Linux 2.4 Advanced Routing HOWTO

Netherlabs BV (bert hubert <bert.hubert@netherlabs.nl>)

Gregory Maxwell <greg@linuxpower.cx>

Remco van Mook <remco@virtu.nl>

Martijn van Oosterhout <kleptog@cupid.suninternet.com>

Paul B Schroeder <paulsch@us.ibm.com>

Jasper Spaans <jasper@spaans.ds9a.nl>

howto@ds9a.nl

A very hands-on approach to iproute2, traffic shaping and a bit of netfilter

Contents

1 Dedication

This document is dedicated to lots of people, and is my attempt to do something back. To list but a few:

- Rusty Russell

- Alexey N. Kuznetsov

- The good folks from Google

- The staff of Casema Internet

2 Introduction

Welcome, gentle reader.

This document hopes to enlighten you on how to do more with Linux 2.2/2.4 routing. Unbeknownst to most users, you already run tools which allow you to do spectacular things. Commands like 'route' and 'ifconfig' are actually very thin wrappers for the very powerful iproute2 infrastructure

I hope that this HOWTO will become as readable as the ones by Rusty Russell of (amongst other things) netfilter fame.

You can always reach us by writing the *HOWTO team* `<mailto:HOWTO@ds9a.nl>`. However, please consider posting to the mailing list (see the relevant section) if you have questions which are not directly related to this HOWTO.

Before losing your way in this HOWTO, if all you want to do is simple traffic shaping, skip everything and head to the 'Other possibilties' chapter, and read about CBQ.init.

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It is also requested that if you publish this HOWTO in hardcopy that you send the authors some samples for 'review purposes' :-)

2.2 Prior knowledge

As the title implies, this is the 'Advanced' HOWTO. While by no means rocket science, some prior knowledge is assumed.

Here are some orther references which might help learn you more:

Rusty Russell's networking-concepts-HOWTO `<http://netfilter.samba.org/unreliable-guides/networking-c`

Very nice introduction, explaining what a network is, and how it is connected to other networks

Linux Networking-HOWTO (Previously the Net-3 HOWTO)

Great stuff, although very verbose. It learns you a lot of stuff that's already configured if you are able to connect to the internet. Should be located in `/usr/doc/HOWTO/NET3-4-HOWTO.txt` but can be also be found *online* `<http://www.linuxports.com/howto/networking>`

2.3 What Linux can do for you

A small list of things that are possible:

- Throttle bandwidth for certain computers

- Throttle bandwidth TO certain computers

- Help you to fairly share your bandwidth

- Protect your network from DoS attacks

- Protect the internet from your customers

- Multiplex several servers as one, for load balancing or enhanced availability

- Restrict access to your computers

- Limit access of your users to other hosts

- Do routing based on user id (yes!), MAC address, source IP address, port, type of service, time of day or content

Currently not many people are using these advanced features. This has several reasons. While the provided documentation is verbose, it is not very hands on. Traffic control is almost undocumented.

2.4 Housekeeping notes

There are several things which should be noted about this document. While I wrote most of it, I really don't want it to stay that way. I am a strong believer in Open Source, so I encourage you to send feedback, updates, patches etcetera. Do not hesitate to inform me of typos or plain old errors. If my English sounds somewhat wooden, please realise that I'm not a native speaker. Feel free to send suggestions.

If you feel to you are better qualified to maintain a section, or think that you can author and maintain new sections, you are welcome to do so. The SGML of this HOWTO is available via CVS, I very much envision more people working on it.

In aid of this, you will find lots of FIXME notices. Patches are always welcome! Wherever you find a FIXME, you should know that you are treading unknown territory. This is not to say that there are no errors elsewhere, but be extra careful. If you have validated something, please let us know so we can remove the FIXME notice.

About this HOWTO, I will take some liberties along the road. For example, I postulate a 10Mbit internet connection, while I know full well that those are not very common.

2.5 Access, CVS & submitting updates

The canonical location for the HOWTO is *here* <http://www.ds9a.nl/2.4Routing>.

We now have anonymous CVS access available for the world at large. This is good in several ways. You can easily upgrade to newer versions of this HOWTO and submitting patches is no work at all.

Furthermore, it allows the authors to work on the source independently, which is good too.

```
$ export CVSROOT=:pserver:anon@outpost.ds9a.nl:/var/cvsroot
$ cvs login
CVS password: [enter 'cvs' (without 's)]
$ cvs co 2.4routing
cvs server: Updating 2.4routing
U 2.4routing/2.4routing.sgml
```

If you spot an error, or want to add something, just fix it locally, and run cvs diff -u, and send the result off to us.

A Makefile is supplied which should help you create postscript, dvi, pdf, html and plain text. You may need to install sgml-tools, ghostscript and tetex to get all formats.

2.6   Mailing list

The authors receive an increasing amount of mail about this HOWTO. Because of the clear interest of the community, it has been decided to start a mailinglist where people can talk to each other about Advanced Routing and Traffic Control. You can subscribe to the list *here* `<http://mailman.ds9a.nl/mailman/listinfo/lartc>`.

It should be pointed out that the authors are very hesitant of answering questions asked not on the list. We would like the archive of the list to become some kind of knowledge base. If you have a question, please search the archive, and then post to the mailinglist.

2.7   Layout of this document

We will be doing interesting stuff almost immediately, which also means that there will initially be parts that are explained incompletely or are not perfect. Please gloss over these parts and assume that all will become clear.

Routing and filtering are two distinct things. Filtering is documented very well by Rusty's HOWTOs, available here:

- *Rusty's Remarkably Unreliable Guides* `<http://netfilter.samba.org/unreliable-guides/>`

We will be focusing mostly on what is possible by combining netfilter and iproute2.

3   Introduction to iproute2

3.1   Why iproute2?

Most Linux distributions, and most UNIX's, currently use the venerable 'arp', 'ifconfig' and 'route' commands. While these tools work, they show some unexpected behaviour under Linux 2.2 and up. For example, GRE tunnels are an integral part of routing these days, but require completely different tools.

With iproute2, tunnels are an integral part of the tool set.

The 2.2 and above Linux kernels include a completely redesigned network subsystem. This new networking code brings Linux performance and a feature set with little competition in the general OS arena. In fact, the

new routing, filtering, and classifying code is more featureful then that provided by many dedicated routers and firewalls and traffic shaping products.

As new networking concepts have been invented, people have found ways to plaster them on top of the existing framework in existing OSes. This constant layering of cruft has lead to networking code that is filled with strange behaviour, much like most human languages. In the past, Linux emulated SunOS's handling of many of these things, which was not ideal.

This new framework makes it possible to clearly express features previously beyond Linux's reach.

3.2 iproute2 tour

Linux has a sophisticated system for bandwidth provisioning called Traffic Control. This system supports various method for classifying, prioritizing, sharing, and limiting both inbound and outbound traffic.

We'll start off with a tiny tour of iproute2 possibilities.

3.3 Prerequisites

You should make sure that you have the userland tools installed. This package is called 'iproute' on both RedHat and Debian, and may otherwise be found at `ftp://ftp.inr.ac.ru/ip-routing/iproute2-2.2.4-now-ss??????.tar.gz"`.

You can also try *here* `<ftp://ftp.inr.ac.ru/ip-routing/iproute2-current.tar.gz>` for the latest version.

Some parts of iproute require you to have certain kernel options enabled. It should also be noted that all releases of RedHat up to and including 6.2 come without most of the traffic control features in the default kernel.

FIXME: can anybody confirm that 7.0 does have the necessary stuff compiled in?

Also make sure that you have netlink support, should you chose to roll your own kernel. Iproute2 needs it.

3.4 Exploring your current configuration

This may come as a surprise, but iproute2 is already configured! The current commands `ifconfig` and `route` are already using the advanced syscalls, but mostly with very default (ie. boring) settings.

The `ip` tool is central, and we'll ask it do display our interfaces for us.

3.4.1 ip shows us our links

```
[ahu@home ahu]$ ip link list
1: lo: <LOOPBACK,UP> mtu 3924 qdisc noqueue
    link/loopback 00:00:00:00:00:00 brd 00:00:00:00:00:00
2: dummy: <BROADCAST,NOARP> mtu 1500 qdisc noop
    link/ether 00:00:00:00:00:00 brd ff:ff:ff:ff:ff:ff
3: eth0: <BROADCAST,MULTICAST,PROMISC,UP> mtu 1400 qdisc pfifo_fast qlen 100
    link/ether 48:54:e8:2a:47:16 brd ff:ff:ff:ff:ff:ff
4: eth1: <BROADCAST,MULTICAST,PROMISC,UP> mtu 1500 qdisc pfifo_fast qlen 100
```

```
        link/ether 00:e0:4c:39:24:78 brd ff:ff:ff:ff:ff:ff
   3764: ppp0: <POINTOPOINT,MULTICAST,NOARP,UP> mtu 1492 qdisc pfifo_fast qlen 10
        link/ppp
```

Your mileage may vary, but this is what it shows on my NAT router at home. I'll only explain part of the output as not everything is directly relevant.

We first see the loopback interface. While your computer may function somewhat without one, I'd advise against it. The MTU size (Maximum Transfer Unit) is 3924 octets, and it is not supposed to queue. Which makes sense because the loopback interface is a figment of your kernel's imagination.

I'll skip the dummy interface for now, and it may not be present on your computer. Then there are my two physical network interfaces, one at the side of my cable modem, the other serves my home ethernet segment. Furthermore, we see a ppp0 interface.

Note the absence of IP addresses. iproute disconnects the concept of 'links' and 'IP addresses'. With IP aliasing, the concept of 'the' IP address had become quite irrelevant anyhow.

It does show us the MAC addresses though, the hardware identifier of our ethernet interfaces.

3.4.2 `ip` shows us our IP addresses

```
   [ahu@home ahu]$ ip address show
   1: lo: <LOOPBACK,UP> mtu 3924 qdisc noqueue
        link/loopback 00:00:00:00:00:00 brd 00:00:00:00:00:00
        inet 127.0.0.1/8 brd 127.255.255.255 scope host lo
   2: dummy: <BROADCAST,NOARP> mtu 1500 qdisc noop
        link/ether 00:00:00:00:00:00 brd ff:ff:ff:ff:ff:ff
   3: eth0: <BROADCAST,MULTICAST,PROMISC,UP> mtu 1400 qdisc pfifo_fast qlen 100
        link/ether 48:54:e8:2a:47:16 brd ff:ff:ff:ff:ff:ff
        inet 10.0.0.1/8 brd 10.255.255.255 scope global eth0
   4: eth1: <BROADCAST,MULTICAST,PROMISC,UP> mtu 1500 qdisc pfifo_fast qlen 100
        link/ether 00:e0:4c:39:24:78 brd ff:ff:ff:ff:ff:ff
   3764: ppp0: <POINTOPOINT,MULTICAST,NOARP,UP> mtu 1492 qdisc pfifo_fast qlen 10
        link/ppp
        inet 212.64.94.251 peer 212.64.94.1/32 scope global ppp0
```

This contains more information. It shows all our addresses, and to which cards they belong. 'inet' stands for Internet (IPv4). There are lots of other address families, but these don't concern us right now.

Let's examine eth0 somewhat closer. It says that it is related to the inet address '10.0.0.1/8'. What does this mean? The /8 stands for the number of bits that are in the Network Address. There are 32 bits, so we have 24 bits left that are part of our network. The first 8 bits of 10.0.0.1 correspond to 10.0.0.0, our Network Address, and our netmask is 255.0.0.0.

The other bits are connected to this interface, so 10.250.3.13 is directly available on eth0, as is 10.0.0.1 for example.

With ppp0, the same concept goes, though the numbers are different. Its address is 212.64.94.251, without a subnet mask. This means that we have a point-to-point connection and that every address, with the exception of 212.64.94.251, is remote. There is more information however, it tells us that on the other side of the link is yet again only one address, 212.64.94.1. The /32 tells us that there are no 'network bits'.

It is absolutely vital that you grasp these concepts. Refer to the documentation mentioned at the beginning of this HOWTO if you have trouble.

You may also note 'qdisc', which stands for Queueing Discipline. This will become vital later on.

3.4.3   `ip` **shows us our routes**

Well, we now know how to find 10.x.y.z addresses, and we are able to reach 212.64.94.1. This is not enough however, so we need instructions on how to reach the world. The internet is available via our ppp connection, and it appears that 212.64.94.1 is willing to spread our packets around the world, and deliver results back to us.

```
[ahu@home ahu]$ ip route show
212.64.94.1 dev ppp0  proto kernel  scope link  src 212.64.94.251
10.0.0.0/8 dev eth0  proto kernel  scope link  src 10.0.0.1
127.0.0.0/8 dev lo  scope link
default via 212.64.94.1 dev ppp0
```

This is pretty much self explanatory. The first 4 lines of output explicitly state what was already implied by `ip address show`, the last line tells us that the rest of the world can be found via 212.64.94.1, our default gateway. We can see that it is a gateway because of the word via, which tells us that we need to send packets to 212.64.94.1, and that it will take care of things.

For reference, this is what the old 'route' utility shows us:

```
[ahu@home ahu]$ route -n
Kernel IP routing table
Destination     Gateway         Genmask         Flags Metric Ref    Use
Iface
212.64.94.1     0.0.0.0         255.255.255.255 UH    0      0        0 ppp0
10.0.0.0        0.0.0.0         255.0.0.0       U     0      0        0 eth0
127.0.0.0       0.0.0.0         255.0.0.0       U     0      0        0 lo
0.0.0.0         212.64.94.1     0.0.0.0         UG    0      0        0 ppp0
```

3.5   ARP

ARP is the Address Resolution Protocol as described in *RFC 826* <http://www.faqs.org/rfcs/rfc826.html>. ARP is used by a networked machine to resolve the hardware location/address of another machine on the same local network. Machines on the Internet are generally known by their names which resolve to IP addresses. This is how a machine on the foo.com network is able to communicate with another machine which is on the bar.net network. An IP address, though, cannot tell you the physical location of a machine. This is where ARP comes into the picture.

Let's take a very simple example. Suppose I have a network composed of several machines. Two of the machines which are currently on my network are foo with an IP address of 10.0.0.1 and bar with an IP address of 10.0.0.2. Now foo wants to ping bar to see that he is alive, but alas, foo has no idea where bar is. So when foo decides to ping bar he will need to send out an ARP request. This ARP request is akin to foo shouting out on the network "Bar (10.0.0.2)! Where are you?" As a result of this every machine on the network will hear foo shouting, but only bar (10.0.0.2) will respond. Bar will then send an ARP reply

directly back to foo which is akin bar saying, "Foo (10.0.0.1) I am here at 00:60:94:E9:08:12." After this simple transaction used to locate his friend on the network foo is able to communicate with bar until he (his arp cache) forgets where bar is.

Now let's see how this works. You can view your machines current arp/neighbor cache/table like so:

```
[root@espa041 /home/src/iputils]# ip neigh show
9.3.76.42 dev eth0 lladdr 00:60:08:3f:e9:f9 nud reachable
9.3.76.1 dev eth0 lladdr 00:06:29:21:73:c8 nud reachable
```

As you can see my machine espa041 (9.3.76.41) knows where to find espa042 (9.3.76.42) and espagate (9.3.76.1). Now let's add another machine to the arp cache.

```
[root@espa041 /home/paulsch/.gnome-desktop]# ping -c 1 espa043
PING espa043.austin.ibm.com (9.3.76.43) from 9.3.76.41 : 56(84) bytes of data.
64 bytes from 9.3.76.43: icmp_seq=0 ttl=255 time=0.9 ms

--- espa043.austin.ibm.com ping statistics ---
1 packets transmitted, 1 packets received, 0% packet loss
round-trip min/avg/max = 0.9/0.9/0.9 ms

[root@espa041 /home/src/iputils]# ip neigh show
9.3.76.43 dev eth0 lladdr 00:06:29:21:80:20 nud reachable
9.3.76.42 dev eth0 lladdr 00:60:08:3f:e9:f9 nud reachable
9.3.76.1 dev eth0 lladdr 00:06:29:21:73:c8 nud reachable
```

As a result of espa041 trying to contact espa043, espa043's hardware address/location has now been added to the arp/nieghbor cache. So until the entry for espa043 times out (as a result of no communication between the two) espa041 knows where to find espa043 and has no need to send an ARP request.

Now let's delete espa043 from our arp cache:

```
[root@espa041 /home/src/iputils]# ip neigh delete 9.3.76.43 dev eth0
[root@espa041 /home/src/iputils]# ip neigh show
9.3.76.43 dev eth0  nud failed
9.3.76.42 dev eth0 lladdr 00:60:08:3f:e9:f9 nud reachable
9.3.76.1 dev eth0 lladdr 00:06:29:21:73:c8 nud stale
```

Now espa041 has again forgotten where to find espa043 and will need to send another ARP request the next time he needs to communicate with espa043. You can also see from the above output that espagate (9.3.76.1) has been changed to the "stale" state. This means that the location shown is still valid, but it will have to be confirmed at the first transaction to that machine.

4 Rules - routing policy database

If you have a large router, you may well cater for the needs of different people, who should be served differently. The routing policy database allows you to do this by having multiple sets of routing tables.

If you want to use this feature, make sure that your kernel is compiled with the "IP: advanced router" and "IP: policy routing" features.

When the kernel needs to make a routing decision, it finds out which table needs to be consulted. By default, there are three tables. The old 'route' tool modifies the main and local tables, as does the ip tool (by default).

The default rules:

```
[ahu@home ahu]$ ip rule list
0:      from all lookup local
32766:  from all lookup main
32767:  from all lookup default
```

This lists the priority of all rules. We see that all rules apply to all packets ('from all'). We've seen the 'main' table before, it's output by `ip route ls`, but the 'local' and 'default' table are new.

If we want to do fancy things, we generate rules which point to different tables which allow us to override system wide routing rules.

For the exact semantics on what the kernel does when there are more matching rules, see Alexey's ip-cref documentation.

4.1   Simple source routing

Let's take a real example once again, I have 2 (actually 3, about time I returned them) cable modems, connected to a Linux NAT ('masquerading') router. People living here pay me to use the internet. Suppose one of my house mates only visits hotmail and wants to pay less. This is fine with me, but you'll end up using the low-end cable modem.

The 'fast' cable modem is known as 212.64.94.251 and is a PPP link to 212.64.94.1. The 'slow' cable modem is known by various ip addresses, 212.64.78.148 in this example and is a link to 195.96.98.253.

The local table:

```
[ahu@home ahu]$ ip route list table local
broadcast 127.255.255.255 dev lo  proto kernel  scope link  src 127.0.0.1
local 10.0.0.1 dev eth0  proto kernel  scope host  src 10.0.0.1
broadcast 10.0.0.0 dev eth0  proto kernel  scope link  src 10.0.0.1
local 212.64.94.251 dev ppp0  proto kernel  scope host  src 212.64.94.251
broadcast 10.255.255.255 dev eth0  proto kernel  scope link  src 10.0.0.1
broadcast 127.0.0.0 dev lo  proto kernel  scope link  src 127.0.0.1
local 212.64.78.148 dev ppp2  proto kernel  scope host  src 212.64.78.148
local 127.0.0.1 dev lo  proto kernel  scope host  src 127.0.0.1
local 127.0.0.0/8 dev lo  proto kernel  scope host  src 127.0.0.1
```

Lots of obvious things, but things that need to specified somewhere. Well, here they are. The default table is empty.

Let's view the 'main' table:

```
[ahu@home ahu]$ ip route list table main
195.96.98.253 dev ppp2  proto kernel  scope link  src 212.64.78.148
212.64.94.1 dev ppp0  proto kernel  scope link  src 212.64.94.251
10.0.0.0/8 dev eth0  proto kernel  scope link  src 10.0.0.1
127.0.0.0/8 dev lo  scope link
default via 212.64.94.1 dev ppp0
```

We now generate a new rule which we call 'John', for our hypothetical house mate. Although we can work with pure numbers, it's far easier if we add our tables to `/etc/iproute2/rt\_tables`.

```
# echo 200 John >> /etc/iproute2/rt_tables
# ip rule add from 10.0.0.10 table John
# ip rule ls
0:      from all lookup local
32765:  from 10.0.0.10 lookup John
32766:  from all lookup main
32767:  from all lookup default
```

Now all that is left is to generate Johns table, and flush the route cache:

```
# ip route add default via 195.96.98.253 dev ppp2 table John
# ip route flush cache
```

And we are done. It is left as an exercise for the reader to implement this in ip-up.

5   GRE and other tunnels

There are 3 kinds of tunnels in Linux. There's IP in IP tunneling, GRE tunneling and tunnels that live outside the kernel (like, for example PPTP).

5.1   A few general remarks about tunnels:

Tunnels can be used to do some very unusual and very cool stuff. They can also make things go horribly wrong when you don't configure them right. Don't point your default route to a tunnel device unless you know **exactly** what you are doing :-). Furthermore, tunneling increases overhead, because it needs an extra set of IP headers. Typically this is 20 bytes per packet, so if the normal packet size (MTU) on a network is 1500 bytes, a packet that is sent through a tunnel can only be 1480 bytes big. This is not necessarily a problem, but be sure to read up on IP packet fragmentation/reassembly when you plan to connect large networks with tunnels. Oh, and of course, the fastest way to dig a tunnel is to dig at both sides.

5.2   IP in IP tunneling

This kind of tunneling has been available in Linux for a long time. It requires 2 kernel modules, ipip.o and new_tunnel.o.

Let's say you have 3 networks: Internal networks A and B, and intermediate network C (or let's say, Internet). So we have network A:

```
network 10.0.1.0
netmask 255.255.255.0
router  10.0.1.1
```

The router has address 172.16.17.18 on network C.

and network B:

```
network 10.0.2.0
netmask 255.255.255.0
router  10.0.2.1
```

The router has address 172.19.20.21 on network C.

As far as network C is concerned, we assume that it will pass any packet sent from A to B and vice versa. You might even use the Internet for this.

Here's what you do:

First, make sure the modules are installed:

```
insmod ipip.o
insmod new_tunnel.o
```

Then, on the router of network A, you do the following:

```
ifconfig tunl0 10.0.1.1 pointopoint 172.19.20.21
route add -net 10.0.2.0 netmask 255.255.255.0 dev tunl0
```

And on the router of network B:

```
ifconfig tunl0 10.0.2.1 pointopoint 172.16.17.18
route add -net 10.0.1.0 netmask 255.255.255.0 dev tunl0
```

And if you're finished with your tunnel:

```
ifconfig tunl0 down
```

Presto, you're done. You can't forward broadcast or IPv6 traffic through an IP-in-IP tunnel, though. You just connect 2 IPv4 networks that normally wouldn't be able to talk to each other, that's all. As far as compatibility goes, this code has been around a long time, so it's compatible all the way back to 1.3 kernels. Linux IP-in-IP tunneling doesn't work with other Operating Systems or routers, as far as I know. It's simple, it works. Use it if you have to, otherwise use GRE.

5.3 GRE tunneling

GRE is a tunneling protocol that was originally developed by Cisco, and it can do a few more things than IP-in-IP tunneling. For example, you can also transport multicast traffic and IPv6 through a GRE tunnel.

In Linux, you'll need the ip_gre.o module.

5.3.1 IPv4 Tunneling

Let's do IPv4 tunneling first:

Let's say you have 3 networks: Internal networks A and B, and intermediate network C (or let's say, Internet).

So we have network A:

```
network 10.0.1.0
netmask 255.255.255.0
router  10.0.1.1
```

The router has address 172.16.17.18 on network C. Let's call this network neta (ok, hardly original)

and network B:

```
network 10.0.2.0
netmask 255.255.255.0
router  10.0.2.1
```

The router has address 172.19.20.21 on network C. Let's call this network netb (still not original)

As far as network C is concerned, we assume that it will pass any packet sent from A to B and vice versa. How and why, we do not care.

On the router of network A, you do the following:

```
ip tunnel add netb mode gre remote 172.19.20.21 local 172.16.17.18 ttl 255
ip link set netb up
ip addr add 10.0.1.1 dev netb
ip route add 10.0.2.0/24 dev netb
```

Let's discuss this for a bit. In line 1, we added a tunnel device, and called it netb (which is kind of obvious because that's where we want it to go). Furthermore we told it to use the GRE protocol (mode gre), that the remote address is 172.19.20.21 (the router at the other end), that our tunneling packets should originate from 172.16.17.18 (which allows your router to have several IP addresses on network C and let you decide which one to use for tunneling) and that the TTL field of the packet should be set to 255 (ttl 255).

The second line enables the device.

In the third line we gave the newly born interface netb the address 10.0.1.1. This is OK for smaller networks, but when you're starting up a mining expedition (LOTS of tunnels), you might want to consider using another IP range for tunneling interfaces (in this example, you could use 10.0.3.0).

In the fourth line we set the route for network B. Note the different notation for the netmask. If you're not familiar with this notation, here's how it works: you write out the netmask in binary form, and you count all the ones. If you don't know how to do that, just remember that 255.0.0.0 is /8, 255.255.0.0 is /16 and 255.255.255.0 is /24. Oh, and 255.255.254.0 is /23, in case you were wondering.

But enough about this, let's go on with the router of network B.

```
ip tunnel add neta mode gre remote 172.16.17.18 local 172.19.20.21 ttl 255
ip link set neta up
ip addr add 10.0.2.1 dev neta
ip route add 10.0.1.0/24 dev neta
```

And when you want to remove the tunnelon router A:

```
ip link set netb down
ip tunnel del netb
```

Of course, you can replace netb with neta for router B.

5.3.2 IPv6 Tunneling

A short bit about IPv6 addresses:

IPv6 addresses are, compared to IPv4 addresses, monstrously big. An example:

`3ffe:2502:200:40:281:48fe:dcfe:d9bc`

So, to make writing them down easier, there are a few rules:

- Don't use leading zeroes. Same as in IPv4.

- Use colons to separate every 16 bits or two bytes.

- When you have lots of consecutive zeroes, you can write this down as ::. You can only do this once in an address and only for quantities of 16 bits, though.

Using these rules, the address 3ffe:0000:0000:0000:0000:0020:34A1:F32C can be written down as 3ffe::20:34A1:F32C, which is a lot shorter.

On with the tunnels.

Let's assume that you have the following IPv6 network, and you want to connect it to 6bone, or a friend.

```
Network 3ffe:406:5:1:5:a:2:1/96
```

Your IPv4 address is 172.16.17.18, and the 6bone router has IPv4 address 172.22.23.24.

```
ip tunnel add sixbone mode sit remote 172.22.23.24 local 172.16.17.18 ttl 255
ip link set sixbone up
ip addr add 3ffe:406:5:1:5:a:2:1/96 dev sixbone
ip route add 3ffe::/15 dev sixbone
```

Let's discuss this. In the first line, we created a tunnel device called sixbone. We gave it mode sit (which is IPv6 in IPv4 tunneling) and told it where to go to (remote) and where to come from (local). TTL is set to maximum, 255. Next, we made the device active (up). After that, we added our own network address, and set a route for 3ffe::/15 (which is currently all of 6bone) through the tunnel.

GRE tunnels are currently the preferred type of tunneling. It's a standard that's also widely adopted outside the Linux community and therefore a Good Thing.

5.4 Userland tunnels

There are literally dozens of implementations of tunneling outside the kernel. Best known are of course PPP and PPTP, but there are lots more (some proprietary, some secure, some that don't even use IP) and that is really beyond the scope of this HOWTO.

6 IPv6 tunneling with Cisco and/or 6bone

By Marco Davids <marco@sara.nl>

NOTE to maintainer:

As far as I am concerned, this IPv6-IPv4 tunneling is not per definition GRE tunneling. You could tunnel IPv6 over IPv4 by means of GRE tunnel devices (GRE tunnels ANY to IPv4), but the device used here ("sit") only tunnels IPv6 over IPv4 and is therefore something different.

6.1 IPv6 Tunneling

This is another application of the tunneling capabilites of Linux. It is populair among the IPv6 early adopters, or pioneers if you like. The 'hands-on' example described below is certainly not the only way to do IPv6 tunneling. However, it is the method that is often used to tunnel between Linux and a Cisco IPv6 capable router and experience learned that this is just the thing many people are after. Ten to one this applies to you too ;-)

A short bit about IPv6 addresses:

IPv6 addresses are, compared to IPv4 addresses, really big: 128 bits against 32 bits. And this provides us just the thing we need: many, many IP-addresses: 340,282,266,920,938,463,463,374,607,431,768,211,465 to be precise. Apart from this, IPv6 (or IPng, for IP Next Generation) is supposed to provide for smaller routing tables on the Internet's backbone routers, simpler configuration of equipment, better security at the IP-level and better support for QoS.

An example: 2002:836b:9820:0000:0000:0000:836b:9886

Writing down IPv6 addresses can be quite a burden. Therefore, to make life easier there are some rules:

- Don't use leading zeroes. Same as in IPv4.

- Use colons to separate every 16 bits or two bytes.

- When you have lots of consecutive zeroes, you can write this down as ::. You can only do this once in an address and only for quantities of 16 bits, though.

The address 2002:836b:9820:0000:0000:0000:836b:9886 can be written down as 2002:836b:9820::836b:9886, which is somewhat friendlier.

IPv6, is intended to be the succesor of the current IPv4. Because it it relatively new technology, there is no worldwide native IPv6 network yet. To be able to move forward swiftly, the 6bone was introduced.

Native IPv6 networks are connected to each other by encapsulating the IPv6 protocol in IPv4 packets and send them over the existing IPv4 infrastructure from one IPv6 site to another.

That is precisely where the tunnels steps in.

To be able to use IPv6, we should have a kernel that supports it. There are many good documents on how to achieve this. But it all comes down to a few steps:

- Get yourself a recent Linux-distribution, with suitable glibc.

- Then get yourself an up-to-date kernel source.

If you are all set, than you can go ahead and compile an IPv6-capable kernel:

- Go to /usr/src/linux and type:

- make menuconfig

- Choose "Networking Options"

- Select "The IPv6 protocol", "IPv6: enable EUI-64 token format", "IPv6: disable provider based addresses"

HINT: Don't go for the 'module' option. Often this won't work well.

In other words, compile IPv6 as 'built-in' in your kernel. You can than save your config like usual and go ahead with compiling the kernel.

HINT: Before doing so, consider editting the Makefile: EXTRAVERSION = -x ; -> ; EXTRAVERSION = -x-IPv6

There is a lot of good documentation about compiling and installing a kernel, however this document is about something else. If you run into problems at this stage, go and look for documentation about compiling a Linux kernel according to your own specifications.

The file /usr/src/linux/README might be a good start. After you acomplished all this, and rebooted with your brand new kernel, you might want to issue an '/sbin/ifconfig -a' and notice the brand new 'sit0-device'. SIT stands for Simple Internet Transition. You may give yourself a compliment; you are now one major step closer to IP, the Next Generation ;-)

No on to the next step. You want to connect your host, or maybe even your entire LAN to another IPv6 capable network. This might be the "6bone" that is setup especially or this particular purpose.

Let's assume that you have the following IPv6 network: 3ffe:604:6:8::/64 and you want to connect it to 6bone, or a friend. Please note that the /64 subnet notation works just like with regular IP adresses.

Your IPv4 address is 145.100.24.181 and the 6bone router has IPv4 address 145.100.1.5

```
# ip tunnel add sixbone mode sit remote 145.100.1.5 [local 145.100.24.181 ttl 225]
# ip link set sixbone up
# ip addr add 3FFE:604:6:7::2/126 dev sixbone
# ip route add 3ffe::0/16 dev sixbone
```

Let's discuss this. In the first line, we created a tunnel device called sixbone. We gave it mode sit (which is IPv6 in IPv4 tunneling) and told it where to go to (remote) and where to come from (local). TTL is set to maximum, 255.

Next, we made the device active (up). After that, we added our own network address, and set a route for 3ffe::/15 (which is currently all of 6bone) through the tunnel. If the particular machine you run this on is your IPv6 gateway, then consider adding the following lines:

```
# echo 1 >/proc/sys/net/ipv6/conf/all/forwarding
# /usr/local/sbin/radvd
```

The latter, radvd is -like zebra- a router advertisement daemon, to support IPv6's autoconfiguration features. Search for it with your favourite search-engine if you like. You can check things like this:

```
# /sbin/ip -f inet6 addr
```

If you happen to have radvd running on your IPv6 gateway and boot your IPv6 capable Linux on a machine on your local LAN, you would be able to enjoy the benefits of IPv6 autoconfiguration:

```
# /sbin/ip -f inet6 addr
1: lo: <LOOPBACK,UP> mtu 3924 qdisc noqueue inet6 ::1/128 scope host

3: eth0: <BROADCAST,MULTICAST,UP> mtu 1500 qdisc pfifo_fast qlen 100
inet6 3ffe:604:6:8:5054:4cff:fe01:e3d6/64 scope global dynamic
valid_lft forever preferred_lft 604646sec inet6 fe80::5054:4cff:fe01:e3d6/10
scope link
```

You could go ahead and configure your bind for IPv6 addresses. The A type has an equivalent for IPv6: AAAA. The in-addr.arpa's equivalent is: ip6.int. There's a lot of information available on this topic.

There is an increasing number of IPv6-aware applications available, including secure shell, telnet, inetd, Mozilla the browser, Apache the websever and a lot of others. But this is all outside the scope of this Routing document ;-)

On the Cisco-site the configuration would be something like this:

```
!
interface Tunnel1
description IPv6 tunnel
no ip address
no ip directed-broadcast
ipv6 enable
ipv6 address 3FFE:604:6:7::1/126
tunnel source Serial0
tunnel destination 145.100.24.181
tunnel mode ipv6ip
!
ipv6 route 3FFE:604:6:8::/64 Tunnel1
```

But if you don't have a Cisco at your disposal, try one of the many IPv6 tunnel brokers available on the Internet. They are willing to configure their Cisco with an extra tunnel for you. Mostly by means of a friendly web-interface. Search for "ipv6 tunnel broker" on your favourite searchengine.

7 IPsec: secure IP over the internet

FIXME: editor vacancy In the meantime, see: *The FreeS/WAN project* <http://www.freeswan.org/>.

8 Multicast routing

FIXME: Editor Vacancy!

9 Using Class Based Queueing for bandwidth management

Now, when I discovered this, it *really* blew me away. Linux 2.2 comes with everything to manage bandwidth in ways comparable to high-end dedicated bandwidth management systems.

Linux even goes far beyond what Frame and ATM provide.

The two basic units of Traffic Control are filters and queues. Filters place traffic into queues, and queues gather traffic and decide what to send first, send later, or drop. There are several flavours of filters and queues.

The most common filters are fwmark and u32, the first lets you use the Linux netfilter code to select traffic, and the second allows you to select traffic based on ANY header. The most notable queue is Class Based Queue. CBQ is a super-queue, in that it contains other queues (even other CBQs).

It may not be immediately clear what queueing has to do with bandwidth management, but it really does work.

For our frame of reference, I have modelled this section on an ISP where I learned the ropes, so to speak, Casema Internet in The Netherlands. Casema, which is actually a cable company, has internet needs both for their customers and for their own office. Most corporate computers there have access to the internet. In reality, they have lots of money to spend and do not use Linux for bandwidth management.

We will explore how our ISP could have used Linux to manage their bandwidth.

9.1 What is queueing?

With queueing we determine the order in which data is *sent*. It it important to realise that we can only shape data that we transmit. How does this changing the order determine the speed of transmission? Imagine a cash register which is able to process 3 customers per minute.

People wishing to pay go stand in line at the 'tail end' of the queue. This is 'FIFO queueing' (First In, First Out). Let's suppose however that we let certain people always join in the middle of the queue, instead of at the end. These people spend a lot less time in the queue and are therefore able to shop faster.

With the way the internet works, we have no direct control of what people send us. It's a bit like your (physical!) mailbox at home. There is no way you can influence the world to modify the amount of mail they send you, short of contacting everybody.

However, the internet is mostly based on TCP/IP which has a few features that help us. TCP/IP has no way of knowing the capacity of the network between two hosts, so it just starts sending data faster and faster ('slow start') and when packets start getting lost, because there is no room to send them, it will slow down.

This is the equivalent of not reading half of your mail, and hoping that people will stop sending it to you. With the difference that it works for the Internet :-)

FIXME: explain congestion windows

```
    [The Internet] ---<E3, T3, whatever>--- [Linux router] --- [Office+ISP]
                                            eth1          eth0
```

Now, our Linux router has two interfaces which I shall dub eth0 and eth1. eth1 is connected to our router which moves packets from to and from our fibre link.

eth0 is connected to a subnet which contains both the corporate firewall and our network head ends, through which we can connect to our customers.

Because we can only limit what we send, we need two separate but possibly very similar sets of rules. By modifying queueing on eth0, we determine how fast data gets sent to our customers, and therefore how much downstream bandwidth is available for them. Their 'download speed' in short.

On eth1, we determine how fast we send data to The Internet, how fast our users, both corporate and commercial can upload data.

9.2   First attempt at bandwidth division

CBQ enables us to generate several classes, and even classes within classes. The larger devisions might be called 'agencies'. Within these classes may be things like 'bulk' or 'interactive'.

For example, we may have a 10 megabit connection to 'the internet' which is to be shared by our customers, and our corporate needs. We should not allow a few people at the office to steal away large amounts of bandwidth which we should sell to our customers.

On the other hand, our customers should not be able to drown out the traffic from our field offices to the customer database.

Previously, one way to solve this was either to use Frame relay/ATM and create virtual circuits. This works, but frame is not very fine grained, ATM is terribly inefficient at carrying IP traffic, and neither have standardised ways to segregate different types of traffic into different VCs.

However, if you do use ATM, Linux can also happily perform deft acts of fancy traffic classification for you too. Another way is to order separate connections, but this is not very practical and also not very elegant, and still does not solve all your problems.

CBQ to the rescue!

Clearly we have two main classes, 'ISP' and 'Office'. Initially, we really don't care what the divisions do with their bandwidth, so we don't further subdivide their classes.

We decide that the customers should always be guaranteed 8 megabits of downstream traffic, and our office 2 megabits.

Setting up traffic control is done with the iproute2 tool `tc`.

```
# tc qdisc add dev eth0 root handle 10: cbq bandwidth 10Mbit avpkt 1000
```

Ok, lots of numbers here. What has happened? We have configured the 'queueing discipline' of eth0. With 'root' we denote that this is the root discipline. We have given it the handle '10:'. We want to do CBQ, so we mention that on the command line as well. We tell the kernel that it can allocate 10Mbit and that the average packet size is somewhere around 1000 octets.

Now we need to generate our root class, from which all others descend:

```
# tc class add dev eth0 parent 10:0 classid 10:1 cbq bandwidth 10Mbit rate \
  10Mbit allot 1514 weight 1Mbit prio 8 maxburst 20 avpkt 1000
```

Even more numbers to worry about - the Linux CBQ implementation is very generic. With 'parent 10:0' we indicate that this class descends from the root of qdisc handle '10:' we generated earlier. With 'classid 10:1' we name this class.

We really don't tell the kernel a lot more, we just generate a class that completely fills the available device. We also specify that the MTU (plus some overhead) is 1514 octets. We also 'weigh' this class with 1Mbit - a tuning parameter.

We now generate our ISP class:

```
# tc class add dev eth0 parent 10:1 classid 10:100 cbq bandwidth 10Mbit rate \
  8Mbit allot 1514 weight 800Kbit prio 5 maxburst 20 avpkt 1000 \
  bounded
```

We allocate 8Mbit, and indicate that this class must not exceed this by adding the 'bounded' parameter. Otherwise this class would have started borrowing bandwidth from other classes, something we will discuss later on.

To top it off, we generate the root Office class:

```
# tc class add dev eth0 parent 10:1 classid 10:200 cbq bandwidth 10Mbit rate \
  2Mbit allot 1514 weight 200Kbit prio 5 maxburst 20 avpkt 1000 \
  bounded
```

To make this a bit clearer, a diagram which shows our classes:

```
+-------------[10: 10Mbit]----------------------+
|+------------[10:1 root 10Mbit]----------------+|
||                                              ||
|| +-----[10:100 8Mbit]---------+ [10:200 2Mbit]  ||
|| |                           | |             | ||
|| |          ISP              | |   Office    | ||
|| |                           | |             | ||
|| +---------------------------+ +-----------+  ||
||                                              ||
|+---------------------------------------------+|
+----------------------------------------------+
```

Ok, now we have told the kernel what our classes are, but not yet how to manage the queues. We do this presently, in one fell swoop for both classes.

```
# tc qdisc add dev eth0 parent 10:100 sfq quantum 1514b perturb 15
# tc qdisc add dev eth0 parent 10:200 sfq quantum 1514b perturb 15
```

In this case we install the Stochastic Fairness Queueing discipline (sfq), which is not quite fair, but works well up to high bandwidths without burning up CPU cycles. There are other queueing disciplines available which are better, but need more CPU. The Token Bucket Filter is often used.

Now there is only one thing left to do and that is to explain to the kernel which packets belong to which class. Initially we will do this natively with iproute2, but more interesting applications are possible in combination with netfilter.

```
# tc filter add dev eth0 parent 10:0 protocol ip prio 100 u32 match ip dst \
  150.151.23.24 flowid 10:200
```

```
# tc filter add dev eth0 parent 10:0 protocol ip prio 25 u32 match ip dst \
  150.151.0.0/16 flowid 10:100
```

Here it is assumed that our office hides behind a firewall with IP address 150.151.23.24 and that all our other IP addresses should be considered to be part of the ISP.

The u32 match is a very simple one - more sophisticated matching rules are possible when using netfilter to mark our packets, which we can than match on in tc.

Now we have fairly divided the downstream bandwidth, we need to do the same for the upstream. For brevity's sake, all in one go:

```
# tc qdisc add dev eth1 root handle 20: cbq bandwidth 10Mbit avpkt 1000

# tc class add dev eth1 parent 20:0 classid 20:1 cbq bandwidth 10Mbit rate \
  10Mbit allot 1514 weight 1Mbit prio 8 maxburst 20 avpkt 1000

# tc class add dev eth1 parent 20:1 classid 20:100 cbq bandwidth 10Mbit rate \
  8Mbit allot 1514 weight 800Kbit prio 5 maxburst 20 avpkt 1000 \
  bounded

# tc class add dev eth1 parent 20:1 classid 20:200 cbq bandwidth 10Mbit rate \
  2Mbit allot 1514 weight 200Kbit prio 5 maxburst 20 avpkt 1000 \
  bounded

# tc qdisc add dev eth1 parent 20:100 sfq quantum 1514b perturb 15
# tc qdisc add dev eth1 parent 20:200 sfq quantum 1514b perturb 15

# tc filter add dev eth1 parent 20:0 protocol ip prio 100 u32 match ip src \
  150.151.23.24 flowid 20:200

# tc filter add dev eth1 parent 20:0 protocol ip prio 25 u32 match ip src \
  150.151.0.0/16 flowid 20:100
```

9.3   What to do with excess bandwidth

In our hypothetical case, we will find that even when the ISP customers are mostly offline (say, at 8AM), our office still gets only 2Mbit, which is rather wasteful.

By removing the 'bounded' statements, classes will be able to borrow bandwidth from each other.

Some classes may not wish to borrow their bandwidth to other classes. Two rival ISPs on a single link may not want to offer each other freebees. In such a case, you can add the keyword 'isolated' at the end of your 'tc class add' lines.

9.4   Class subdivisions

FIXME: completely untested suppositions! Try this!

We can go further than this. Should the employees at the office decide to all fire up their 'napster' clients, it is still possible that our database runs out of bandwidth. Therefore, we create two subclasses, 'Human' and 'Database'.

Our database always needs 500Kbit, so we have 1.5Mbit left for Human consumption.

We now need to create two new classes, within our Office class:

```
# tc class add dev eth0 parent 10:200 classid 10:250 cbq bandwidth 10Mbit rate \
  500Kbit allot 1514 weight 50Kbit prio 5 maxburst 20 avpkt 1000 \
  bounded
```

```
# tc class add dev eth0 parent 10:200 classid 10:251 cbq bandwidth 10Mbit rate \
  1500Kbit allot 1514 weight 150Kbit prio 5 maxburst 20 avpkt 1000 \
  bounded
```

FIXME: Finish this example!

9.5   Loadsharing over multiple interfaces

There are several ways of doing this. One of the easiest and straightforward ways is 'TEQL' - "True" (or "trivial") link equalizer. Like most things having to do with queueing, loadsharing goes both ways. Both ends of a link may need to participate for full effect.

Imagine this situation:

```
            +-------+   eth1   +-------+
            |       |=========|       |
'network 1' ----|   A   |         |   B   |---- 'network 2'
            |       |=========|       |
            +-------+   eth2   +-------+
```

A and B are routers, and for the moment we'll assume both run Linux. If traffic is going from network 1 to network 2, router A needs to distribute the packets over both links to B. Router B needs to be configured to accept this. Same goes the other way around, when packets go from network 2 to network 1, router B needs to send the packets over both eth1 and eth2.

The distributing part is done by a 'TEQL' device, like this (it couldn't be easier):

```
# tc qdisc add dev eth1 root teql0
# tc qdisc add dev eth2 root teql0
```

This needs to be done on both hosts. The device teql0 is basically a roundrobbin distributor over eth1 and eth2, for sending packets. No data ever comes in over an teql device, that just appears on the 'raw' eth1 and eth2.

But now we just have devices, we also need proper routing. One way to do this is to assign a /31 network to both links, and a /31 to the teql0 device as well:

FIXME: does this need something like 'nobroadcast'? A /31 is too small to house a network address and a broadcast address - if this doesn't work as planned, try a /30, and adjust the ip adresses accordingly. You might even try to make eth1 and eth2 do without an IP address!

On router A:

```
# ip addr add dev eth1 10.0.0.0/31
# ip addr add dev eth2 10.0.0.2/31
# ip addr add dev teql0 10.0.0.4/31
```

On router B:

```
# ip addr add dev eth1 10.0.0.1/31
# ip addr add dev eth2 10.0.0.3/31
# ip addr add dev teql0 10.0.0.5/31
```

Router A should now be able to ping 10.0.0.1, 10.0.0.3 and 10.0.0.5 over the 2 real links and the 1 equalized device. Router B should be able to ping 10.0.0.0, 10.0.0.2 and 10.0.0.4 over the links.

If this works, Router A should make 10.0.0.5 its route for reaching network 2, and Router B should make 10.0.0.4 its route for reaching network 1. For the special case where network 1 is your network at home, and network 2 is the internet, Router A should make 10.0.0.5 its default gateway.

9.5.1 Caveats

Nothing is as easy as it seems. eth1 and eth2 on both router A and B need to have return path filtering turned off, because they will otherwise drop packets destined for ip addresses other than their own:

```
# echo 0 > /proc/net/ipv4/conf/eth1/rp_filter
# echo 0 > /proc/net/ipv4/conf/eth2/rp_filter
```

Then there is the nasty problem of packet reordering. Let's say 6 packets need to be sent from A to B - eth1 might get 1, 3 and 5. eth2 would then do 2, 4 and 6. In an ideal world, router B would receive this in order, 1, 2, 3, 4, 5, 6. But the possibility is very real that the kernel gets it like this: 2, 1, 4, 3, 6, 5. The problem is that this confuses TCP/IP. While not a problem for links carrying many different TCP/IP sessions, you won't be able to to a bundle multiple links and get to ftp a single file lots faster, except when your receiving or sending OS is Linux, which is not easily shaken by some simple reordering.

However, for lots of applications, link loadbalancing is a great idea.

10   More queueing disciplines

The Linux kernel offers us lots of queueing disciplines. By far the most widely used is the pfifo_fast queue - this is the default. This also explains why these advanced features are so robust. They are nothing more than 'just another queue'.

Each of these queues has specific strengths and weaknesses. Not all of them may be as well tested.

10.1   pfifo_fast

This queue is, as the name says, First In, First Out, which means that no packet receives special treatment. At least, not quite. This queue has 3 so called 'bands'. Within each band, FIFO rules apply. However, as long as there are packets waiting in band 0, band 1 won't be processed. Same goes for band 1 and band 2.

10.2   Stochastic Fairness Queueing

SFQ, as said earlier, is not quite deterministic, but works (on average). Its main benefits are that it requires little CPU and memory. 'Real' fair queueing requires that the kernel keep track of all running sessions.

Stochastic Fairness Queueing (SFQ) is a simple implementation of fair queueing algorithms family. It's less accurate than others, but it also requires less calculations while being almost perfectly fair.

The key word in SFQ is conversation (or flow), being a sequence of data packets having enough common parameters to distinguish it from other conversations. The parameters used in case of IP packets are source and destination address, and the protocol number.

SFQ consists of dynamically allocated number of FIFO queues, one queue for one conversation. The discipline runs in round-robin, sending one packet from each FIFO in one turn, and this is why it's called fair. The main advantage of SFQ is that it allows fair sharing the link between several applications and prevent bandwidth take-over by one client. SFQ however cannot determine interactive flows from bulk ones – one usually needs to do the selection with CBQ before, and then direct the bulk traffic into SFQ.

10.3   Token Bucket Filter

The Token Bucket Filter (TBF) is a simple queue, that only passes packets arriving at rate in bounds of some administratively set limit, with possibility to buffer short bursts.

The TBF implementation consists of a buffer (bucket), constatly filled by some virtual pieces of information called tokens, at specific rate (token rate). The most important parameter of the bucket is its size, that is number of tokens it can store.

Each arriving token lets one incoming data packet of out the queue and is then deleted from the bucket. Associating this algorithm with the two flows – token and data, gives us three possible scenarios:

- The data arrives into TBF at rate *equal* the rate of incoming tokens. In this case each incoming packet has its matching token and passes the queue without delay.

- The data arrives into TBF at rate *smaller* than the token rate. Only some tokens are deleted at output of each data packet sent out the queue, so the tokens accumulate, up to the bucket size. The saved tokens can be then used to send data over the token rate, if short data burst occurs.

- The data arrives into TBF at rate *bigger* than the token rate. In this case filter overrun occurs – incoming data can be only sent out without loss until all accumulated tokens are used. After that, overlimit packets are dropped.

The last scenario is very important, because it allows to administratively shape the bandwidth available to data, passing the filter. The accumulation of tokens allows short burst of overlimit data to be still passed without loss, but any lasting overload will cause packets to be constantly dropped.

The Linux kernel seems to go beyond this specification, and also allows us to limit the speed of the burst transmission. However, Alexey warns us:

```
Note that the peak rate TBF is much more tough:  with MTU 1500 P_crit = 150Kbytes/sec.
So, if you need greater peak rates, use alpha with HZ=1000 :-)
```

FIXME: is this still true with TSC (pentium+)? Well sort of

FIXME: if not, add section on raising HZ

10.4   Random Early Detect

RED has some extra smartness built in. When a TCP/IP session starts, neither end knows the amount of bandwidth available. So TCP/IP starts to transmit slowly and goes faster and faster, though limited by the latency at which ACKs return.

Once a link is filling up, RED starts dropping packets, which indicate to TCP/IP that the link is congested, and that it should slow down. The smart bit is that RED simulates real congestion, and starts to drop some packets some time before the link is entirely filled up. Once the link is completely saturated, it behaves like a normal policer.

For more information on this, see the Backbone chapter.

10.5   Ingress policer qdisc

The Ingress qdisc comes in handy if you need to ratelimit a host without help from routers or other Linux boxes. You can police incoming bandwidth and drop packets when this bandwidth exceeds your desired rate. This can save your host from a SYN flood, for example, and also works to slow down TCP/IP, which responds to dropped packets by reducing speed.

FIXME: instead of dropping, can we also assign it to a real queue?

FIXME: shaping by dropping packets seems less desirable than using, for example, a token bucket filter. Not sure though, Cisco CAR works this way, and people appear happy with it.

See the reference to 21 (IOS Committed Access Rate) at the end of this document.

In short: you can use this to limit how fast your computer downloads files, thus leaving more of the available bandwidth for others.

See the section on protecting your host from SYN floods for an example on how this works.

10.6   DSMARK

This chapter was written by Esteve Camps <esteve@hades.udg.es>.

10.6.1   Introduction

First of all, first of all, it would be a great idea for you to read RFCs written about this (RFC2474, RFC2475, RFC2597 and RFC2598) at *IETF DiffServ working Group web site* <http://www.ietf.org/html.carters/diffserv-charter.html> and *Werner Almesberger web site* <http://ica1www.epfl.ch/~almesber> (he wrote the code to support Differentiated Services on Linux).

10.6.2   What is Dsmark related to?

Dsmark is a queueing discipline that offers the capabilities needed in Differentiated Services (also called DiffServ or, simply, DS). DiffServ is one of two actual QoS architectures (the other one is called Integrated Services) that is based on a value carried by packets in the DS field of the IP header.

One of the first solutions in IP designed to offer some QoS level was the Type of Service field (TOS byte) in IP header. Changing that value we could choose a high/low level of throughput, delay or reliability. But this

didn't provided sufficient flexibility to the needs of new services (such as real-time applications, interactive applications and others). After this, new architectures appeared. One of these was DiffServ which kept TOS bits and renamed DS field.

10.6.3   Differentiated Services guidelines

Differentiated Services is group-oriented. I mean, we don't know nothing about flows (this will be the Integrated Services purpose); we know about flow aggregations and we will apply different behaviours depending on which aggregation a packet belongs to.

When a packet arrives to an edge node (entry node to a DiffServ domain) entering to a DiffServ Domain we'll have to policy, shape and/or mark those packets (marking refers to assign a value to DS field. It's just like the cows :-)). This will be the mark/value that the internal/core nodes on our DiffServ Domain will look at to determine which behaviour or QoS level apply.

As you can deduce, Differentiated Services involves a domain on which all DS rules will have to be applied. In fact you can think "I will classify all the packets entering my domain. Once they enter my domain they will be subjected to the rules that my classification dictates and every traversed node will apply that QoS level".

In fact, you can apply your own policies into your local domains, but some *Service Level Agreements* should be considered when connecting to other DS domains.

At this point, you maybe have a lot of questions. DiffServ is more than I've explained. In fact, you can understand that I can not resume more than 3 RFC's in just 50 lines :-).

10.6.4   Working with Dsmark

As the DiffServ bibliography specifies, we differentiate boundary nodes and interior nodes. These are two important points in the traffic path. Both types perform a classification when the packets arrive. Its result may be used in different places along the DS process before the packet is released to the network. It's just because of this diffserv code supplies an structure called sk_buff, including a new field called skb->tc_index where we'll store the result of initial classification that may be used in several points in DS treatment.

The skb->tc_index value will be initially set by the DSMARK qdisc, retrieving it from the DS field in IP header of every received packet. Besides, cls_tcindex classifier will read all or part of skb->tcindex value and use it to select classes.

But, first of all, take a look at DSMARK qdisc command and its parameters:

```
... dsmark indices INDICES [ default_index DEFAULT_INDEX ] [ set_tc_index ]
```

What do these parameters mean?

- **indices**: size of table of (mask,value) pairs. Maximum value is 2^n, where n>=0.

- **Default_index**: the default table entry index if classifier finds no match.

- **Set_tc_index**: instructs dsmark discipline to retrieve the DS field and store it onto skb->tc_index.

Let's see the DSMARK process.

10.6.5   How SCH_DSMARK works.

This qdisc will apply the next steps:

- If we have declared set_tc_index option in qdisc command, DS field is retrieved and stored onto skb->tc_index variable.

- Classifier is invoked. The classifier will be executed and it will return a class ID that will be stored in skb->tc_index variable.If no filter matches are found, we consider the default_index option to be the classId to store. If neither set_tc_index nor default_index has been declared results may be impredictibles.

- After been sent to internal qdisc's where you can reuse the result of the filter, the classid returned by the internal qdisc is stored into skb->tc_index. We will use this value in the future to index a mask-value table. The final result to assign to the packet will be that resulting from next operation:

      New_Ds_field = (Old_DS_field & mask) | value

- Thus, new value will result from "anding" ds_field and mask values and next, this result "ORed" with value parameter. See next diagram to understand all this process:

```
                           skb->ihp->tos
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - >

    |                                                    |      ^
    | -- If you declare set_tc_index, we set DS          |      |  <-----May change
    |     value into skb->tc_index variable              |      |O        DS field
    |                                                    A|      |R
  +-|-+       +------+    +---+-+    Internal    +-+     +---N|-----|----+
  | | |       | tc   |--->|   | |-->  . . .  -->| |     |   D|     |    |
  | | |----->|index |--->|   | |       Qdisc    | |---->|   v     |    |
  | | |       |filter|--->| | | +---------------+ |    ---->(mask,value) |
-->| O |       +------+    +-|-+---------------^----+  /  |  (.  ,  .)    |
  | | |          ^         |                   |       | |  | (.  ,  .)   |
  | | +---------|---------|---------------|-------|--+  (.  ,  .)    |
  | | sch_dsmark |         |               |       |                  |
  +-|-----------|---------|---------------|-------|-----------------+
    |           |         | <- tc_index -> |       |
    |           |(read)   |   may change   |       | <--------------Index to the
    |           |         |                |       |                    (mask,value)
    v           |         v                v       |                    pairs table
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - ->
                       skb->tc_index
```
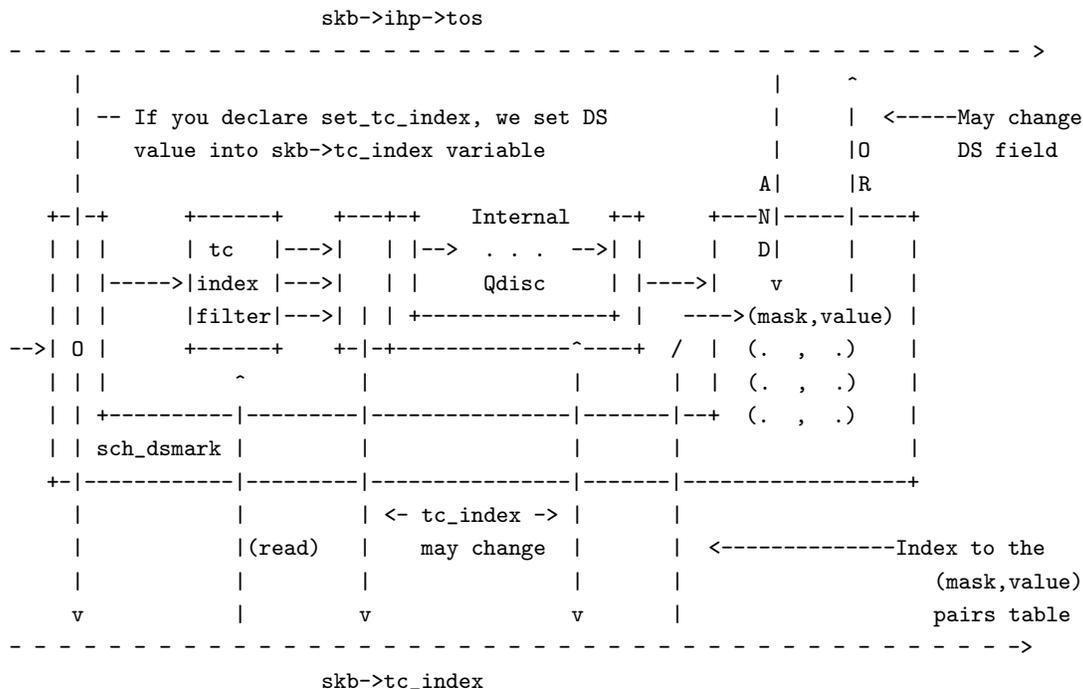
How to do marking? Just change the mask and value of the class you want to remark. See next line of code:

      tc class change dev eth0 classid 1:1 dsmark mask 0x3 value 0xb8

This changes the (mask,value) pair in hash table, to remark packets belonging to class 1:1.You have to "change" this values because of default values that (mask,value) gets initially (see table below).

Now, we'll explain how TC_INDEX filter works and how fits into this. Besides, TCINDEX filter can be used in other configurations rather than those including DS services.

10.6.6   TC_INDEX Filter

This is the basic command to declare a TC_INDEX filter:
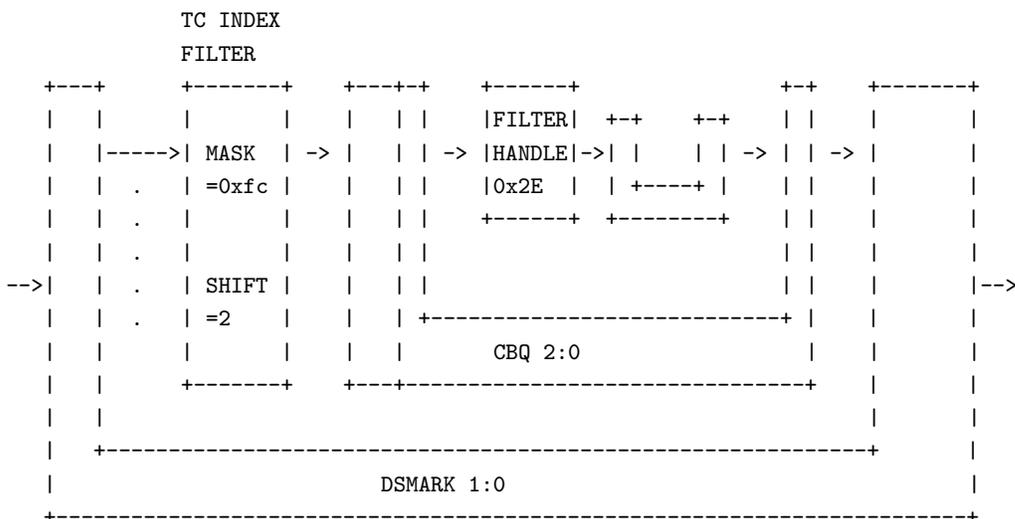
```
... tcindex [ hash SIZE ] [ mask MASK ] [ shift SHIFT ]
            [ pass_on | fall_through ]
            [ classid CLASSID ] [ police POLICE_SPEC ]
```

Next, we show the example used to explain TC_INDEX operation mode. Pay attention to bolded words:

tc qdisc add dev eth0 handle 1:0 root dsmark indices 64 **set_tc_index**

tc filter add dev eth0 parent 1:0 protocol ip prio 1 tcindex **mask 0xfc shift 2**

tc qdisc add dev eth0 parent 1:0 handle 2:0 cbq bandwidth 10Mbit cell 8 avpkt 1000 mpu 64

\# EF traffic class

tc class add dev eth0 parent 2:0 classid 2:1 cbq bandwidth 10Mbit rate 1500Kbit avpkt 1000 prio 1 bounded isolated allot 1514 weight 1 maxburst 10

\# Packet fifo qdisc for EF traffic

tc qdisc add dev eth0 parent 2:1 pfifo limit 5

tc filter add dev eth0 parent 2:0 protocol ip prio 1 **handle 0x2e** tcindex **classid 2:1 pass_on**

(This code is not complete. It's just an extract from EFCBQ example included in iproute2 distribution).

First of all, supose we receive a packet marked as EF . If you read RFC2598, you'll see that DSCP recommended value for EF traffic is 101110. This means that DS field will be 10111000 (remember that less signifiant bits in TOS byte are not used in DS) or 0xb8 in hexadecimal codification.

```
                    TC INDEX
                    FILTER
     +---+      +-------+   +---+-+   +------+              +-+   +-------+
     |   |      |       |   |   | |   |FILTER|  +-+    +-+  | |   |       |
     |   |----->| MASK  | ->|   | | -> |HANDLE|->| |    | | -> | | -> |       |
     |   | .    | =0xfc |   |   | |   |0x2E  |  | +----+ |   | |   |       |
     |   | .    |       |   |   | |   +------+  +--------+   | |   |       |
     |   | .    |       |   |   | |                         | |   |       |
  -->|   | .    | SHIFT |   |   | |                         | |   |       |-->
     |   | .    | =2    |   |   | +---------------------------+ |   |       |
     |   |      |       |   |   | |          CBQ 2:0            |   |       |
     |   |      +-------+   +---+-------------------------------+   |       |
     |   |                                                         |       |
     |   +-----------------------------------------------------------+       |
     |                        DSMARK 1:0                                 |
     +-----------------------------------------------------------------------+
```

The packet arrives, then, set with 0xb8 value at DS field. As we explained before, dsmark qdisc identified by 1:0 id in the example, retrieves DS field and store it in skb->tc_index variable. Next step in the example will correspond to the filter associated to this qdisc (second line in the example). This will perform next operations:

```
    Value1 = skb->tc_index & MASK
    Key = Value1 >> SHIFT
```

In the example, MASK=0xFC i SHIFT=2.

```
    Value1 = 10111000 & 11111100 = 10111000
    Key = 10111000 >> 2 = 00101110 -> 0x2E in hexadecimal
```

The returned value will correspond to a qdisc interal filter handle (in the example, identifier 2:0). If a filter with this id exists, policing and metering conditions will be verified (in case that filter includes this) and the classid will be returned (in our example, classid 2:1) and stored in skb->tc_index variable.

But if any filter with that identifier is found, the result will depend on fall_through flag declaration. If so, value key is returned as classid. If not, an error is returned and process continues with the rest filters. Be careful if you use fall_through flag; this can be done if a simple relation exists between values of skb->tc_index variable and class id's.

The latest parameters to comment are hash and pass_on. The first one relates to hash table size. Pass_on will be used to indicate that if no classid equal to the result of this filter is found, try next filter. The default action is fall_through (look at next table).

Finally, let's see which possible values can be set to all this TCINDEX parameters:

```
    TC Name                 Value           Default
    ---------------------------------------------------------------
    Hash                    1...0x10000     Implementation dependent
    Mask                    0...0xffff      0xffff
    Shift                   0...15          0
    Fall through / Pass_on  Flag            Fall_through
    Classid                 Major:minor     None
    Police                  .....           None
```

This kind of filter is very powerfull. It's necessary to explore all possibilities. Besides, this filter it's not only used in DiffServ configurations. You can use it as any other kind of filter.

I recommend you to look at all DiffServ examples included in iproute2 distribution. I promise I will try to complement this text as soon as I can. Besides, all I have explained is the result of a lot of tests. I would thank you tell me if I'm wrong in any point.

11   Other information

Esteve Camps Chust <marvin@grn.es>
This text is an extract from my thesis on "QoS Support in Linux", September 2000.

Source documents:

- *Draft-almesberger-wajhak-diffserv-linux-01.txt* <http://ica1www.epfl.ch/~almesber>.

- Examples in iproute2 distribution.

- *White Paper-QoS protocols and architectures* `<http://www.qosforum.com/white-papers/qosprot_v3.pdf>` and *IP QoS Frequently Asked Questions* `<http://www.qosforum.com/docs/faq>` both by *Quality of Service Forum*.

11.1   WRR

This qdisc is not included in the standard kernels but can be downloaded from `<http://wipl-wrr.dkik.dk/wrr/>`. Currently the qdisc is only tested with Linux 2.2 kernels but it will probably work with 2.4 kernels too.

The WRR qdisc distributes bandwidth between its classes using the weighted round robin scheme. That is, like the CBQ qdisc it contains classes into which arbitrary qdiscs can be plugged. All classes which have sufficient demand will get bandwidth proportional to the weights associated with the classes. The weights can be set manually using the `tc` program. But they can also be made automatically decreasing for classes transferring much data.

The qdisc has a build-in classifier which assigns packets coming from or sent to different machines to different classes. Either the MAC or IP and either source or destination addresses can be used. The MAC address can only be used when the Linux box is acting as an ethernet bridge, however. The classes are automatically assigned to machines based on the packets seen.

The qdisc can be very useful at sites such as dorms where a lot of unrelated individuals share an Internet connection. A set of scripts setting up a relevant behavior for such a site is a central part of the WRR distribution.

12   Netfilter & iproute - marking packets

So far we've seen how iproute works, and netfilter was mentioned a few times. This would be a good time to browse through *Rusty's Remarkably Unreliable Guides* `<http://netfilter.samba.org/unreliable-guides/>`. Netfilter itself can be found *here* `<http://netfilter.filewatcher.org/>`.

Netfilter allows us to filter packets, or mangle their headers. One special feature is that we can mark a packet with a number. This is done with the –set-mark facility.

As an example, this command marks all packets destined for port 25, outgoing mail:

```
# iptables -A PREROUTING -i eth0 -t mangle -p tcp --dport 25 \
 -j MARK --set-mark 1
```

Let's say that we have multiple connections, one that is fast (and expensive, per megabyte) and one that is slower, but flat fee. We would most certainly like outgoing mail to go via the cheap route.

We've already marked the packets with a '1', we now instruct the routing policy database to act on this:

```
# echo 201 mail.out >> /etc/iproute2/rt_tables
# ip rule add fwmark 1 table mail.out
# ip rule ls
0:      from all lookup local
32764:  from all fwmark        1 lookup mail.out
32766:  from all lookup main
```

```
    32767:  from all lookup default
```

Now we generate the mail.out table with a route to the slow but cheap link:

```
    # /sbin/ip route add default via 195.96.98.253 dev ppp0 table mail.out
```

And we are done. Should we want to make exceptions, there are lots of ways to achieve this. We can modify the netfilter statement to exclude certain hosts, or we can insert a rule with a lower priority that points to the main table for our excepted hosts.

We can also use this feature to honour TOS bits by marking packets with a different type of service with different numbers, and creating rules to act on that. This way you can even dedicate, say, an ISDN line to interactive sessions.

Needless to say, this also works fine on a host that's doing NAT ('masquerading').

IMPORTANT: We received a report that MASQ and SNAT at least collide with marking packets. Rusty Russell explains it in *this posting* <http://lists.samba.org/pipermail/netfilter/2000-November/006089.html>. Turn off the reverse path filter to make it work properly.

Note: to mark packets, you need to have some options enabled in your kernel:

```
    IP: advanced router (CONFIG_IP_ADVANCED_ROUTER) [Y/n/?]
     IP: policy routing (CONFIG_IP_MULTIPLE_TABLES) [Y/n/?]
      IP: use netfilter MARK value as routing key (CONFIG_IP_ROUTE_FWMARK) [Y/n/?]
```

See also 16.5 (Transparent web-caching using netfilter, iproute2, ipchains and squid) in the Cookbook.

13 More classifiers

Classifiers are the way by which the kernel decides which queue a packet should be placed into. There are various different classifiers, each of which can be used for different purposes.

fw

> Bases the decision on how the firewall has marked the packet.

u32

> Bases the decision on fields within the packet (i.e. source IP address, etc)

route

> Bases the decision on which route the packet will be routed by.

rsvp, rsvp6

> Bases the decision on the target (destination,protocol) and optionally the source as well. (I think)

tcindex

> FIXME: Fill me in

Note that in general there are many ways in which you can classify packet and that it generally comes down to preference as to which system you wish to use.

Classifiers in general accept a few arguments in common. They are listed here for convenience:

protocol

> The protocol this classifier will accept. Generally you will only be accepting only IP traffic. Required.

parent

> The handle this classifier is to be attached to. This handle must be an already existing class. Required.

prio

> The priority of this classifier. Higher numbers get tested first.

handle

> This handle means different things to different filters.

> FIXME: Add more

All the following sections will assume you are trying to shape the traffic going to `HostA`. They will assume that the root class has been configured on 1: and that the class you want to send the selected traffic to is 1:1.

13.1   The "fw" classifier

The "fw" classifier relies on the firewall tagging the packets to be shaped. So, first we will setup the firewall to tag them:

```
# iptables -I PREROUTING -t mangle -p tcp -d HostA \
 -j MARK --set-mark 1
```

Now all packets to that machine are tagged with the mark 1. Now we build the packet shaping rules to actually shape the packets. Now we just need to indicate that we want the packets that are tagged with the mark 1 to go to class 1:1. This is accomplished with the command:

```
# tc filter add dev eth1 protocol ip parent 1:0 prio 1 handle 1 fw classid 1:1
```

This should be fairly self-explanatory. Attach to the 1:0 class a filter with priority 1 to filter all packet marked with 1 in the firewall to class 1:1. Note how the handle here is used to indicate what the mark should be.

That's all there is to it! This is the (IMHO) easy way, the other ways are I think harder to understand. Note that you can apply the full power of the firewalling code with this classifier, including matching MAC addresses, user IDs and anything else the firewall can match.

13.2   The "u32" classifier

The U32 filter is the most advanced filter available in the current implementation. It entirely based on hashing tables, which make it robust when there are many filter rules.

In its simplest form the U32 filter is a list of records, each consisting of two fields: a selector and an action. The selectors, described below, are compared with the currently processed IP packet until the first match and the associated action is performed. The simplest type of action would be directing the packet into defined CBQ class.

The commandline of `tc filter` program, used to configure the filter, consists of three parts: filter specification, a selector and an action. The filter specification can be defined as:

```
tc filter add dev IF [ protocol PROTO ]
                     [ (preference|priority) PRIO ]
                     [ parent CBQ ]
```

The `protocol` field describes protocol that the filter will be applied to. We will only discuss case of `ip` protocol. The `preference` field (`priority` can be used alternatively) sets the priority of currently defined filter. This is important, since you can have several filters (lists of rules) with different priorities. Each list will be passed in the order the rules were added, then list with lower priority (higher preference number) will be processed. The `parent` field defines the CBQ tree top (e.g. 1:0), the filter should be attached to.

The options decribed apply to all filters, not only U32.

13.2.1   U32 selector

The U32 selector contains definition of the pattern, that will be matched to the currently processed packet. Precisely, it defines which bits are to be matched in the packet header and nothing more, but this simple method is very powerful. Let's take a look at the following examples, taken directly from a pretty complex, real-world filter:

```
# filter parent 1: protocol ip pref 10 u32 fh 800::800 order 2048 key ht 800 bkt 0 flowid 1:3 \
  match 00100000/00ff0000 at 0
```

For now, leave the first line alone - all these parameters describe the filter's hash tables. Focus on the selector line, containing `match` keyword. This selector will match to IP headers, whose second byte will be 0x10 (0010). As you can guess, the 00ff number is the match mask, telling the filter exactly which bits to match. Here it's 0xff, so the byte will match if it's exactly 0x10. The `at` keyword means that the match is to be started at specified offset (in bytes) – in this case it's beginning of the packet. Translating all that to human language, the packet will match if its Type of Service field will have 'low delay' bits set. Let's analyze another rule:

```
# filter parent 1: protocol ip pref 10 u32 fh 800::803 order 2051 key ht 800 bkt 0 flowid 1:3 \
  match 00000016/0000ffff at nexthdr+0
```

The `nexthdr` option means next header encapsulated in the IP packet, i.e. header of upper-layer protocol. The match will also start here at the beginning of the next header. The match should occur in the second, 32-bit word of the header. In TCP and UDP protocols this field contains packet's destination port. The

number is given in big-endian format, i.e. older bits first, so we simply read 0x0016 as 22 decimal, which stands for SSH service if this was TCP. As you guess, this match is ambigous without a context, and we will discuss this later.

Having understood all the above, we will find the following selector quite easy to read: `match c0a80100/ffffff00 at 16`. What we got here is a three byte match at 17-th byte, counting from the IP header start. This will match for packets with destination address anywhere in 192.168.1/24 network. After analyzing the examples, we can summarize what we have learnt.

13.2.2   General selectors

General selectors define the pattern, mask and offset the pattern will be matched to the packet contents. Using the general selectors you can match virtually any single bit in the IP (or upper layer) header. They are more difficult to write and read, though, than specific selectors that described below. The general selector syntax is:

```
match [ u32 | u16 | u8 ] PATTERN MASK [ at OFFSET | nexthdr+OFFSET]
```

One of the keywords `u32`, `u16` or `u8` specifies length of the pattern in bits. PATTERN and MASK should follow, of length defined by the previous keyword. The OFFSET parameter is the offset, in bytes, to start matching. If `nexthdr+` keyword is given, the offset is relative to start of the upper layer header.

Some examples:

```
# tc filter add dev ppp14 parent 1:0 prio 10 u32 \
    match u8 64 0xff at 8 \
    flowid 1:4
```

Packet will match to this rule, if its time to live (TTL) is 64. TTL is the field starting just after 8-th byte of the IP header.

```
# tc filter add dev ppp14 parent 1:0 prio 10 u32 \
    match u8 0x10 0xff at nexthdr+13 \
    protocol tcp \
    flowid 1:3 \
```

This rule will only match TCP packets with ACK bit set. Here we can see an example of using two selectors, the final result will be logical AND of their results. If we take a look at TCP header diagram, we can see that the ACK bit is second older bit (0x10) in the 14-th byte of the TCP header (`at nexthdr+13`). As for the second selector, if we'd like to make our life harder, we could write `match u8 0x06 0xff at 9` instead if using the specific selector `protocol tcp`, because 6 is the number of TCP protocol, present in 10-th byte of the IP header. On the other hand, in this example we couldn't use any specific selector for the first match - simply because there's no specific selector to match TCP ACK bits.

13.2.3   Specific selectors

The following table contains a list of all specific selectors the author of this section has found in the `tc` program source code. They simply make your life easier and increase readability of your filter's configuration.

FIXME: table placeholder - the table is in separate file ,,selector.html"

FIXME: it's also still in Polish :-(

FIXME: must be sgml'ized

Some examples:

```
# tc filter add dev ppp0 parent 1:0 prio 10 u32 \
     match ip tos 0x10 0xff \
     flowid 1:4
```

The above rule will match packets, which have the TOS field set to 0x10. The TOS field starts at second byte of the packet and is one byte big, so we coul write an equivalent general selector: `match u8 0x10 0xff at 1`. This gives us hint to the internals of U32 filter – the specific rules are always translated to general ones, and in this form they are stored in the kernel memory. This leads to another conclusion – the `tcp` and `udp` selectors are exactly the same and this is why you can't use single `match tcp dst 53 0xffff` selector to match TCP packets sent to given port – they will also match UDP packets sent to this port. You must remember to also specify the protocol and end up with the following rule:

```
# tc filter add dev ppp0 parent 1:0 prio 10 u32 \
       match tcp dst 53 0xffff \
       match ip protocol 0x6 0xff \
       flowid 1:2
```

13.3 The "route" classifier

This classifier filters based on the results of the routing tables. When a packet that is traversing through the classes reaches one that is marked with the "route" filter, it splits the packets up based on information in the routing table.

```
# tc filter add dev eth1 parent 1:0 protocol ip prio 100 route
```

Here we add a route classifier onto the parent node 1:0 with priority 100. When a packet reaches this node (which, since it is the root, will happen immediately) it will consult the routing table and if one matches will send it to the given class and give it a priority of 100. Then, to finally kick it into action, you add the appropriate routing entry:

The trick here is to define 'realm' based on either destination or source. The way to do it is like this:

```
# ip route add Host/Network via Gateway dev Device realm RealmNumber
```

For instance, we can define our destination network 192.168.10.0 with a realm number 10:

```
# ip route add 192.168.10.0/24 via 192.168.10.1 dev eth1 realm 10
```

When adding route filters, we can use realm numbers to represent the networks or hosts and specify how the routes match the filters.

```
# tc filter add dev eth1 parent 1:0 protocol ip prio 100 \
  route to 10 classid 1:10
```

The above rule says packets going to the network 192.168.10.0 match class id 1:10.

Route filter can also be used to match source routes. For example, there is a subnetwork attached to the Linux router on eth2.

```
# ip route add 192.168.2.0/24 dev eth2 realm 2
# tc filter add dev eth1 parent 1:0 protocol ip prio 100 \
  route from 2 classid 1:2
```

Here the filter specifies that packets from the subnetwork 192.168.2.0 (realm 2) will match class id 1:2.

13.4   The "rsvp" classifier

FIXME: Fill me in

13.5   The "tcindex" classifier

FIXME: Fill me in

14   Kernel network parameters

The kernel has lots of parameters which can be tuned for different circumstances. While, as usual, the default parameters serve 99% of installations very well, we don't call this the Advanced HOWTO for the fun of it!

The interesting bits are in /proc/sys/net, take a look there. Not everything will be documented here initially, but we're working on it.

14.1   Reverse Path Filtering

By default, routers route everything, even packets which 'obviously' don't belong on your network. A common example is private IP space escaping onto the internet. If you have an interface with a route of 195.96.96.0/24 to it, you do not expect packets from 212.64.94.1 to arrive there.

Lots of people will want to turn this feature off, so the kernel hackers have made it easy. There are files in /proc where you can tell the kernel to do this for you. The method is called "Reverse Path Filtering". Basically, if the reply to this packet wouldn't go out the interface this packet came in, then this is a bogus packet and should be ignored.

The following fragment will turn this on for all current and future interfaces.

```
# for i in /proc/sys/net/ipv4/conf/*/rp_filter ; do
>   echo 2 > $i
> done
```

Going by the example above, if a packet arrived on the Linux router on eth1 claiming to come from the Office+ISP subnet, it would be dropped. Similarly, if a packet came from the Office subnet, claiming to be from somewhere outside your firewall, it would be dropped also.

The above is full reverse path filtering. The default is to only filter based on IPs that are on directly connected networks. This is because the full filtering breaks in the case of asymmetric routing (where packets come in one way and go out another, like satellite traffic, or if you have dynamic (bgp, ospf, rip) routes in your network. The data comes down through the satellite dish and replies go back through normal land-lines).

If this exception applies to you (and you'll probably know if it does) you can simply turn off the `rp\_filter` on the interface where the satellite data comes in. If you want to see if any packets are being dropped, the `log\_martians` file in the same directory will tell the kernel to log them to your syslog.

```
# echo 1 >/proc/sys/net/ipv4/conf/<interfacename>/log_martians
```

FIXME: is setting the conf/{default,all}/* files enough? - martijn

14.2   Obscure settings

Ok, there are a lot of parameters which can be modified. We try to list them all. Also documented (partly) in `Documentation/ip-sysctl.txt`.

Some of these settings have different defaults based on whether you answered 'Yes' to 'Configure as router and not host' while compiling your kernel.

14.2.1   Generic ipv4

As a generic note, most rate limiting features don't work on loopback, so don't test them locally. The limits are supplied in 'jiffies', and are enforced using the earlier mentioned token bucket filter.

The kernel has an internal clock which runs at 'HZ' ticks (or 'jiffies') per second. On intel, 'HZ' is mostly 100. So setting a *_rate file to, say 50, would allow for 2 packets per second. The token bucket filter is also configured to allow for a burst of at most 6 packets, if enough tokens have been earned.

Several entries in the following list have been copied from /usr/src/linux/Documentation/networking/ip-sysctl.txt, written by Alexey Kuznetsov <kuznet@ms2.inr.ac.ru> and Andi Kleen <ak@muc.de>

/proc/sys/net/ipv4/icmp_destunreach_rate

> If the kernel decides that it can't deliver a packet, it will drop it, and send the source of the packet an ICMP notice to this effect.

/proc/sys/net/ipv4/icmp_echo_ignore_all

> Don't act on echo packets at all. Please don't set this by default, but if you are used as a relay in a DoS attack, it may be useful.

/proc/sys/net/ipv4/icmp_echo_ignore_broadcasts [Useful]

> If you ping the broadcast address of a network, all hosts are supposed to respond. This makes for a dandy denial-of-service tool. Set this to 1 to ignore these broadcast messages.

/proc/sys/net/ipv4/icmp_echoreply_rate

The rate at which echo replies are sent to any one destination.

/proc/sys/net/ipv4/icmp_ignore_bogus_error_responses

Set this to ignore ICMP errors caused by hosts in the network reacting badly to frames sent to what they perceive to be the broadcast address.

/proc/sys/net/ipv4/icmp_paramprob_rate

A relatively unknown ICMP message, which is sent in response to incorrect packets with broken IP or TCP headers. With this file you can control the rate at which it is sent.

/proc/sys/net/ipv4/icmp_timeexceed_rate

This the famous cause of the 'Solaris middle star' in traceroutes. Limits number of ICMP Time Exceeded messages sent.

/proc/sys/net/ipv4/igmp_max_memberships

Maximum number of listening igmp (multicast) sockets on the host. FIXME: Is this true?

/proc/sys/net/ipv4/inet_peer_gc_maxtime

FIXME: Add a little explanation about the inet peer storage?
Minimum interval between garbage collection passes. This interval is in effect under low (or absent) memory pressure on the pool. Measured in jiffies.

/proc/sys/net/ipv4/inet_peer_gc_mintime

Minimum interval between garbage collection passes. This interval is in effect under high memory pressure on the pool. Measured in jiffies.

/proc/sys/net/ipv4/inet_peer_maxttl

Maximum time-to-live of entries. Unused entries will expire after this period of time if there is no memory pressure on the pool (i.e. when the number of entries in the pool is very small). Measured in jiffies.

/proc/sys/net/ipv4/inet_peer_minttl

Minimum time-to-live of entries. Should be enough to cover fragment time-to-live on the reassembling side. This minimum time-to-live is guaranteed if the pool size is less than inet_peer_threshold. Measured in jiffies.

/proc/sys/net/ipv4/inet_peer_threshold

The approximate size of the INET peer storage. Starting from this threshold entries will be thrown aggressively. This threshold also determines entries' time-to-live and time intervals between garbage collection passes. More entries, less time-to-live, less GC interval.

/proc/sys/net/ipv4/ip_autoconfig

This file contains the number one if the host received its IP configuration by RARP, BOOTP, DHCP or a similar mechanism. Otherwise it is zero.

/proc/sys/net/ipv4/ip default ttl

Time To Live of packets. Set to a safe 64. Raise it if you have a huge network. Don't do so for fun - routing loops cause much more damage that way. You might even consider lowering it in some circumstances.

/proc/sys/net/ipv4/ip dynaddr

You need to set this if you use dial-on-demand with a dynamic interface address. Once your demand interface comes up, any local TCP sockets which haven't seen replies will be rebound to have the right address. This solves the problem that the connection that brings up your interface itself does not work, but the second try does.

/proc/sys/net/ipv4/ip forward

If the kernel should attempt to forward packets. Off by default.

/proc/sys/net/ipv4/ip local port range

Range of local ports for outgoing connections. Actually quite small by default, 1024 to 4999.

/proc/sys/net/ipv4/ip no pmtu disc

Set this if you want to disable Path MTU discovery - a technique to determine the largest Maximum Transfer Unit possible on your path. See also the section on Path MTU discovery in the cookbook chapter.

/proc/sys/net/ipv4/ipfrag high thresh

Maximum memory used to reassemble IP fragments. When ipfrag high thresh bytes of memory is allocated for this purpose, the fragment handler will toss packets until ipfrag low thresh is reached.

/proc/sys/net/ipv4/ip nonlocal bind

Set this if you want your applications to be able to bind to an address which doesn't belong to a device on your system. This can be useful when your machine is on a non-permanent (or even dynamic) link, so your services are able to start up and bind to a specific address when your link is down.

/proc/sys/net/ipv4/ipfrag low thresh

Minimum memory used to reassemble IP fragments.

/proc/sys/net/ipv4/ipfrag time

Time in seconds to keep an IP fragment in memory.

/proc/sys/net/ipv4/tcp abort on overflow

A boolean flag controlling the behaviour under lots of incoming connections. When enabled, this causes the kernel to actively send RST packets when a service is overloaded.

/proc/sys/net/ipv4/tcp fin timeout

Time to hold socket in state FIN-WAIT-2, if it was closed by our side. Peer can be broken and never close its side, or even died unexpectedly. Default value is 60sec. Usual value used in 2.2 was 180 seconds, you may restore it, but remember that if your machine is even underloaded WEB server, you risk to overflow memory with kilotons of dead sockets, FIN-WAIT-2 sockets are less dangerous than FIN-WAIT-1, because they eat maximum 1.5K of memory, but they tend to live longer. Cf. tcp max orphans.

/proc/sys/net/ipv4/tcp_keepalive_time

How often TCP sends out keepalive messages when keepalive is enabled.
Default: 2hours.

/proc/sys/net/ipv4/tcp_keepalive_intvl

How frequent probes are retransmitted, when a probe isn't acknowledged.
Default: 75 seconds.

/proc/sys/net/ipv4/tcp_keepalive_probes

How many keepalive probes TCP will send, until it decides that the connection is broken.
Default value: 9.
Multiplied with tcp_keepalive_intvl, this gives the time a link can be nonresponsive after a keepalive has been sent.

/proc/sys/net/ipv4/tcp_max_orphans

Maximal number of TCP sockets not attached to any user file handle, held by system. If this number is exceeded orphaned connections are reset immediately and warning is printed. This limit exists only to prevent simple DoS attacks, you _must_ not rely on this or lower the limit artificially, but rather increase it (probably, after increasing installed memory), if network conditions require more than default value, and tune network services to linger and kill such states more aggressively. Let me to remind again: each orphan eats up to 64K of unswappable memory.

/proc/sys/net/ipv4/tcp_orphan_retries

How may times to retry before killing TCP connection, closed by our side. Default value 7 corresponds to 50sec-16min depending on RTO. If you machine is loaded WEB server, you should think about lowering this value, such sockets may consume significant resources. Cf. tcp_max_orphans.

/proc/sys/net/ipv4/tcp_max_syn_backlog

Maximal number of remembered connection requests, which are still did not receive an acknowledgement from connecting client. Default value is 1024 for systems with more than 128Mb of memory, and 128 for low memory machines. If server suffers of overload, try to increase this number. Warning! If you make it greater than 1024, it would be better to change TCP_SYNQ_HSIZE in include/net/tcp.h to keep TCP_SYNQ_HSIZE*16<=tcp_max_syn_backlog and to recompile kernel.

/proc/sys/net/ipv4/tcp_max_tw_buckets

Maximal number of timewait sockets held by system simultaneously. If this number is exceeded timewait socket is immediately destroyed and warning is printed. This limit exists only to prevent simple DoS attacks, you _must_ not lower the limit artificially, but rather increase it (probably, after increasing installed memory), if network conditions require more than default value.

/proc/sys/net/ipv4/tcp_retrans_collapse

Bug-to-bug compatibility with some broken printers. On retransmit try to send bigger packets to work around bugs in certain TCP stacks.

/proc/sys/net/ipv4/tcp_retries1

How many times to retry before deciding that something is wrong and it is necessary to report this suspicion to network layer. Minimal RFC value is 3, it is default, which corresponds to 3sec-8min depending on RTO.

/proc/sys/net/ipv4/tcp_retries2

How may times to retry before killing alive TCP connection. RFC1122 says that the limit should be longer than 100 sec. It is too small number. Default value 15 corresponds to 13-30min depending on RTO.

/proc/sys/net/ipv4/tcp_rfc1337

This boolean enables a fix for 'time-wait assassination hazards in tcp', described in RFC 1337. If enabled, this causes the kernel to drop RST packets for sockets in the time-wait state.
Default: 0

/proc/sys/net/ipv4/tcp_sack

Use Selective ACK which can be used to signify that specific packets are missing - therefore helping fast recovery.

/proc/sys/net/ipv4/tcp_stdurg

Use the Host requirements interpretation of the TCP urg pointer field.
Most hosts use the older BSD interpretation, so if you turn this on Linux might not communicate correctly with them.
Default: FALSE

/proc/sys/net/ipv4/tcp_syn_retries

Number of SYN packets the kernel will send before giving up on the new connection.

/proc/sys/net/ipv4/tcp_synack_retries

To open the other side of the connection, the kernel sends a SYN with a piggybacked ACK on it, to acknowledge the earlier received SYN. This is part 2 of the threeway handshake. This setting determines the number of SYN+ACK packets sent before the kernel gives up on the connection.

/proc/sys/net/ipv4/tcp_timestamps

Timestamps are used, amongst other things, to protect against wrapping sequence numbers. A 1 gigabit link might conceivably re-encounter a previous sequence number with an out-of-line value, because it was of a previous generation. The timestamp will let it recognise this 'ancient packet'.

/proc/sys/net/ipv4/tcp_tw_recycle

Enable fast recycling TIME-WAIT sockets. Default value is 1. It should not be changed without advice/request of technical experts.

/proc/sys/net/ipv4/tcp_window_scaling

TCP/IP normally allows windows up to 65535 bytes big. For really fast networks, this may not be enough. The window scaling options allows for almost gigabyte windows, which is good for high bandwidth*delay products.

14.2.2   Per device settings

DEV can either stand for a real interface, or for 'all' or 'default'. Default also changes settings for interfaces yet to be created.

/proc/sys/net/ipv4/conf/DEV/accept_redirects

> If a router decides that you are using it for a wrong purpose (ie, it needs to resend your packet on the same interface), it will send us a ICMP Redirect. This is a slight security risk however, so you may want to turn it off, or use secure redirects.

/proc/sys/net/ipv4/conf/DEV/accept_source_route

> Not used very much anymore. You used to be able to give a packet a list of IP addresses it should visit on its way. Linux can be made to honor this IP option.

/proc/sys/net/ipv4/conf/DEV/bootp_relay

> FIXME: fill this in

/proc/sys/net/ipv4/conf/DEV/forwarding

> FIXME:

/proc/sys/net/ipv4/conf/DEV/log_martians

> See the section on reverse path filters.

/proc/sys/net/ipv4/conf/DEV/mc_forwarding

> If we do multicast forwarding on this interface

/proc/sys/net/ipv4/conf/DEV/proxy_arp

> If you set this to 1, all other interfaces will respond to arp queries destined for addresses on this interface. Can be very useful when building 'ip pseudo bridges'. Do take care that your netmasks are very correct before enabling this!

/proc/sys/net/ipv4/conf/DEV/rp_filter

> See the section on reverse path filters.

/proc/sys/net/ipv4/conf/DEV/secure_redirects

> FIXME: fill this in

/proc/sys/net/ipv4/conf/DEV/send_redirects

> If we send the above mentioned redirects.

/proc/sys/net/ipv4/conf/DEV/shared_media

> FIXME: fill this in

/proc/sys/net/ipv4/conf/DEV/tag

> FIXME: fill this in

14.2.3   Neighbor pollicy

Dev can either stand for a real interface, or for 'all' or 'default'. Default also changes settings for interfaces yet to be created.

/proc/sys/net/ipv4/neigh/DEV/anycast_delay

> FIXME: fill this in

/proc/sys/net/ipv4/neigh/DEV/app_solicit

    FIXME: fill this in

/proc/sys/net/ipv4/neigh/DEV/base_reachable_time

    FIXME: fill this in

/proc/sys/net/ipv4/neigh/DEV/delay_first_probe_time

    FIXME: fill this in

/proc/sys/net/ipv4/neigh/DEV/gc_stale_time

    FIXME: fill this in

/proc/sys/net/ipv4/neigh/DEV/locktime

    FIXME: fill this in

/proc/sys/net/ipv4/neigh/DEV/mcast_solicit

    FIXME: fill this in

/proc/sys/net/ipv4/neigh/DEV/proxy_delay

    FIXME: fill this in

/proc/sys/net/ipv4/neigh/DEV/proxy_qlen

    FIXME: fill this in

/proc/sys/net/ipv4/neigh/DEV/retrans_time

    FIXME: fill this in

/proc/sys/net/ipv4/neigh/DEV/ucast_solicit

    FIXME: fill this in

/proc/sys/net/ipv4/neigh/DEV/unres_qlen

    FIXME: fill this in

14.2.4 Routing settings

/proc/sys/net/ipv4/route/error_burst

    FIXME: fill this in

/proc/sys/net/ipv4/route/error_cost

    FIXME: fill this in

/proc/sys/net/ipv4/route/flush

    FIXME: fill this in

/proc/sys/net/ipv4/route/gc_elasticity

    FIXME: fill this in

/proc/sys/net/ipv4/route/gc_interval

    FIXME: fill this in

/proc/sys/net/ipv4/route/gc_min_interval

> FIXME: fill this in

/proc/sys/net/ipv4/route/gc_thresh

> FIXME: fill this in

/proc/sys/net/ipv4/route/gc_timeout

> FIXME: fill this in

/proc/sys/net/ipv4/route/max_delay

> FIXME: fill this in

/proc/sys/net/ipv4/route/max_size

> FIXME: fill this in

/proc/sys/net/ipv4/route/min_adv_mss

> FIXME: fill this in

/proc/sys/net/ipv4/route/min_delay

> FIXME: fill this in

/proc/sys/net/ipv4/route/min_pmtu

> FIXME: fill this in

/proc/sys/net/ipv4/route/mtu_expires

> FIXME: fill this in

/proc/sys/net/ipv4/route/redirect_load

> FIXME: fill this in

/proc/sys/net/ipv4/route/redirect_number

> FIXME: fill this in

/proc/sys/net/ipv4/route/redirect_silence

> FIXME: fill this in

15 Backbone applications of traffic control

This chapter is meant as an introduction to backbone routing, which often involves >100 megabit bandwidths, which requires a different approach then your ADSL modem at home.

15.1 Router queues

The normal behaviour of router queues on the Internet is called tail-drop. Tail-drop works by queueing up to a certain amount, then dropping all traffic that 'spills over'. This is very unfair, and also leads to retransmit synchronisation. When retransmit synchronisation occurs, the sudden burst of drops from a router that has reached its fill will cause a delayed burst of retransmits, which will over fill the congested router again.

In order to cope with transient congestion on links, backbone routers will often implement large queues. Unfortunately, while these queues are good for throughput, they can substantially increase latency and cause TCP connections to behave very bursty during congestion.

These issues with tail-drop are becoming increasingly troublesome on the Internet because the use of network unfriendly applications is increasing. The Linux kernel offers us RED, short for Random Early Detect.

RED isn't a cure-all for this, applications which inappropriately fail to implement exponential backoff still get an unfair share of the bandwidth, however, with RED they do not cause as much harm to the throughput and latency of other connections.

RED statistically drops packets from flows before it reaches its hard limit. This causes a congested backbone link to slow more gracefully, and prevents retransmit synchronisation. This also helps TCP find its 'fair' speed faster by allowing some packets to get dropped sooner keeping queue sizes low and latency under control. The probability of a packet being dropped from a particular connection is proportional to its bandwidth usage rather then the number of packets it transmits.

RED is a good queue for backbones, where you can't afford the complexity of per-session state tracking needed by fairness queueing.

In order to use RED, you must decide on three parameters: Min, Max, and burst. Min sets the minimum queue size in bytes before dropping will begin, Max is a soft maximum that the algorithm will attempt to stay under, and burst sets the maximum number of packets that can 'burst through'.

You should set the min by calculating that highest acceptable base queueing latency you wish, and multiply it by your bandwidth. For instance, on my 64kbit/s ISDN link, I might want a base queueing latency of 200ms so I set min to 1600 bytes. Setting min too small will degrade throughput and too large will degrade latency. Setting a small min is not a replacement for reducing the MTU on a slow link to improve interactive response.

You should make max at least twice min to prevent synchronisation. On slow links with small min's it might be wise to make max perhaps four or more times large then min.

Burst controls how the RED algorithm responds to bursts. Burst must be set larger then min/avpkt. Experimentally, I've found (min+min+max)/(3*avpkt) to work okay.

Additionally, you need to set limit and avpkt. Limit is a safety value, after there are limit bytes in the queue, RED 'turns into' tail-drop. I typical set limit to eight times max. Avpkt should be your average packet size. 1000 works okay on high speed Internet links with a 1500byte MTU.

Read *the paper on RED queueing* <http://www.aciri.org/floyd/papers/red/red.html> by Sally Floyd and Van Jacobson for technical information.

FIXME: more needed. This means *you* greg :-) - ahu

16 Cookbook

This section contains 'cookbook' entries which may help you solve problems. A cookbook is no replacement for understanding however, so try and comprehend what is going on.

16.1 Running multiple sites with different SLAs

You can do this in several ways. Apache has some support for this with a module, but we'll show how Linux can do this for you, and do so for other services as well. These commands are stolen from a presentation by Jamal Hadi that's referenced below.

Let's say we have two customers, with http, ftp and streaming audio, and we want to sell them a limited amount of bandwidth. We do so on the server itself.

Customer A should have at most 2 megabits, customer B has paid for 5 megabits. We separate our customers by creating virtual IP addresses on our server.

```
# ip address add 188.177.166.1 dev eth0
# ip address add 188.177.166.2 dev eth0
```

It is up to you to attach the different servers to the right IP address. All popular daemons have support for this.

We first attach a CBQ qdisc to eth0:

```
# tc qdisc add dev eth0 root handle 1: cbq bandwidth 10Mbit cell 8 avpkt 1000 \
  mpu 64
```

We then create classes for our customers:

```
# tc class add dev eth0 parent 1:0 classid 1:1 cbq bandwidth 10Mbit rate \
  2MBit avpkt 1000 prio 5 bounded isolated allot 1514 weight 1 maxburst 21
# tc class add dev eth0 parent 1:0 classid 1:2 cbq bandwidth 10Mbit rate \
  5Mbit avpkt 1000 prio 5 bounded isolated allot 1514 weight 1 maxburst 21
```

Then we add filters for our two classes:

```
##FIXME: Why this line, what does it do?, what is a divisor?:
##FIXME: A divisor has something to do with a hash table, and the number of
##       buckets - ahu
# tc filter add dev eth0 parent 1:0 protocol ip prio 5 handle 1: u32 divisor 1
# tc filter add dev eth0 parent 1:0 prio 5 u32 match ip src 188.177.166.1
  flowid 1:1
# tc filter add dev eth0 parent 1:0 prio 5 u32 match ip src 188.177.166.2
  flowid 1:2
```

And we're done.

FIXME: why no token bucket filter? is there a default pfifo_fast fallback somewhere?

16.2   Protecting your host from SYN floods

From Alexey's iproute documentation, adapted to netfilter and with more plausible paths. If you use this, take care to adjust the numbers to reasonable values for your system.

If you want to protect an entire network, skip this script, which is best suited for a single host.

It appears that you need the very latest version of the iproute2 tools to get this to work with 2.4.0.

```
#! /bin/sh -x
#
# sample script on using the ingress capabilities
# this script shows how one can rate limit incoming SYNs
# Useful for TCP-SYN attack protection. You can use
# IPchains to have more powerful additions to the SYN (eg
# in addition the subnet)
#
#path to various utilities;
#change to reflect yours.
#
TC=/sbin/tc
IP=/sbin/ip
IPTABLES=/sbin/iptables
INDEV=eth2
#
# tag all incoming SYN packets through $INDEV as mark value 1
############################################################
$iptables -A PREROUTING -i $INDEV -t mangle -p tcp --syn \
  -j MARK --set-mark 1
############################################################
#
# install the ingress qdisc on the ingress interface
############################################################
$TC qdisc add dev $INDEV handle ffff: ingress
############################################################


#
#
# SYN packets are 40 bytes (320 bits) so three SYNs equals
# 960 bits (approximately 1kbit); so we rate limit below
# the incoming SYNs to 3/sec (not very useful really; but
#serves to show the point - JHS
############################################################
$TC filter add dev $INDEV parent ffff: protocol ip prio 50 handle 1 fw \
police rate 1kbit burst 40 mtu 9k drop flowid :1
############################################################


#
echo "---- qdisc parameters Ingress  ----------"
$TC qdisc ls dev $INDEV
echo "---- Class parameters Ingress  ----------"
```

```
$TC class ls dev $INDEV
echo "---- filter parameters Ingress ----------"
$TC filter ls dev $INDEV parent ffff:

#deleting the ingress qdisc
#$TC qdisc del $INDEV ingress
```

16.3   Ratelimit ICMP to prevent dDoS

Recently, distributed denial of service attacks have become a major nuisance on the internet. By properly filtering and ratelimiting your network, you can both prevent becoming a casualty or the cause of these attacks.

You should filter your networks so that you do not allow non-local IP source addressed packets to leave your network. This stops people from anonymously sending junk to the internet.

Rate limiting goes much as shown earlier. To refresh your memory, our ASCIIgram again:

```
[The Internet] ---<E3, T3, whatever>--- [Linux router] --- [Office+ISP]
                                        eth1           eth0
```

We first set up the prerequisite parts:

```
# tc qdisc add dev eth0 root handle 10: cbq bandwidth 10Mbit avpkt 1000
# tc class add dev eth0 parent 10:0 classid 10:1 cbq bandwidth 10Mbit rate \
  10Mbit allot 1514 prio 5 maxburst 20 avpkt 1000
```

If you have 100Mbit, or more, interfaces, adjust these numbers. Now you need to determine how much ICMP traffic you want to allow. You can perform measurements with tcpdump, by having it write to a file for a while, and seeing how much ICMP passes your network. Do not forget to raise the snapshot length!

If measurement is impractical, you might want to choose 5% of your available bandwidth. Let's set up our class:

```
# tc class add dev eth0 parent 10:1 classid 10:100 cbq bandwidth 10Mbit rate \
  100Kbit allot 1514 weight 800Kbit prio 5 maxburst 20 avpkt 250 \
  bounded
```

This limits at 100Kbit. Now we need a filter to assign ICMP traffic to this class:

```
# tc filter add dev eth0 parent 10:0 protocol ip prio 100 u32 match ip
  protocol 1 0xFF flowid 10:100
```

16.4   Prioritizing interactive traffic

If lots of data is coming down your link, or going up for that matter, and you are trying to do some maintenance via telnet or ssh, this may not go too well. Other packets are blocking your keystrokes. Wouldn't it be great if there were a way for your interactive packets to sneak past the bulk traffic? Linux can do this for you!

As before, we need to handle traffic going both ways. Evidently, this works best if there are Linux boxes on both ends of your link, although other UNIX's are able to do this. Consult your local Solaris/BSD guru for this.

The standard pfifo_fast scheduler has 3 different 'bands'. Traffic in band 0 is transmitted first, after which traffic in band 1 and 2 gets considered. It is vital that our interactive traffic be in band 0!

We blatantly adapt from the (soon to be obsolete) ipchains HOWTO:

There are four seldom-used bits in the IP header, called the Type of Service (TOS) bits. They effect the way packets are treated; the four bits are "Minimum Delay", "Maximum Throughput", "Maximum Reliability" and "Minimum Cost". Only one of these bits is allowed to be set. Rob van Nieuwkerk, the author of the ipchains TOS-mangling code, puts it as follows:

```
Especially the "Minimum Delay" is important for me.  I switch it on for "interactive"
packets in my upstream (Linux) router.  I'm behind a 33k6 modem link.  Linux prioritizes
packets in 3 queues.  This way I get acceptable interactive performance while doing bulk
downloads at the same time.
```

The most common use is to set telnet & ftp control connections to "Minimum Delay" and FTP data to "Maximum Throughput". This would be done as follows, on your upstream router:

```
# iptables -A PREROUTING -t mangle -p tcp --sport telnet \
  -j TOS --set-tos Minimize-Delay
# iptables -A PREROUTING -t mangle -p tcp --sport ftp \
  -j TOS --set-tos Minimize-Delay
# iptables -A PREROUTING -t mangle -p tcp --sport ftp-data \
  -j TOS --set-tos Maximize-Throughput
```

Now, this only works for data going from your telnet foreign host to your local computer. The other way around appears to be done for you, ie, telnet, ssh & friends all set the TOS field on outgoing packets automatically.

Should you have a client that does not do this, you can always do it with netfilter. On your local box:

```
# iptables -A OUTPUT -t mangle -p tcp --dport telnet \
  -j TOS --set-tos Minimize-Delay
# iptables -A OUTPUT -t mangle -p tcp --dport ftp \
  -j TOS --set-tos Minimize-Delay
# iptables -A OUTPUT -t mangle -p tcp --dport ftp-data \
  -j TOS --set-tos Maximize-Throughput
```

16.5 Transparent web-caching using netfilter, iproute2, ipchains and squid

This section was sent in by reader Ram Narula from Internet for Education (Thailand).

The regular technique in accomplishing this in Linux is probably with use of ipchains AFTER making sure that the "outgoing" port 80(web) traffic gets routed through the server running squid.

There are 3 common methods to make sure "outgoing" port 80 traffic gets routed to the server running squid and 4th one is being introduced here.

Making the gateway router do it.

If you can tell your gateway router to match packets that has outgoing destination port of 80 to be sent to the IP address of squid server.

BUT

This would put additional load on the router and some commercial routers might not even support this.

Using a Layer 4 switch.

Layer 4 switches can handle this without any problem.

BUT

The cost for this equipment is usually very high. Typical layer 4 switch would normally cost more than a typical router+good linux server.

Using cache server as network's gateway.

You can force ALL traffic through cache server.

BUT

This is quite risky because Squid does utilize lots of cpu power which might result in slower over-all network performance or the server itself might crash and no one on the network will be able to access the internet if that occurs.

Linux+NetFilter router.

By using NetFilter another technique can be implemented which is using NetFilter for "mark"ing the packets with destination port 80 and using iproute2 to route the "mark"ed packets to the Squid server.

```
|----------------|
| Implementation |
|----------------|

 Addresses used
 10.0.0.1 naret (NetFilter server)
 10.0.0.2 silom (Squid server)
 10.0.0.3 donmuang (Router connected to the internet)
 10.0.0.4 kaosarn (other server on network)
 10.0.0.5 RAS
 10.0.0.0/24 main network
 10.0.0.0/19 total network

|---------------|
|Network diagram|
|---------------|

Internet
|
donmuang
|
------------hub/switch----------
|         |             |       |
naret   silom        kaosarn  RAS etc.
```

First, make all traffic pass through naret by making sure it is the default gateway except for silom. Silom's default gateway has to be donmuang (10.0.0.3) or this would create web traffic loop.

(all servers on my network had 10.0.0.1 as the default gateway which was the former IP address of donmuang router so what I did was changed the IP address of donmuang to 10.0.0.3 and gave naret ip address of 10.0.0.1)

```
Silom
-----
-setup squid and ipchains
```

Setup Squid server on silom, make sure it does support transparent caching/proxying, the default port is usually 3128, so all traffic for port 80 has to be redirected to port 3128 locally. This can be done by using ipchains with the following:

```
silom# ipchains -N allow1
silom# ipchains -A allow1 -p TCP -s 10.0.0.0/19 -d 0/0 80 -j REDIRECT 3128
silom# ipchains -I input -j allow1
```

Or, in netfilter lingo:

```
silom# iptables -t nat -A PREROUTING -i eth0 -p tcp --dport 80 -j REDIRECT --to-port 3128
```

(note: you might have other entries as well)

For more information on setting Squid server please refer to Squid faq page on *http://squid.nlanr.net* <http://squid.nlanr.net>).

Make sure ip forwarding is enabled on this server and the default gateway for this server is donmuang router (NOT naret).

```
Naret
-----
-setup iptables and iproute2
-disable icmp REDIRECT messages (if needed)
```

1. "Mark" packets of destination port 80 with value 2

```
naret# iptables -A PREROUTING -i eth0 -t mangle -p tcp --dport 80 \
 -j MARK --set-mark 2
```

2. Setup iproute2 so it will route packets with "mark" 2 to silom

```
naret# echo 202 www.out >> /etc/iproute2/rt_tables
naret# ip rule add fwmark 2 table www.out
naret# ip route add default via 10.0.0.2 dev eth0 table www.out
naret# ip route flush cache
```

If donmuang and naret is on the same subnet then naret should not send out icmp REDIRECT messages. In this case it is, so icmp REDIRECTs has to be disabled by:

```
      naret# echo 0 > /proc/sys/net/ipv4/conf/all/send_redirects
      naret# echo 0 > /proc/sys/net/ipv4/conf/default/send_redirects
      naret# echo 0 > /proc/sys/net/ipv4/conf/eth0/send_redirects
```

The setup is complete, check the configuration

```
   On naret:

   naret# iptables -t mangle -L
   Chain PREROUTING (policy ACCEPT)
   target     prot opt source               destination
   MARK       tcp  --  anywhere             anywhere            tcp dpt:www MARK set 0x2

   Chain OUTPUT (policy ACCEPT)
   target     prot opt source               destination

   naret# ip rule ls
   0:      from all lookup local
   32765:  from all fwmark        2 lookup www.out
   32766:  from all lookup main
   32767:  from all lookup default

   naret# ip route list table www.out
   default via 203.114.224.8 dev eth0

   naret# ip route
   10.0.0.1 dev eth0  scope link
   10.0.0.0/24 dev eth0  proto kernel  scope link  src 10.0.0.1
   127.0.0.0/8 dev lo  scope link
   default via 10.0.0.3 dev eth0

   (make sure silom belongs to one of the above lines, in this case
   it's the line with 10.0.0.0/24)

   |------|
   |-DONE-|
   |------|
```

16.5.1 Traffic flow diagram after implementation

```
   |---------------------------------------|
   |Traffic flow diagram after implementation|
   |---------------------------------------|

   INTERNET
   /\
   ||
   \/
```

```
-----------------donmuang router--------------------
/\                                    /\          ||
||                                    ||          ||
||                                    \/          ||
naret                                silom        ||
*destination port 80 traffic=========>(cache)     ||
/\                                    ||          ||
||                                    \/          \/
\\==================================kaosarn, RAS, etc.
```

Note that the network is asymmetric as there is one extra hop on general outgoing path.

```
Here is run down for packet traversing the network from kaosarn
to and from the internet.


For web/http traffic:
kaosarn http request->naret->silom->donmuang->internet
http replies from internet->donmuang->silom->kaosarn


For non-web/http requests(eg. telnet):
kaosarn outgoing data->naret->donmuang->internet
incoming data from internet->donmuang->kaosarn
```

16.6   Circumventing Path MTU Discovery issues with per route MTU settings

For sending bulk data, the internet generally works better when using larger packets. Each packet implies a routing decision, when sending a 1 megabyte file, this can either mean around 700 packets when using packets that are as large as possible, or 4000 if using the smallest default.

However, not all parts of the internet support full 1460 bytes of payload per packet. It is therefore necessary to try and find the largest packet that will 'fit', in order to optimize a connection.

This process is called 'Path MTU Discovery', where MTU stands for 'Maximum Transfer Unit.'

When a router encounters a packet that's too big too send in one piece, AND it has been flagged with the "Don't Fragment" bit, it returns an ICMP message stating that it was forced to drop a packet because of this. The sending host acts on this hint by sending smaller packets, and by iterating it can find the optimum packet size for a connection over a certain path.

This used to work well until the internet was discovered by hooligans who do their best to disrupt communications. This in turn lead administrators to either block or shape ICMP traffic in a misguided attempt to improve security or robustness of their internet service.

What has happened now is that Path MTU Discovery is working less and less well and fails for certain routes, which leads to strange TCP/IP sessions which die after a while.

Although I have no proof for this, two sites who I used to have this problem with both run Alteon Acedirectors before the affected systems - perhaps somebody more knowledgeable can provide clues as to why this happens.

16.6.1   Solution

When you encounter sites that suffer from this problem, you can disable Path MTU discovery by setting it manually. Koos van den Hout, slightly edited, writes:

> The following problem: I set the mtu/mru of my leased line running ppp to 296 because it's only 33k6 and I cannot influence the queueing on the other side. At 296, the response to a keypress is within a reasonable timeframe.
>
> And, on my side I have a masqrouter running (of course) Linux.
>
> Recently I split 'server' and 'router' so most applications are run on a different machine then the routing happens on.
>
> I then had trouble logging into irc. Big panic! Some digging did find out that I got connected to irc, even showed up as 'connected' on irc but I did not receive the motd from irc. I checked what could be wrong and noted that I already had some previous trouble reaching certain websites related to the MTU, since I had no trouble reaching them when the MTU was 1500, the problem just showed when the MTU was set to 296. Since irc servers block about every kind of traffic not needed for their immediate operation, they also block icmp.
>
> I managed to convince the operators of a webserver that this was the cause of a problem, but the irc server operators were not going to fix this.
>
> So, I had to make sure outgoing masqueraded traffic started with the lower mtu of the outside link. But I want local ethernet traffic to have the normal mtu (for things like nfs traffic).
>
> Solution:
>
> ```
> ip route add default via 10.0.0.1 mtu 296
> ```
>
> (10.0.0.1 being the default gateway, the inside address of the masquerading router)

In general, it is possible to override PMTU Discovery by setting specific routes. For example, if only a certain subnet is giving problems, this should help:

```
ip route add 195.96.96.0/24 via 10.0.0.1 mtu 1000
```

16.7   Circumventing Path MTU Discovery issues with MSS Clamping (for ADSL, cable, PPPoE & PPtP users)

As explained above, Path MTU Discovery doesn't work as well as it should anymore. If you know for a fact that a hop somewhere in your network has a limited (<1500) MTU, you cannot rely on PMTU Discovery finding this out.

Besides MTU, there is yet another way to set the maximum packet size, the so called Maximum Segment Size. This is a field in the TCP Options part of a SYN packet.

Recent Linux kernels, and a few pppoe drivers (notably, the excellent Roaring Penguin one), feature the possibility to 'clamp the MSS'.

The good thing about this is that by setting the MSS value, you are telling the remote side unequivocally 'do not ever try to send me packets bigger than this value'. No ICMP traffic is needed to get this to work.

The bad thing is that it's an obvious hack - it breaks 'end to end' by modifying packets. Having said that, we use this trick in many places and it works like a charm.

In order for this to work you need at least iptables-1.2.1a and Linux 2.4.3 or higher. The basic commandline is:

```
# iptables -A FORWARD -p tcp --tcp-flags SYN,RST SYN -j TCPMSS  --clamp-mss-to-pmtu
```

This calculates the proper MSS for your link. If you are feeling brave, or think that you know best, you can also do something like this:

```
# iptables -A FORWARD -p tcp --tcp-flags SYN,RST SYN -j TCPMSS --set-mss 128
```

This sets the MSS of passing SYN packets to 128. Use this if you have VoIP with tiny packets, and huge http packets which are causing chopping in your voice calls.

17   Building bridges, and pseudo-bridges with Proxy ARP

Bridges are devices which can be installed in a network without any reconfiguration. A network switch is basically a many-port bridge. A bridge is often a 2-port switch. Linux does however support multiple interfaces in a bridge, making it a true switch.

Bridges are often deployed when confronted with a broken network that needs to be fixed without any alterations. Because the bridge is a layer-2 device, one layer below IP, routers and servers are not aware of its existence. This means that you can transparently block or modify certain packets, or do shaping.

Another good thing is that a bridge can often be replaced by a cross cable or a hub, should it break down.

The bad news is that a bridge can cause great confusion unless it is very well documented. It does not appear in traceroutes, but somehow packets disappear or get changed from point A to point B. You should also wonder if an organization that 'does not want to change anything' is doing the right thing.

17.1   State of bridging and iptables

As of Linux 2.4.3, bridging and iptables do not 'see' each other without help. If you bridge packets from eth0 to eth1, they do not 'pass' by iptables. This means that you cannot do filtering, or NAT or mangling or whatever.

There are several projects going on to fix this, the truly right one is by the author of the Linux 2.4 briding code, Lennert Buytenhek. The patch is not yet finished however, but it does work somewhat. It can be found on *the experimental bridge patches page* <http://www.math.leidenuniv.nl/~buytenh/bridge/devel/bridge-nf/>.

We expect this problem to be fixed soon.

17.2   Bridging and shaping

This does work as advertised. Be sure to figure out which side each interface is on, otherwise you might be shaping outbound traffic in your internal interface, which won't work. Use tcpdump if needed.

17.3 Pseudo-bridges with Proxy-ARP

If you just want to implement a Pseudo-bridge, skip down a few sections to 'Implementing it', but it is wise to read a bit about how it works in practice.

A Pseudo-bridge works a bit differently. By default, a bridge passes packets unaltered from one interface to the other. It only looks at the hardware address of packets to determine what goes where. This in turn means that you can bridge traffic that Linux does not understand, as long as it has an hardware address it does.

A 'Pseudo-bridge' works differently and looks more like a hidden router than a bridge, but like a bridge, it has little impact on network design.

An advantage of the fact that it is not a brige lies in the fact that packets really pass through the kernel, and can be filtered, changed, redirected or rerouted.

A real bridge can also be made to perform these feats, but it needs special code, like the Ethernet Frame Diverter, or the above mentioned patch.

Another advantage of a pseudo-bridge is that it does not pass packets it does not understand - thus cleaning your network of a lot of cruft. In cases where you need this cruft (like SAP packets, or Netbeui), use a real bridge.

17.3.1 ARP & Proxy-ARP

When a host wants to talk to another host on the same physical network segment, it sends out an Address Resolution Protocol packet, which, somewhat simplified, reads like this 'who has 10.0.0.1, tell 10.0.0.7'. In response to this, 10.0.0.1 replies with a short 'here' packet.

10.0.0.7 then sends packets to the hardware address mentioned in the 'here' packet. It caches this hardware address for a relatively long time, and after the cache expires, it reasks the question.

When building a Pseudo-bridge, we instruct the bridge to reply to these ARP packets, which causes the hosts in the network to send its packets to the bridge. The brige then processes these packets, and sends them to the relevant interface.

So, in short, whenever a host on one side of the bridge asks for the hardware address of a host on the other, the bridge replies with a packet that says 'hand it to me'.

This way, all data traffic gets transmitted to the right place, and always passes through the bridge

17.3.2 Implementing it

In the bad old days, it used to be possible to instruct the Linux Kernel to perform 'proxy-ARP' for just any subnet. So, so to configure a pseudo-bridge, you would have to specify both the proper routes to both sides of the bridge AND create proxy-ARP rules. This is bad in that it requires a lot of typing, but also because it easily allows you to make mistakes which make your bridge respond to ARP queries for networks it does not know how to route.

With Linux 2.4 (and possibly 2.2), this possibility has been withdrawn and has been replaced by a flag in the /proc directory, called 'proxy_arp'. The procedure for building a pseudo-bridge is then:

  1. Assign an IP address to both interfaces, the 'left' and the 'right' one

2. Create routes so your machine knows which hosts reside on the left, and which on the right

3. Turn on proxy-ARP on both interfaces, echo 1 > /proc/sys/net/ipv4/conf/ethL/proxy_arp, echo 1 > /proc/sys/net/ipv4/conf/ethR/proxy_arp, where L and R stand for the numbers of your interfaces on the left and on the right side

Also, do not forget to turn on the ip_forwarding flag! When converting from a true bridge, you may find that this flag was turned off as it is not needed when bridging.

Another thing you might note when converting is that you need to clear the arp cache of computers in the network - the arp cache might contain old pre-bridge hardware addresses which are no longer correct.

On a Cisco, this is done using the command 'clear arp-cache', under Linux, use 'arp -d ip.address'. You can also wait for the cache to expire manually, which can take rather long.

18 Advanced Linux Routing

This section is for all you people who either want to understand why the whole system works or have a configuration that's so bizarre that you need the low down to make it work.

This section is completely optional. It's quite possible that this section will be quite complex and really not intended for normal users. You have been warned.

FIXME: Decide what really need to go in here.

18.1 How does packet queueing really work?

This is the low-down on how the packet queueing system really works.

Lists the steps the kernel takes to classify a packet, etc...

FIXME: Write this.

18.2 Advanced uses of the packet queueing system

Go through Alexey's extremely tricky example involving the unused bits in the TOS field.

FIXME: Write this.

18.3 Other packet shaping systems

I'd like to include a brief description of other packet shaping systems in other operating systems and how they compare to the Linux one. Since Linux is one of the few OSes that has a completely original (non-BSD derived) TCP/IP stack, I think it would be useful to see how other people do it.

Unfortunately I have no experience with other systems so cannot write this.

FIXME: Anyone? - Martijn

19 Dynamic routing - OSPF and BGP

Once your network starts to get really big, or you start to consider 'the internet' as your network, you need tools which dynamically route your data. Sites are often connected to each other with multiple links, and more are popping up all the time.

The Internet has mostly standardised on OSPF and BGP4 (rfc1771). Linux supports both, by way of `gated` and `zebra`

While currently not within the scope of this document, we would like to point you to the definitive works:

Overview:

Cisco Systems *Designing large-scale IP internetworks* <http://www.cisco.com/univercd/cc/td/doc/cisintwk/idg4/nd2003.htm>

For OSPF:

Moy, John T. "OSPF. The anatomy of an Internet routing protocol" Addison Wesley. Reading, MA. 1998.

Halabi has also written a good guide to OSPF routing design, but this appears to have been dropped from the Cisco web site.

For BGP:

Halabi, Bassam "Internet routing architectures" Cisco Press (New Riders Publishing). Indianapolis, IN. 1997.

also

Cisco Systems

Using the Border Gateway Protocol for interdomain routing <http://www.cisco.com/univercd/cc/td/doc/cisintwk/ics/icsbgp4.htm>

Although the examples are Cisco-specific, they are remarkably similar to the configuration language in Zebra :-)

20 Other possibilities

This chapter is a list of projects having to do with advanced Linux routing & traffic shaping. Some of these links may deserve chapters of their own, some are documented very well of themselves, and don't need more HOWTO.

802.1Q VLAN Implementation for Linux *(site)* <http://scry.wanfear.com/~greear/vlan.html>

> VLANs are a very cool way to segregate your networks in a more virtual than physical way. Good information on VLANs can be found *here* <ftp://ftp.netlab.ohio-state.edu/pub/jain/courses/cis788-97/virtual_lans/index.htm>. With this implementation, you can have your Linux box talk VLANs with machines like Cisco Catalyst, 3Com: {Corebuilder, Netbuilder II, SuperStack II switch 630}, Extreme Ntwks Summit 48, Foundry: {ServerIronXL, FastIron}.

Alternate 802.1Q VLAN Implementation for Linux *(site)* <http://vlan.sourceforge.net>

Alternative VLAN implementation for linux. This project was started out of disagreement with the 'established' VLAN project's architecture and coding style, resulting in a cleaner overall design.

Linux Virtual Server *(site)* `<http://www.LinuxVirtualServer.org/>`

These people are brilliant. The Linux Virtual Server is a highly scalable and highly available server built on a cluster of real servers, with the load balancer running on the Linux operating system. The architecture of the cluster is transparent to end users. End users only see a single virtual server.

In short whatever you need to loadbalance, at whatever level of traffic, LVS will have a way of doing it. Some of their techniques are positively evil! For example, they let several machines have the same IP address on a segment, but turn of ARP on them. Only the LVS machine does ARP - it then decides which of the backend hosts should handle an incoming packet, and sends it directly to the right MAC address of the backend server. Outgoing traffic will flow directly to the router, and not via the LVS machine, which does therefor not need to see your 5Gbit/s of content flowing to the world, and cannot be a bottleneck.

The LVS is implemented as a kernel patch in Linux 2.0 and 2.2, but as a Netfilter module in 2.4, so it does not need kernel patches! Their 2.4 support is still in early development, so beat on it and give feedback or send patches.

CBQ.init *(site)* `<ftp://ftp.equinox.gu.net/pub/linux/cbq/>`

Configuring CBQ can be a bit daunting, especially if all you want to do is shape some computers behind a router. CBQ.init can help you configure Linux with a simplified syntax.

For example, if you want all computers in your 192.168.1.0/24 subnet (on 10mbit eth1) to be limited to 28kbit/s download speed, put this in the CBQ.init configuration file:

```
DEVICE=eth1,10Mbit,1Mbit
RATE=28Kbit
WEIGHT=2Kbit
PRIO=5
RULE=192.168.1.0/24
```

By all means use this program if the 'how and why' don't interest you. We're using CBQ.init in production and it works very well. It can even do some more advanced things, like time dependent shaping. The documentation is embedded in the script, which explains why you can't find a README.

Chronox easy shaping scripts *(site)* `<http://www.chronox.de>`

Stephan Mueller (smueller@chronox.de) wrote two useful scripts, 'limit.conn' and 'shaper'. The first one allows you to easily throttle a single download session, like this:

```
# limit.conn -s SERVERIP -p SERVERPORT -l LIMIT
```

It works on Linux 2.2 and 2.4.

The second script is more complicated, and can be used to make lots of different queues based on iptables rules, which are used to mark packets which are then shaped.

Virtual Router Redundancy Protocol implementation *(site)* `<http://w3.arobas.net/~jetienne/vrrpd/index.h`

This is purely for redundancy. Two machines with their own IP address and MAC Address together create a third IP Address and MAC Address, which is virtual. Originally intended purely for routers, which need constant MAC addresses, it also works for other servers.

The beauty of this approach is the incredibly easy configuration. No kernel compiling or patching required, all userspace.

Just run this on all machines participating in a service:

```
# vrrpd -i eth0 -v 50 10.0.0.22
```

And you are in business! 10.0.0.22 is now carried by one of your servers, probably the first one to run the vrrp daemon. Now disconnect that computer from the network and very rapidly one of the other computers will assume the 10.0.0.22 address, as well as the MAC address.

I tried this over here and had it up and running in 1 minute. For some strange reason it decided to drop my default gateway, but the -n flag prevented that.

This is a 'live' failover:

```
64 bytes from 10.0.0.22: icmp_seq=3 ttl=255 time=0.2 ms
64 bytes from 10.0.0.22: icmp_seq=4 ttl=255 time=0.2 ms
64 bytes from 10.0.0.22: icmp_seq=5 ttl=255 time=16.8 ms
64 bytes from 10.0.0.22: icmp_seq=6 ttl=255 time=1.8 ms
64 bytes from 10.0.0.22: icmp_seq=7 ttl=255 time=1.7 ms
```

Not *one* ping packet was lost! Just after packet 4, I disconnected my P200 from the network, and my 486 took over, which you can see from the higher latency.

21   Further reading

http://snafu.freedom.org/linux2.2/iproute-notes.html <http://snafu.freedom.org/linux2.2/iproute-notes.html>

Contains lots of technical information, comments from the kernel

http://www.davin.ottawa.on.ca/ols/ <http://www.davin.ottawa.on.ca/ols/>

Slides by Jamal Hadi Salim, one of the authors of Linux traffic control

http://defiant.coinet.com/iproute2/ip-cref/ <http://defiant.coinet.com/iproute2/ip-cref/>

HTML version of Alexeys LaTeX documentation - explains part of iproute2 in great detail

http://www.aciri.org/floyd/cbq.html <http://www.aciri.org/floyd/cbq.html>

Sally Floyd has a good page on CBQ, including her original papers. None of it is Linux specific, but it does a fair job discussing the theory and uses of CBQ. Very technical stuff, but good reading for those so inclined.

http://ceti.pl/~kravietz/cbq/NET4_tc.html <http://ceti.pl/~kravietz/cbq/NET4_tc.html>

Yet another HOWTO, this time in Polish! You can copy/paste command lines however, they work just the same in every language. The author is cooperating with us and may soon author sections of this HOWTO.

Differentiated Services on Linux <http://snafu.freedom.org/linux2.2/docs/draft-almesberger-wajhak-diffse>

Discussion on how to use Linux in a diffserv compliant environment. Pretty far removed from your everyday routing needs, but very interesting none the less. We may include a section on this at a later date.

IOS Committed Access Rate <http://www.cisco.com/univercd/cc/td/doc/product/software/ios111/cc111/car.h

> From the helpful folks of Cisco who have the laudable habit of putting their documentation online. Cisco syntax is different but the concepts are the same, except that we can do more and do it without routers the price of cars :-)

TCP/IP Illustrated, volume 1, W. Richard Stevens, ISBN 0-201-63346-9

> Required reading if you truly want to understand TCP/IP. Entertaining as well.

22   Acknowledgements

It is our goal to list everybody who has contributed to this HOWTO, or helped us demystify how things work. While there are currently no plans for a Netfilter type scoreboard, we do like to recognise the people who are helping.

- Ron Brinker <service%emcis.com>
- Lennert Buytenhek <buytenh@gnu.org>
- Esteve Camps <esteve@hades.udg.es>
- Marco Davids <marco@sara.nl>
- Stephan "Kobold" Gehring <Stephan.Gehring@bechtle.de>
- Nadeem Hasan <nhasan@usa.net>
- Koos van den Hout <koos@kzdoos.xs4all.nl>
- Philippe Latu <philippe.latu%linux-france.org>
- Jason Lunz <j@cc.gatech.edu>
- Alexey Mahotkin <alexm@formulabez.ru>
- Pawel Krawczyk <kravietz%alfa.ceti.pl>
- Wim van der Most
- Stephan Mueller <smueller@chronox.de>
- Ram Narula <ram@princess1.net>
- Jorge Novo <jnovo@educanet.net>
- Patrik <ph@kurd.nu>
- Jason Pyeron <jason%pyeron.com>
- Rusty Russell (with apologies for always misspelling your name)
- Jamal Hadi Salim <hadi%cyberus.ca>
- Sheharyar Suleman Shaikh <sss23@drexel.edu>

- Nick Silberstein <nhsilber%yahoo.com>

- Konrads Smelkov <konrads@interbaltika.com>

- Jason Tackaberry <tack@linux.com>

- Charles Tassell <ctassell%isn.net>

- Glen Turner <glen.turner%aarnet.edu.au>

- Song Wang <wsong@ece.uci.edu>