Hartmeier's "Design and Performance of the OpenBSD Stateful Packet Filter (pf)" *(http://www.benzedrine.cx/pf-paper.html)* is the paper he presented at Usenix 2002. It describes the initial design and implementation of PF.
- Daniel Hartmeier's three-part *undeadly.org* PF series includes "PF: Firewall Ruleset Optimization" *(http://undeadly.org/cgi?action=article&sid=20060927091645)*, "PF: Testing Your Firewall *(http://undeadly.org/cgi?action=article&sid=20060928081238)*, and "PF: Firewall Management" *(http://undeadly.org/cgi?action=article&sid=20060929080943)*. The three articles cover their respective subjects in great detail yet manage to be quite readable.
- RFC 1631, The IP Network Address Translator (NAT), May 1994 (*http://www.ietf.org/rfc/rfc1631.txt*, written by K. Egevang and P. Francis) is the first part of the NAT specification, which has proved longer-lived than the authors had apparently intended. While still an important resource for understanding NAT, it has been largely superseded by the updated RFC 3022 (*http://www.ietf.org/rfc/rfc3022.txt*, written by P. Srisuresh and K. Egevang), dated January 2001.

- RFC 1918, Address Allocation for Private Internets, February 1996 (*http://www.ietf.org/rfc/rfc1918.txt*, written by Y. Rebhter, B. Moskowitz, D. Karrenberg, G.J. de Groot, and E. Lear) is the second part of the NAT and private address space puzzle. This RFC describes the motivations for the allocation of private, nonroutable address space and defines the address ranges. RFC 1918 has been designated a Best Current Practice.
- If you're looking for a text that gives you a thorough and detailed treatment of network protocols with a clear slant toward the TCP/IP worldview, Charles M. Kozierok's *The TCP/IP Guide* (No Starch Press, October 2005), available online with updates at *http://www.tcpipguide.com/*, has few, if any, serious rivals. At more than 1,600 pages, it's not exactly a pocket guide, but it's very useful to have on your desk or in a browser window to set the record straight on any networking terms that you find insufficiently explained in other texts.

Sample Configurations and Related Musings

A number of people have been kind enough to write up their experiences and make sample configurations available on the Web. The following are some of my favorites.

- Marcus Ranum's "The Six Dumbest Ideas in Computer Security" *(http://www.ranum.com/security/computer_security/editorials/dumb/index.html)*, from September 1, 2005, is a longtime favorite of mine. This article explores some common misconceptions about security and their unfortunate implications for real-world security efforts.
- Randal L. Schwartz's "Monitoring Net Traffic with OpenBSD's Packet Filter" *(http://www.stonehenge.com/merlyn/UnixReview/col51.html)* shows a real-life example of traffic monitoring and using labels for accounting. Some details about PF and labels have changed in the intervening years, but the article is still quite readable and presents several important concepts well.
- The Swedish user group Unix.se's *Brandvägg med OpenBSD (http://unix.se/Brandv%E4gg_med_OpenBSD)* and its sample configurations, such as the basic ALTQ configurations, were quite useful to me early on. The site serves as a nice reminder that volunteer efforts, such as local user groups, can be excellent sources of information.
- The *#pf* IRC channel wiki (*http://www.probsd.net/pf/*) is a collection of documentation, sample configurations, and other PF information maintained by participants in the *#pf* IRC channel discussions. It's another example of a very worthwhile volunteer effort.

- Daniele Mazzocchio, an OpenBSD fan from Italy, maintains the website Kernel Panic, which houses a collection of useful articles and tutorial-like documents on various OpenBSD topics at *http://www.kernel-panic.it/openbsd.html* (in English and Italian). It's well worth the visit for a fresh perspective on various interesting topics from someone who seems to be dedicated to keeping the material up-to-date with the latest stable OpenBSD versions.
- Kenjiro Cho's "Managing Traffic with ALTQ" *(http://www.usenix.org/publications/library/proceedings/usenix99/cho.html)* is the original paper that describes the ALTQ design and early implementation on FreeBSD.
- Jason Dixon's "Failover Firewalls with OpenBSD and CARP," from the May 2005 *SysAdmin Magazine (http://planet.admon.org/howto/failover-firewalls-with-openbsd-and-carp/)* is an overview of CARP and pfsync, with some practical examples.
- Theo de Raadt's OpenCON 2006 presentation "Open Documentation for Hardware: Why hardware documentation matters so much and why it is so hard to get" *(http://openbsd.org/papers/opencon06-docs/index.html)* was an important inspiration for the note in Appendix B about hardware for free operating systems in general and for OpenBSD in particular.

PF on Other BSD Systems

PF has been ported from OpenBSD to the other BSDs, and while the stated goal for these efforts naturally is to be as up-to-date as possible in relation to the newest PF versions coming out of OpenBSD, it's useful to keep track of the PF projects in the other BSDs.

- The FreeBSD packet filter (pf) home page *(http://pf4freebsd.love2party.net/)* describes the early work with PF on FreeBSD and the project goals. At the moment, the page isn't quite up-to-date with the latest developments, but it'll hopefully spring to life again once Max Laier notices that he's referenced in a printed book.
- The NetBSD project maintains its PF pages at *http://www.netbsd.org/docs/network/pf.html*, where you can find updated information about PF on NetBSD.

BSD and Networking Books

In addition to what appears to be an ever-expanding number of online resources, several books may be useful as companions or supplements to this book.

- Michael W. Lucas, *Absolute OpenBSD*, 2nd edition (No Starch Press, 2013). This volume offers a thorough walk-through of OpenBSD with a wealth of hands-on, practical material.

- Michael W. Lucas, *Network Flow Analysis* (No Starch Press, 2010). One of a select few books about network analysis and management using free NetFlow-based tools, this book shows you the tools and methods to discover just what really happens in your network.
- Brandon Palmer and Jose Nazario, *Secure Architectures with OpenBSD* (Addison-Wesley, 2004). This book provides an overview of OpenBSD's features with a marked slant toward building secure and reliable systems. The book references OpenBSD 3.4 as the then up-to-date version.
- Douglas R. Mauro and Kevin J. Schmidt, *Essential SNMP*, 2nd edition (O'Reilly Media, 2005). As the title says, this is an essential reference book about SNMP.
- Jeremy C. Reed (editor), *The OpenBSD PF Packet Filter Book* (Reed Media Services, 2006). The book, based on the *PF User Guide*, extends to cover PF on FreeBSD, NetBSD, and DragonFly BSD and includes some additional material on third-party tools that interoperate with PF.
- Christopher M. Buechler and Jim Pingle, *pfSense: The Definitive Guide* (Reed Media Services, 2009). At some 515 pages, this is a comprehensive guide to the FreeBSD- and PF-based firewall appliance distribution. A revised edition is planned for 2014 publication as of this writing.

Wireless Networking Resources

Kjell Jørgen Hole's Wi-Fi courseware *(http://www.nowires.org/)* is an excellent resource for understanding wireless networks. The courseware is mainly aimed at University of Bergen students who take Professor Hole's courses, but it's freely available and well worth reading.

spamd and Greylisting-Related Resources

If handling email is part of your life (or is likely to be in the future), you've probably enjoyed the descriptions of `spamd`, tarpitting, and greylisting in this book. If you want a little more background information than what you find in the relevant RFCs, the following documents and web resources provide it.

- Greylisting.org (*http://www.greylisting.org/*) has a useful collection of greylisting-related articles and other information about greylisting and SMTP in general.
- Evan Harris's "The Next Step in the Spam Control War: Greylisting" *(http://greylisting.org/articles/whitepaper.shtml)* is the original greylisting paper.
- Bob Beck's "OpenBSD spamd—greylisting and beyond" *(http://www.ualberta.ca/~beck/nycbug06/spamd/)* is an NYCBUG presentation that explains how `spamd` works, leading up to a description of `spamd`'s role in University of Alberta's infrastructure. (Note that much of the "future work" mentioned in the presentation has already been implemented.)

- "Effective spam and malware countermeasures" *(http://bsdly.blogspot.com/2014/02/effective-spam-and-malware.html)*, originally my BSDCan 2007 paper with some updates, includes a best-practice description of how to use greylisting, `spamd`, and various other free tools and OpenBSD to successfully fight spam and malware in your network.
- A promising new development is Peter Hessler's *BGP-spamd* project, which abuses the BGP routing protocol slightly to distribute `spamd` data between participating hosts. See the project's website at *http://bgp-spamd.net/* for further information.

Book-Related Web Resources

For news and updates about this book, check the book's home page at the No Starch Press website *(http://www.nostarch.com/pf3/)*. That page contains links to pages on my personal web space, where various updates and book-related resources will appear as they become available. I'll post book-related news and updates at *http://www.bsdly.net/bookofpf/*. Announcements relevant to the book are likely to turn up via my blog at *http://bsdly.blogspot.com/*, too.

I maintain the tutorial manuscript "Firewalling with OpenBSD's PF packet filter," which is the forerunner of this book. My policy is to make updates when appropriate, usually as I become aware of changes or features of PF and related software and while preparing for appearances at conferences. The tutorial manuscript is available under a BSD license and can be downloaded in several formats from my web space at *http://home.nuug.no/~peter/pf/*. Updated versions will appear at that URL more or less in the natural course of tinkering in between events.

Buy OpenBSD CDs and Donate!

If you've enjoyed this book or found it useful, please go to the OpenBSD.org ordering page at *http://www.openbsd.org/orders.html* to buy CD sets, or for that matter, go to the donations page at *http://www.openbsd.org/donations.html* to support further development work by the OpenBSD project via a monetary contribution.

If you're the kind of entity that's more comfortable with donating to a corporation, you can contact the OpenBSD foundation, a Canadian nonprofit corporation created in 2007 for that specific purpose. See the OpenBSD Foundation website at *http://www.openbsdfoundation.org/* for more information.

If you've found this book at a conference, there might even be an OpenBSD booth nearby where you can buy CDs, T-shirts, and other items.

Remember that even free software takes real work and real money to develop and maintain.

B

A NOTE ON HARDWARE SUPPORT

"How's the hardware support?" I tend to hear that a lot, and my answer is usually, "In my experience, OpenBSD and other free systems tend to just work."

But for some reason, there's a general perception that going with free software means that getting hardware components to work will be a serious struggle. In the past, there was some factual basis for this. I remember struggling to install FreeBSD 2.0.5 on the hardware I had available. I was able to boot off the installation CD, but the install never completed because my CD drive wasn't fully supported.

But that was back in June 1995, when PC CD drives usually came with an almost-but-not-quite IDE interface attached to a sound card, and cheap PCs didn't come with networking hardware of any kind built in. Configuring a machine for network use usually meant moving jumpers around on the network interface card or the motherboard or running some weird proprietary setup software—if you had the good luck to be on a system that had or could be fitted with an Ethernet interface.

Times have changed. Today, you can reasonably expect all important components in your system to work with OpenBSD. Sure, some caution and a bit of planning may be required for building the optimal setup, but that's not necessarily a bad thing.

Getting the Right Hardware

Getting the right hardware for your system is essentially a matter of checking that your system meets the needs of your project and network:

- Check the online hardware compatibility lists.
- Check the man pages, or use `apropos` *`keyword`* commands (where *`keyword`* is the type of device you're looking for).
- Search the archives of relevant mailing lists if you want more background information.
- Use your favorite web search engine to find useful information about how well a specific device works with your operating system.

In most cases, the hardware will work as expected. However, sometimes otherwise functional hardware may come with odd restrictions.

Quite a number of devices are designed to depend on firmware that must be loaded before the operating system can make use of the device. The motivation for this design choice is almost always to lower the cost of the device. When some manufacturers refuse to grant redistribution rights for the firmware, the decision becomes a problem because it means that operating systems like OpenBSD can't package the firmware with their releases.

Problems of this type have surfaced in connection with several types of hardware. In many cases, the manufacturers have been persuaded to change their minds and allow redistribution. However, this doesn't happen in all cases. One example is the Intel-based wireless networking hardware that's built into many popular laptop models. The hardware is supported in many operating systems, including OpenBSD via the `wpi` and `iwn` drivers. But even with those drivers in place, the hardware simply won't work unless the user has manually fetched and installed the required firmware files. Once the install has completed and some sort of Internet connectivity is available, OpenBSD users can run the command `fw_update` to fetch and install or upgrade firmware for components the system recognizes as needing firmware files.

NOTE *Where supported hardware is restricted, the OpenBSD man pages usually note that fact and may even include the email addresses of people who might be able to change the manufacturer's policy.*

It would take only a minor change in the manufacturer's licensing policy to make life easier for free software users everywhere and to boost sales. It's possible that most situations like these will be resolved by the time you read this. Be sure to check the latest information online—and be prepared to vote with your wallet if a particular company refuses to act sensibly.

If you shop online, keep the man pages available in another tab or window. If you go to a physical store, make sure to tell the clerks you'll be using a BSD. If you're not sure about the parts they're trying to sell you, ask to borrow a machine to browse the man pages and other documentation online. You might even ask for permission to boot a machine with the hardware you're interested in from a CD or USB stick and study the `dmesg` output. Telling shop staff up front about your project could make it easier to get a refund if the part doesn't work. And if the part does work, letting the vendor know is good advocacy. Your request could very well be the first time the seller has heard of your favorite operating system.

Issues Facing Hardware Support Developers

Systems such as OpenBSD and the other BSDs didn't spring fully formed from the forehead of a deity (although some will argue that the process was not that different). Rather, they're the result of years of effort by a number of smart and dedicated developers.

BSD developers are all highly qualified and extremely dedicated people who work tirelessly—the majority, in their spare time—to produce amazing results. However, they don't live in a bubble with access to everything they need. The hardware itself or adequate documentation to support it is often unavailable to them. Another common problem is that documentation is often provided only under a nondisclosure agreement (NDA), which limits how developers can use the information.[1]

Through *reverse engineering*, developers can write drivers to support hardware even without proper documentation, but the process is a complicated one that consists of educated guessing, coding, and testing until results begin to emerge. Reverse engineering takes a long time and—for reasons known only to lawmakers and lobbyists—it has legal consequences in several jurisdictions around the world.

The good news is that you can help the developers get the hardware and other material they need.

1. This is a frequent talk topic, too. For example, see Theo de Raadt's OpenCON 2006 presentation "Why hardware documentation matters so much and why it is so hard to get," available at *http://www.openbsd.org/papers/opencon06-docs/index.html*.

How to Help the Hardware Support Efforts

If you can contribute quality code, the BSD projects want to hear from you. If you're not a developer yourself, contributing code may not be an option. Here are several other ways you can contribute:

- *Buy your hardware from open source–friendly vendors.* When making decisions or recommendations regarding your organization's equipment purchases, tell suppliers that *open source friendliness* is a factor in your purchasing decision.
- *Let hardware vendors know what you think about their support (or lack thereof) for your favorite operating system.* Some hardware vendors have been quite helpful, supplying both sample units and programmer documentation. Others have been less forthcoming or downright hostile. Both kinds of vendors, and the ones in between, need encouragement. Write to them to tell them what you think they're doing right and what they can do to improve. If, for example, a vendor has refused to make programming documentation available or will make it available only under an NDA, a reasoned, well-formulated letter from a potential customer could make the difference.
- *Help test systems and check out the drivers for hardware you're interested in.* If a driver exists or is being developed, the developers are always interested in reports on how their code behaves on other people's equipment. Reports that the system is working fine are always appreciated, but bug reports with detailed descriptions of what goes wrong are even more essential to creating and maintaining a high-quality system.
- *Donate hardware or money.* The developers can always use hardware to develop on, and money certainly helps with day-to-day needs as well. If you can donate money or hardware, check out the project's donations page (*http://www.openbsd.org/donations.html* for OpenBSD) or items-needed page (*http://www.openbsd.org/want.html* for OpenBSD). Corporate entities or others that prefer to donate to OpenBSD via a Canadian nonprofit corporation may do so via the OpenBSD Foundation, whose website can be found at *http://www.openbsdfoundation.org/*. Donations to OpenBSD will most likely help PF development, but if you prefer to donate to FreeBSD, NetBSD, or DragonFly BSD instead, you can find information about how to do so at their websites.

Whatever your relationship with the BSDs and your hardware, I hope that this appendix has helped you to make intelligent decisions about what to buy and how to support the development of the BSDs. Your support will contribute to making more and better quality free software available for everyone.

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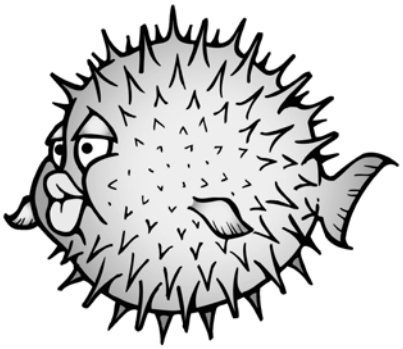

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The OpenBSD Foundation exists to support OpenBSD—the home of pf—and related projects. While the OpenBSD Foundation works in close cooperation with the developers of these wonderful free software projects, it is a separate entity.

If you use pf in a corporate environment, please point management to the URL below, and encourage them to contribute financially to the Foundation.

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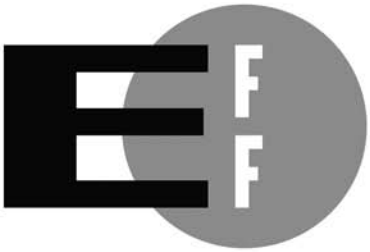

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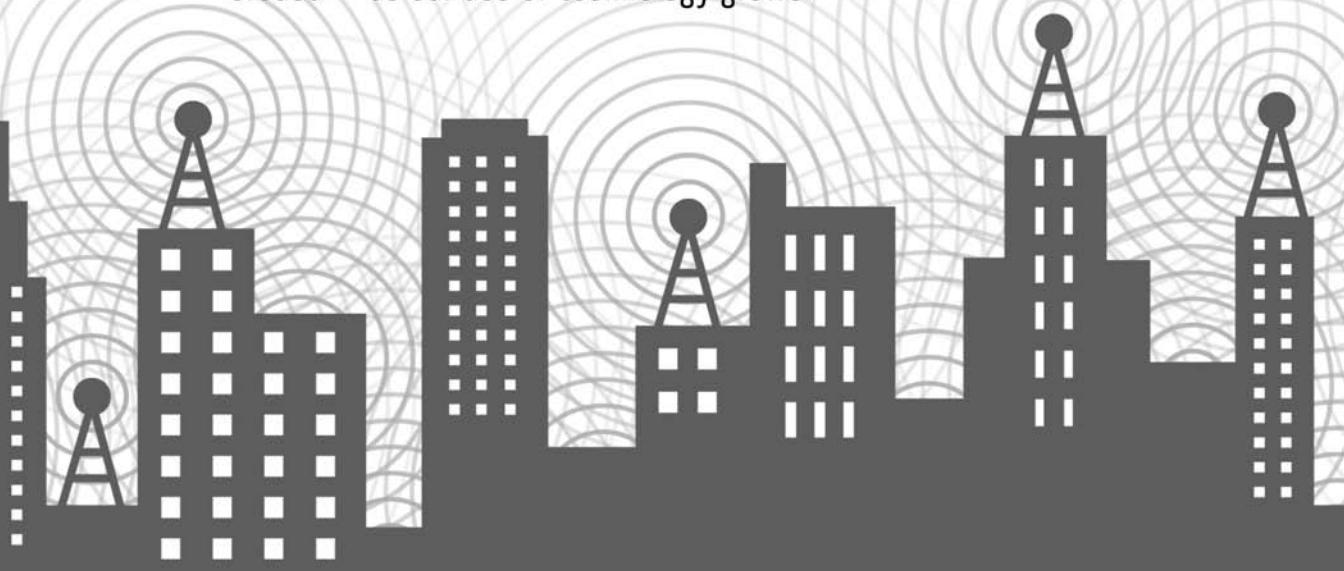

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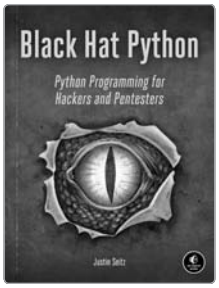

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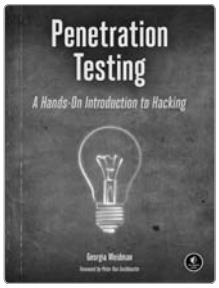

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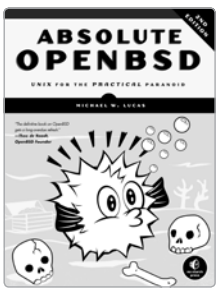

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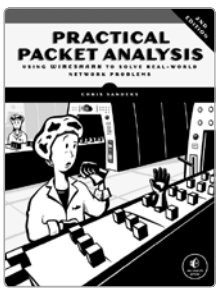

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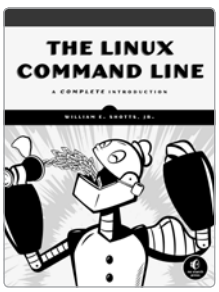

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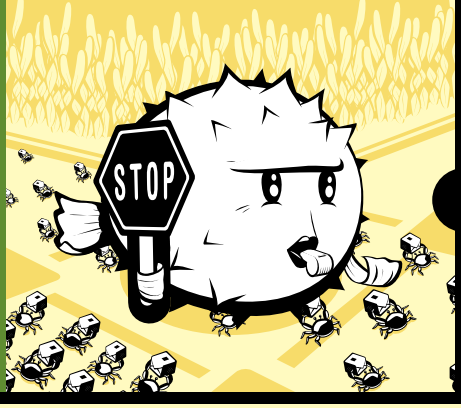

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ABOUT THE AUTHOR

Peter N.M. Hansteen is a consultant, writer, and sysadmin based in Bergen, Norway. A longtime Freenix advocate, Hansteen is a frequent lecturer on OpenBSD and FreeBSD topics, an occasional contributor to *BSD Magazine*, and the author of an often-slashdotted blog (*http://bsdly.blogspot.com/*). Hansteen was a participant in the original RFC 1149 implementation team. *The Book of PF* is an expanded follow-up to his very popular online PF tutorial (*http://home.nuug.no/~peter/pf/*).

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