High speed firewalls with ipset

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Content

- Why we need an additional tool?
- Properties of ipset
- ipset and iptables examples

Special firewalls

- High number of rules
  - Fast evaluation algorithm
- Need to change the rules often
  - The rule storage method must support fast modifications

Special firewalls: iptables?

- iptables: http://www.netfilter.org/
- High number of rules: slow
  - Linear evaluation
- Change rules: slow/inefficient
  - **All** rule must be sent back and forth between kernel-userspace for the sake of changing a **single** rule
  - iptables-restore

Special firewalls: nf-hipac?

- nf-hipac: http://www.hipac.org/
- High number of rules: fast
  - Complex evaluation algorithm
- Change rules: fast
  - Just the change is sent
- Dead, last modification: 2005.

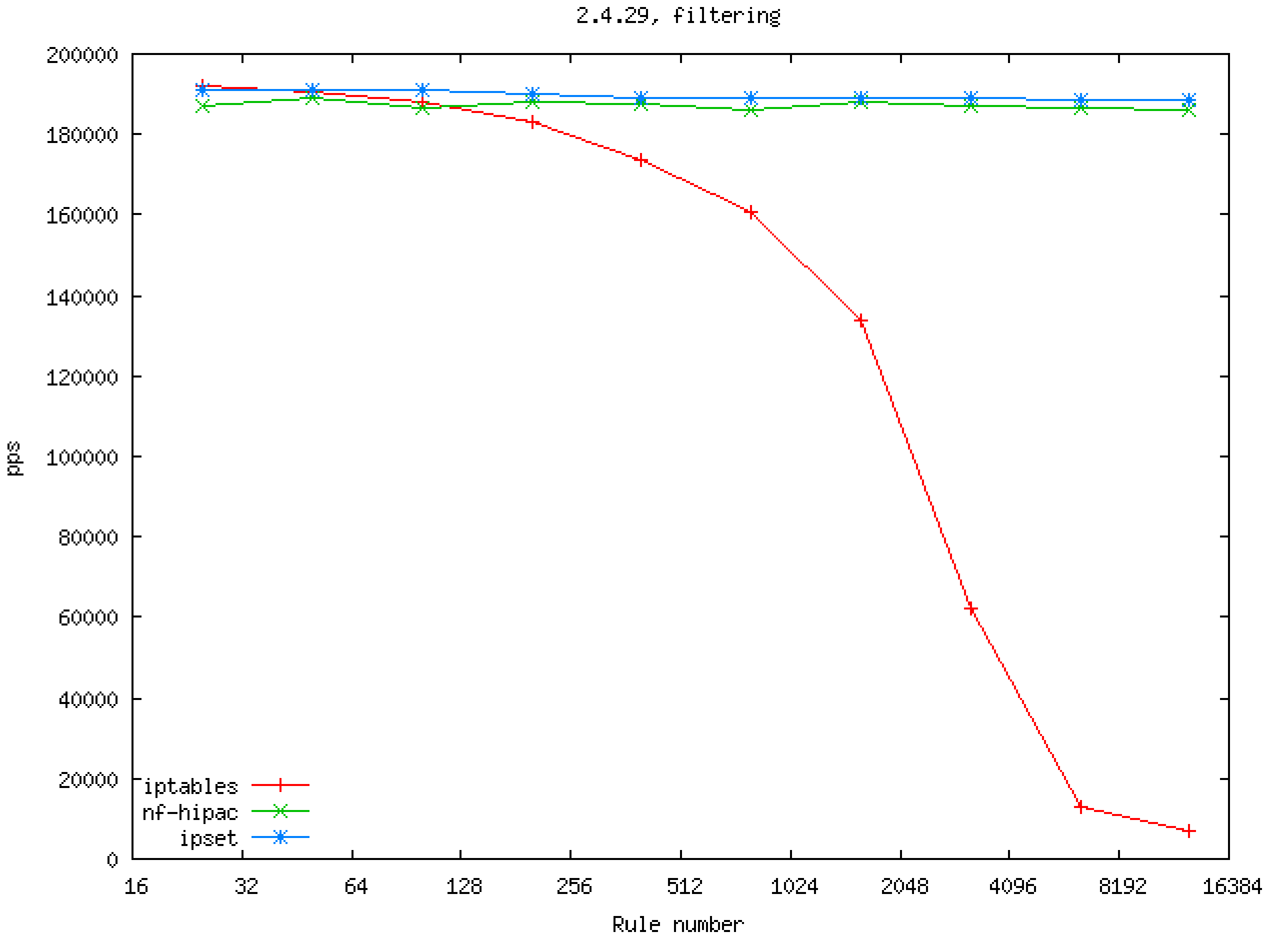
Special firewalls: ipset?

- ipset: http://ipset.netfilter.org/
- High number of rules: fast
  - Simple evaluation algorithms
- Change rules: fast
  - Just the change is sent, simple storage methods
- From 2.6.39 it's in the vanilla kernel

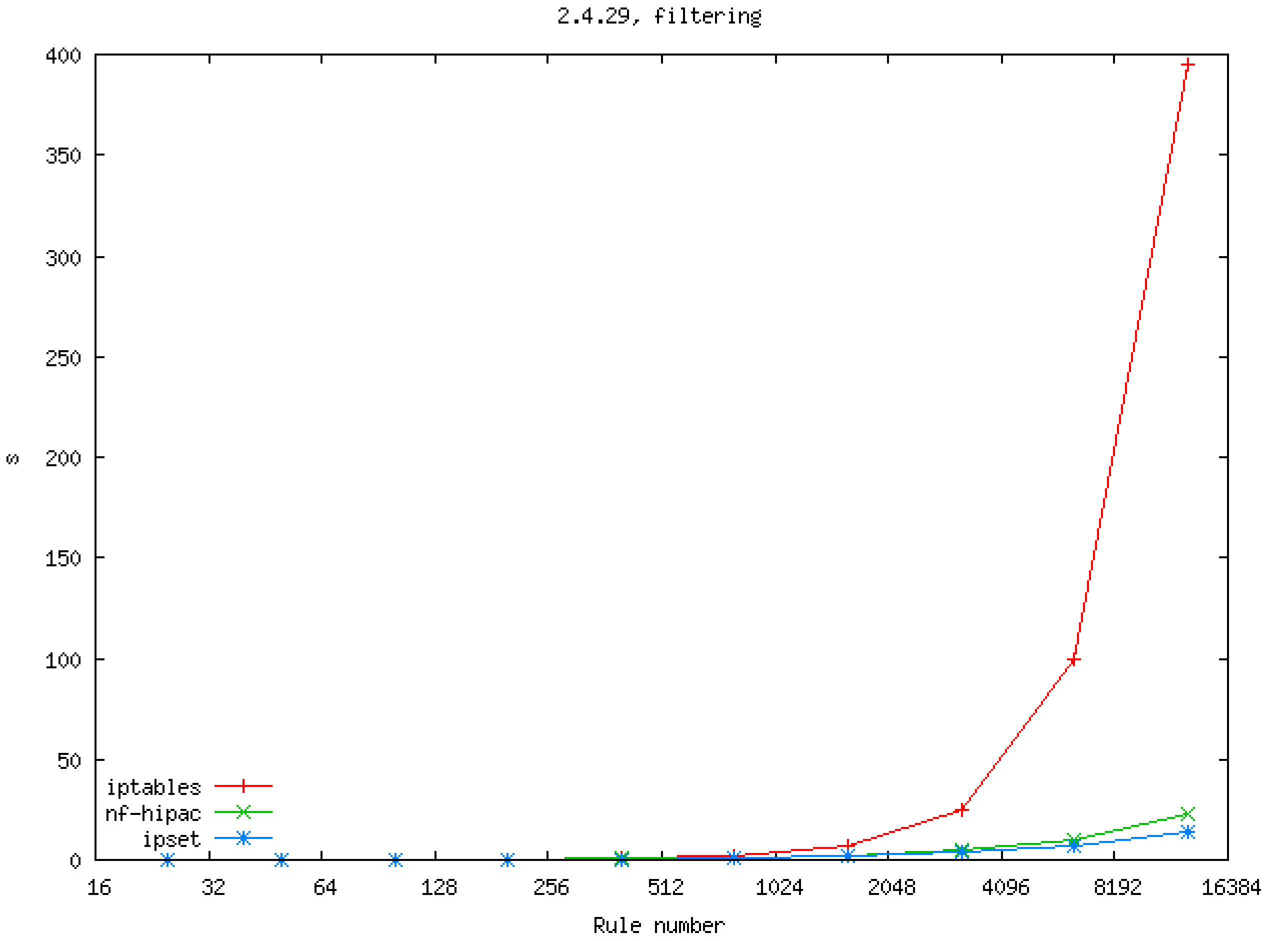
Real comparisons I.

- Netfilter performance testing (2005)
  - Dual Intel Xeon 2.4GHz
  - 2GB DDR RAM, 200MHz
  - ServerWorks GC-LE chipset
  - Intel 82545EM Gbit Ethernet, 64bit, 66MHz

iptables, nf-hipac and ipset I.

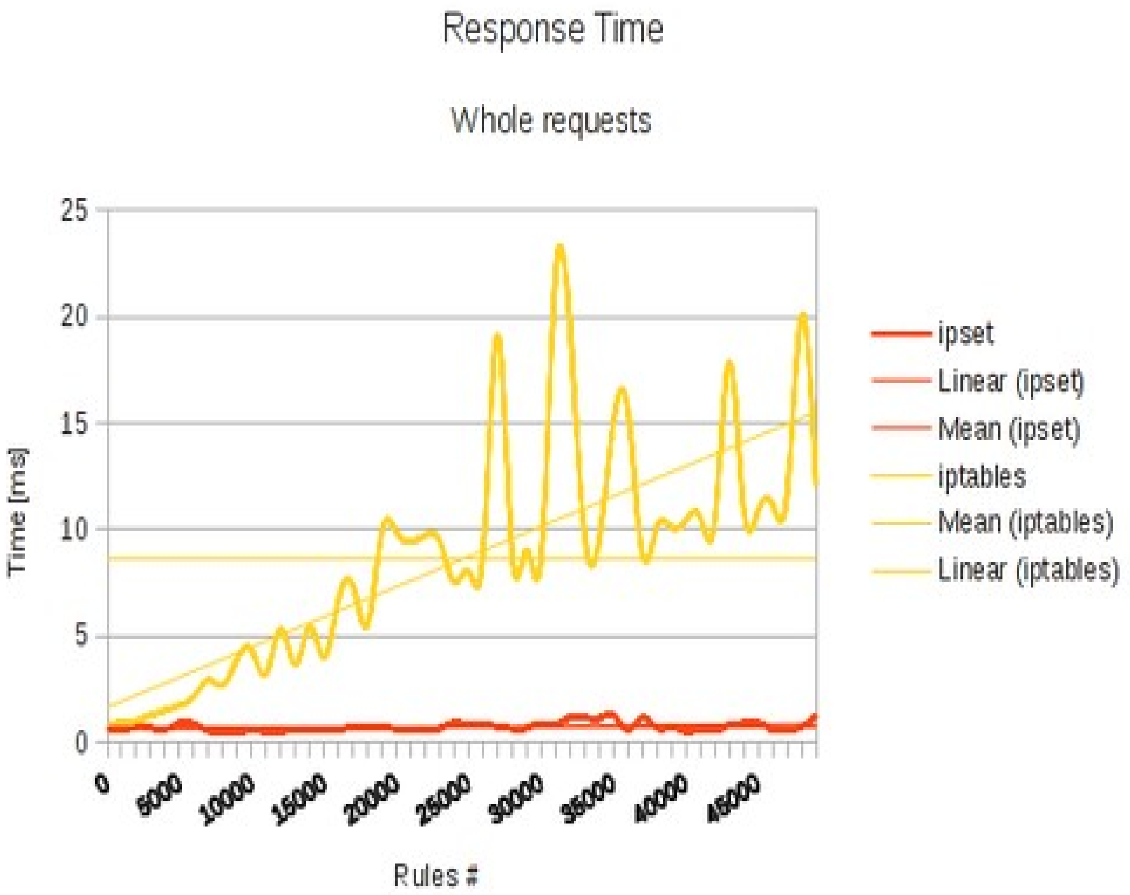


iptables, nf-hipac and ipset II.



Real comparisons II.

- Mass blocking IP addresses with ipset (2012)
  http://daemonkeeper.net/781/mass-blocking-ip-addresses-with-ipset/



ipset and ippool

- Joakim Axelsson: ippool, bitmap type
- Joakim Axelsson, Patrick Schaaf and Martin Josefsson: modular ippool, bitmap and macipmap types
- ipset: rewritten ippool, more types
- ipset 6.x: ipset rewritten from the ground

ipset

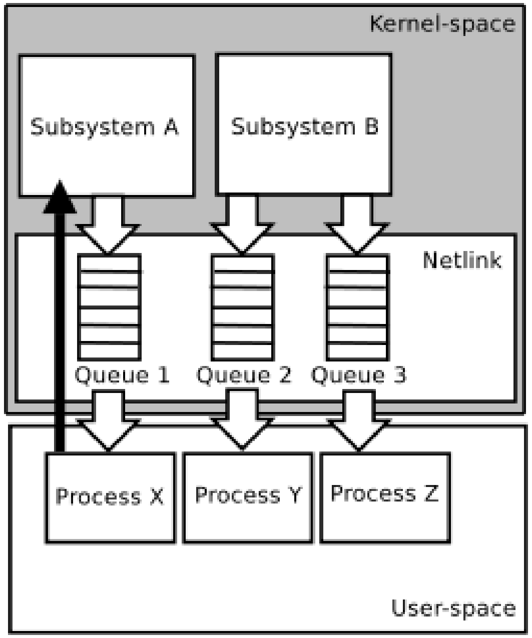
- In-kernel data sets: IP addresses, protocol/port numbers, MAC addresses, interfaces and several combinations
- Different storage methods: *bitmap, hash*, *list*
- Program to handle the sets: `ipset`
- Use the sets from iptables: `set` match and `SET` target

ipset 6.x

- Kernel-userspace communication: netlink
  - Flexible protocol, TLV
  - save-restore: PAGE_SIZE chunks
- IPv6 support
- Syntax similar to **ip**

netlink

- Queue handling over BSD socket infrastructure
- Pablo Neira Ayuso: *Communicating between the kernel and user-space in Linux using Netlink sockets.* Software: Practice and Experience, 2010.



netlink II.

- Netlink subsystems:
  - Rtnetlink
  - Nfnetlink
    - Conntrack-tools
    - NFLOG
    - ...
    - ipset
  - Genetlink

ipset netlink protocol

- Formalized
- Needs a simple kernel netlink interface modification:
  - netlink.patch below 2.6.39
- Supports batch mode (create + add)
- Userspace netlink library:
  - libnfnetlink
  - libnl
  - **libmnl**

ipset: unified syntax

- Type: method:elem1[,elem2[,elem3]]
  - hash:ip,port,ip
- Elem: part1[,part2[,part3]]
  - 192.168.1.1,80,10.10.10.10
- Iptables match/target: dir[,dir[,dir]]
  - dst,dst,src

Keyword-based syntax

- create, add, del, test, ...
  - No need for the dashes: `--create, --add, ...`
- Abbreviation, one-letter commands
- Backward compatibility

Timeout

- Every type supports timeouts:
  - Type without timeout
  - Type with timeout
- Timeout value can be reset:

```
create test hash:ip timeout 10

add test 10.0.0.1 timeout 0

add --exist test 10.0.0.1 timeout 20
```

ipset save-restore

- Restore implemented as batch mode

```
ipset save > ipset.rules

ipset restore < ipset.rules
```

iptables set match

- Search a match in an set by iptables: set match
- -m set <setname> src|dst[,src|dst]

```
ipset create servers hash:ip,port
ipset add servers 192.168.0.1,tcp:25
ipset add servers 192.168.0.2,tcp:80
iptables -A FORWARD -m set \
    --match-set servers dst,dst \
    -m state --state NEW -j log-accept
```

SET target

- Add/delete elements from sets by an iptables rule
- -j SET –add-set|--del-set <setname> src|dst[,...]

```
ipset create scanners hash:ip \
      --timeout $((60*60*24*7))
iptables -A FORWARD -d <honeypot> \
          -p tcp --dport 22 \
         -j SET --add-set scanners src
```

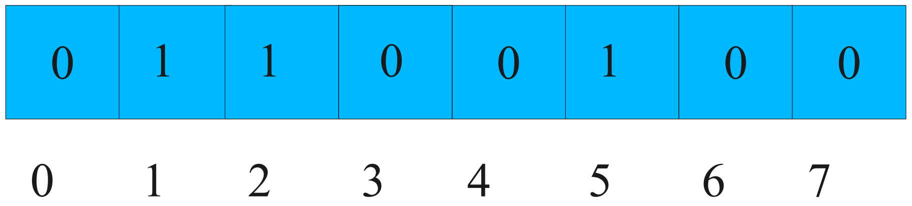
Swap

- A set referenced by a rule cannot be deleted – but can be swapped with another set:

```
ipset create main-set ...

iptables -A ... -m set --match-set main-set ...

ipset create main-set-tmp

ipset add main-set-tmp

...

ipset swap main-set main-set-tmp

ipset destroy main-set-tmp
```

Storage method: bitmap

- Continuous binary area, every bit can store and IPv4 address: 192.168.0.1, 192.168.0.2, 192.168.0.5



0	1	1	0	0	1	0	0
0	1	2	3	4	5	6	7

- Can be generalized to store same-sized networks, IPv4 and MAC pairs and TCP/UDP port numbers

bitmap:ip type

- Store IPv4 addresses from a range
  - One addess is stored in one **bit**
- Max 65536 elements (/16)

bitmap:ip examples

- Store IP addresses:

```
ipset create set1 bitmap:ip range 192.168.0.0-192.168.255.255

[ipset create set1 bitmap:ip range 192.168.0.0/16]

ipset add set1 192.168.0.1

ipset add set1 192.168.0.2-192.168.0.15
```

- Store same-sized whole networks:

```
ipset create set2 bitmap:ip range 0.0.0.0/0 netmask 16

ipset add set2 10.1.0.0

ipset add set2 10.7.0.1
```

bitmap:ip,mac type

- IPv4 and MAC pair
- Only source MAC
- First matching can fill out unspecified MAC

```
ipset create set3 bitmap:ip,mac range 192.168.0.0/16

ipset add set3 192.168.1.1,00:01:23:45:67:89

ipset add set3 192.168.2.3
```

bitmap:port type

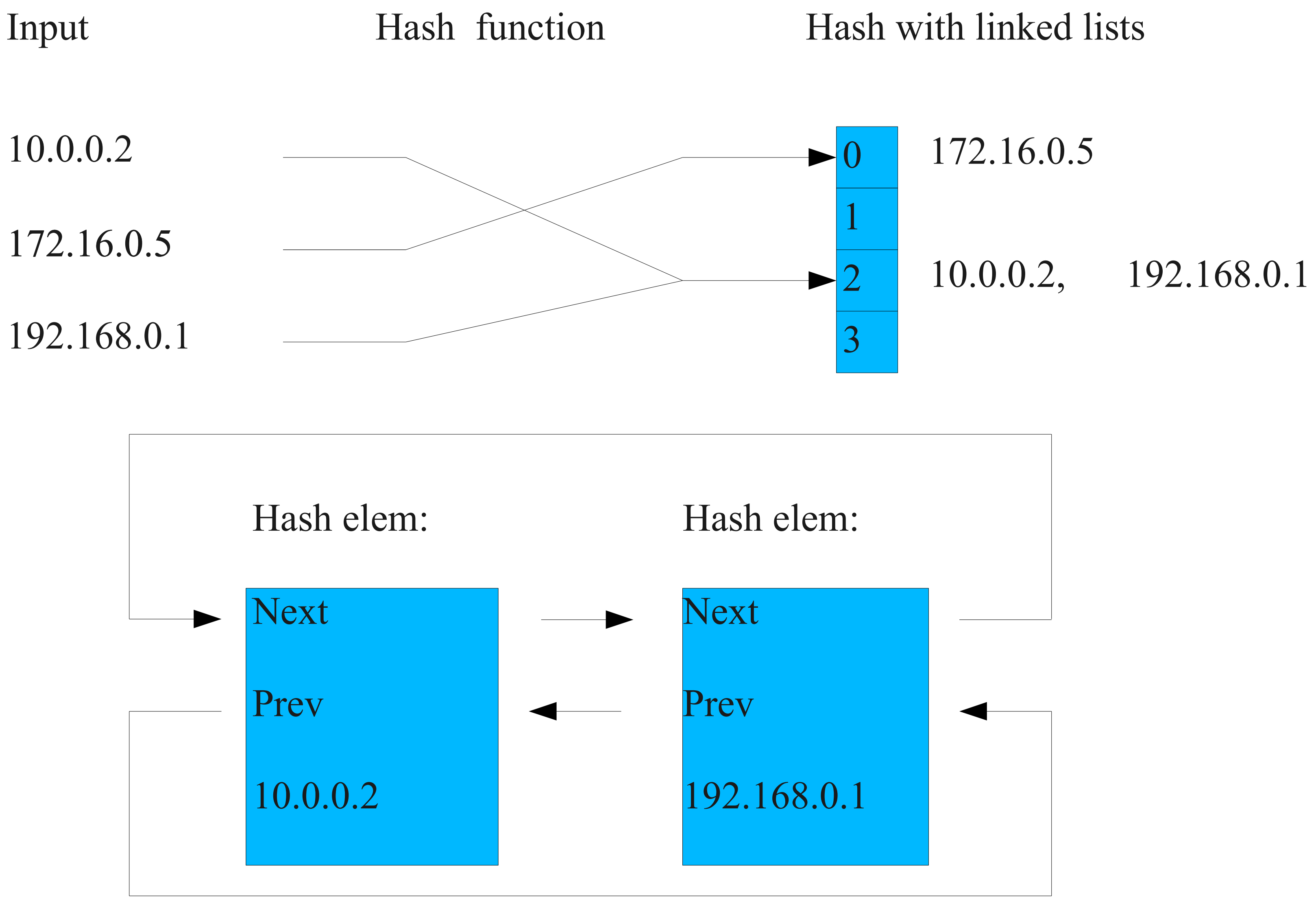
- Just for fun

```
ipset create set4 bitmap:port range 0-1024

ipset add set4 22
```

Storage method: hash I.

- Hashing: map a number space to a smaller number space with a method, which is
  - Fast
  - Deterministic
  - Uniform: every hash value has got the same probability
- Collision handling: typically with linked lists

Storage method: hash II.



Input

Hash function

Hash with linked lists

10.0.0.2

172.16.0.5

192.168.0.1

0 172.16.0.5

1

2 10.0.0.2, 192.168.0.1

3

Hash elem:

Next

Prev

10.0.0.2

Hash elem:

Next

Prev

192.168.0.1

Hash family

- Data stored in a *hashsize* sized hash
  - Size is the power of two
  - Array hash: data block for four elements, max three times increased
  - Hash size duplicated and rehashing when “full”
- Hash max size indirectly limited by the *maxelem* parameter
- Supports IPv4 or IPv6 addresses

hash:ip type

- Random IP addresses
- Store IP addresses

```
ipset create set5 hash:ip hashsize 1024

ipset add set5 10.1.1.1

ipset add set5 192.168.52.3
```

- Store same-sized netblocks:

```
ipset create set6 hash:ip family inet6 netmask 64

ipset add set6 2001:2001:2001::

ipset add set6 2001:2001:abcd::
```

Hash and netblocks

- Possible stored netblocks:
  - IPv4: /1 - /32
  - IPv6: /1 - /128
- Exceptions: “nomatch”
- Speed linearly grows with the number of different sizes of the netblocks

hash:net type

- Store different sized netblocks in a set

```
ipset create set7 hash:net

ipset add set7 192.168.1.0/24

Ipset add set7 192.168.1.0/30 nomatch

ipset add set7 10.1.8.0/21
```

Store networks

- Same sized nets from a single network:

```
ipset create set1 bitmap:ip range 192.168.0.0/16 netmask 24

ipset add set1 192.168.1.0/24

ipset add set1 192.168.2.0/24
```

- Same sized nets from different networks:

```
ipset create set2 hash:ip netmask 24

ipset add set2 10.1.1.0/24

ipset add set2 192.168.2.0/24
```

- Different sized nets: hash:net

```
ipset create set3 hash:net

ipset add set3 192.168.1.0/24

ipset add set3 10.1.8.0/21
```

Hash type and port

- We store both the protocol and port
  - TCP, UDP, SCTP, UDPLite, ICMP, ICMPv6
  - default TCP
  - ICMP and ICMPv6: type/code
  - Any other protocol

hash:ip,port type

- Store given services

```
ipset create set8 hash:ip,port

ipset add set8 192.168.1.1,icmp:ping

ipset add set8 192.168.1.1,22

ipset add set8 192.168.1.1,80

ipset add set8 192.168.1.4,25

ipset add set8 192.168.1.254,udp:53

ipset add set8 192.168.1.254,tcp:53
```

hash:ip,port,ip type

- Services with restrictions

```
ipset create set9 hash:ip,port,ip

ipset add set9 192.168.1.1,22,10.1.1.1

ipset add set9 192.168.1.1,80,10.1.1.2

ipset add set9 192.168.1.4,25,10.1.1.1
```

hash:ip,port,net types

- Services with restrictions for a subnet:

```
ipset create set10 hash:ip,port,net

ipset add set10 192.168.1.1,22,10.1.1.0/24

ipset add set10 192.168.1.1,80,10.2.0.0/16

ipset add set10 192.168.1.4,25,10.1.1.0/24
```

hash:net,port type

- Networks and port numbers together:

```
ipset create set7 hash:net,port

ipset add set7 192.168.1.0/24,tcp:80

ipset add set7 10.1.8.0/21,icmp:ping
```

From most to least specific

- hash:ip,port,ip
- hash:ip,port,net
- hash:ip,port
- hash:net,port
- hash:ip
- hash:net

hash:net,iface type

- Networks and interfaces: eggress ingress filtering

```
ipset create set7 hash:net,iface

ipset add set7 192.168.1.0/24,eth1

ipset add set7 10.1.8.0/21,eth0
```

list:set type

- Set “union”
- First match in a subset wins

```
ipset create set13 list:set size 6

ipset add set13 set1

ipset add set13 set2

ipset add set13 set3
```

Firewall built by ipset I.

```
# All internal clients who may access the Internet
# (Could have a bitmap:ip,mac type if the clients are on the same
# LAN or hash:ip,port with port restrictions):
ipset create clients bitmap:ip range 192.168.0.0/16
ipset add clients 192.168.10.1
...
# All servers with the servcies
ipset create servers hash:ip,port
ipset add servers 192.168.0.1,22
ipset add servers 192.168.0.2,25
...
```

Firewall built by ipset II.

```
# Stateful rules

iptables -A FORWARD -m state --state ESTABLISHED,RELATED -J ACCEPT

# Define logging chains

...

# Egress/ingress filtering

iptables -A FORWARD -s 192.168.0.0/16 -i ext-iface -j log-drop

iptables -A FORWARD ! -s 192.168.0.0/16 -i int-iface -j log-drop
```

Firewall built by ipset III.

```
# The rule for the servers
iptables -A FORWARD -m set --match-set servers dst,dst \
                    -m state --state NEW -J log-accept
# The rule for the clients
iptables -A FORWARD -m set --match-set clients src \
                    -m state --state NEW -J log-accept
# Otherwise we log and drop everything else
iptables -A FORWARD -j log-drop
```

Ipset and tc

- **tc** supports matching in sets, thanks to Florian Westphal

New features in next version

- Optional packet and byte counters for the elements, including the list of sets
- `set` match is extended with packet and byte counter matching

Thanks!