# Packet Filtering and NAT

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# Lesson contents

## Overview

- Netfilter/Iptables Structure
- Policy construction
- Rules setting
- Network Address Translation
- IP-over-IP tunnels

# Packet filtering

## What's in a Firewall...

- A firewall (or packet filter) is a toolkit deciding whether packets passing from an host are to be kept or discarded
- Structurally :
  - Integrated with the network stack as much as possible
  - Usually the packet filtering is in kernelspace, mainly due to performance reasons
  - Firewall management tools usually reside in userspace, due to ease of use
- We will examine the NetFilter (kernelspace) / IpTables (userspace) packet filtering suite

# Packet filtering

## Where?

The (main) firewall should be the single point of contact between the secure and insecure zone

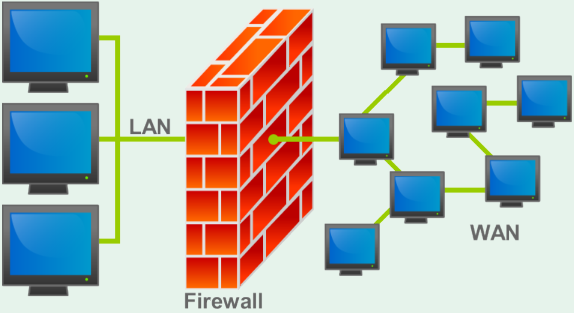



Figure: Firewall Placement

# Packet filtering

## Why firewalling?

- Avoiding unauthorized connections regardless of the availability of a server
- Packet sanitization (integrity check via checksum) can be performed during filtering
- Stateful packet filtering also enforces observance of Level 3+ protocols
- Network and Port Address translation strategies can be employed by a packet-mangling firewall

# Netfilter Structure

## Overview

- NetFilter is a set of kernel modules implementing filtering functions
- The NetFilter structure is based on five hooks, placed on the path of incoming/outgoing packets
- The communication with the userspace management tools happens via Netlink sockets
- Each of the five hooks executes a set of rules each time a packet passes through it

# Structure

## Overview

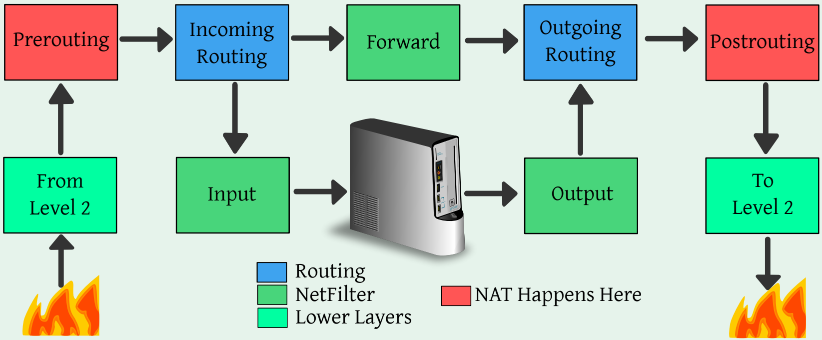



Figure: NetFilter Structure

# Netfilter chains

## Overview

- A Netfilter chain is characterised by an ordered list of rules which are triggered on a certain condition on the packet
- If no rule matches the packet, the default action, i.e. the chain policy is adopted
- Up to four tables containing chains are present (filter,nat, mangle and raw) for each Netfilter hook
- It is possible to create custom chains of rules in order to avoid the crowding of the default chain
- There is no possibility to add hook structures by default (obviously, you can write an extra module :) )

# Hook policies

## Setting the defaults

- Every builtin chain has a default policy, i.e. a default action to be performed on the packet
  - `ACCEPT`: the packet flows through the hook, towards its destination
  - `QUEUE`: the packet is sent to the userspace via Netlink for examination
  - `DROP`: the packet is discarded and treated as it never existed
- A hook policy can be set up with `iptables -P <chain> <policy>`
- The default policy, the one the kernel bootstraps NetFilter with, is `ACCEPT` for all the base chains

# Hook policies

## Reasonable policies

- Reasonable policies usually are:
  - `PRE/POSTROUTING`: set to `ACCEPT`, these chains are not meant for dropping
  - `INPUT`: set to `DROP`, whitelist is better than blacklist
  - `FORWARD`: set to `DROP`, "Thou shall not pass" is a reasonable default for the same reasons
  - `OUTPUT`: set to `ACCEPT`, although particularly restrictive policies may need a `DROP`

# Rules - management

## Rule structure

- The Netfilter behaviour is modified via the `iptables` command
- A rule is composed of two parts, the match and the target
- The match specifies the conditions regarding the packet which will trigger the rule
- The target specifies the fate of the packet
- For basically all match specifications , prepending a `!` mark inverts the match

# Rules - management

## Targets

- Possible targets (with extensions) for a rule are:
  - `ACCEPT/DROP` : behave exactly as the policies
  - `REJECT`: The packet is dropped but, if allowed by the protocol, the sender is notified of the rejection
  - `LOG`: A line in the kernel log is written, and the check on the chain of rules goes on
  - `MIRROR`: Swaps source and destination address and immediately sends the packets without passing via the other chains
  - `RATEEST`: adds this packet to the statistic of a rate estimator, then the chain checks are resumed

# Rules - management

## Rule management

- The generic iptables command is structured as : `iptables [-t table] <action> <rule>`
- Possible actions are :
  - `-A <chain>` : appends a rule at the end of the chain
  - `-D <chain>` : deletes the specific rule (the number of the rule may be indicated instead)
  - `-I <chain> <num>`: inserts the rule as the n-th
  - `-R <chain> <num>`: replaces the n-th rule
  - `-L`: lists all the rules of a chain
  - `-F`: flushes a chain (but does not reset the policy to `ACCEPT`)

# Rules - 1

## Matching interfaces

- The first and most simple match for a packet is to decide an action depending on the interface it was received on
- The inbound/outbound interface matches are specified via the `-i <iface>`/`-o <iface>` option
- The `-i`/`-o` options are limited to some chains, namely:
  - `-i` can only be used in `INPUT`, `FORWARD` and `PREROUTING`
  - `-o` can only be used in `OUTPUT`, `FORWARD` and `POSTROUTING`
- The most common use of this match is to differentiate the reasonably trusted zone of the network (LAN side) from the really untrusted side (WAN side)

# Rules - 1

## Matching interfaces - 2

- A special case for interface matching is the loopback interface `lo`
- This interface should never be filtered, lest a couple of applications *will* misbehave
- Accepting all packets with destination address equal to 127.0.0.1 is not equivalent to accepting `lo` (See RFC3330)
- Accepting all packets with destination address equal to 127.0.0.0/8 is not equivalent to accepting `lo` either (packets directed to an address you own are routed to `lo` when you self connect)

# Rules - 2

## Matching Addresses

- The most common match is the one checking either the source `-s` or the destination `-d` address
- It is possible to specify the mask as the number of contiguous bits set to one `/n` or explicitly `/a.b.c.d`
- If the rule does not specify any mask, the default is /32, i.e. an exact match of the specified address
- Also non contiguous masks are usable: e.g. 255.255.255.249 (0xFFFFFFF9) matches all the odd hosts up to .7
- Employing non contiguous masks may help in reducing the number of rules

# Rules - 3

## Matching protocols

- After matching the address, the next most simple match is the one on the L4 protocol
- The `-p [tcp|udp|udplite|icmp|esp|ah|sctp|all]` option specifies the protocol to be matched
- Take care in not filtering fundamental ICMP messages, f.i. Type 3 (Destination Unreachable)
- Filtering non fundamental-but-useful messages (traceroute, echo/echo reply) is widely considered a brain damage unless specific reasons to do so are present

# Rules - 4

## Matching Ports

- In addition to source/destination address matching, also port matching is allowed via the `--sports`/`--dports`
- Both options allow to match a set of comma-separated ports (e.g. `--dport 22,80`)
- If the ports to be matched are contiguous, the range `:` operator can be used (e.g. `--dport 6881:6890`)
- The `--sports`/`--dports` need the `-p` option to be explicitly specified and to be matching either UDP or TCP

# Rules - 5

## Matching connection status

- The difference from a regular and a stateful packet filter resides in the ability to filter according to the connection status
- The -m state --state <conn_state> match allows to specify the status of the connection (for connection oriented protocols)
- Possible statuses are :
  - `NEW` : The packet beginning a connection (f.i.TCP/SYN)
  - `ESTABLISHED` : The packet is part of a connection flow
  - `RELATED` : The packet belongs to a related connection (f.i. active FTP mode)
  - `INVALID` : The packet does cannot be part of a valid connection (TCP SYN/FIN packets)
  - `UNTRACKED` : The packet is not being tracked

# Rules - 6

## Matching rate

- Sometimes it is desirable to limit the bandwidth for a specific class of connections
- The `-m limit <times/s>` match allows to send to the rule target only a specific amount of connections
- The `-m recent --set` option tags a connection as one of a set of recently happened ones
- The `-m recent --<time> <n> --hitcount` option allows to send all the connections exceeding the hitcount/time to a specific target
- Notice that rate limiting does not in any way limit the bandwidth of the single connection

# Configuration Management

## Saving and Restoring

- The `iptables` utility updates a rule at a time via Netlink
- In case multiple rule changes should be performed atomically it is not a good idea to call it a volley of times
- The `iptables-apply` is able to insert atomically the changes in the Netfilter tables
- The `iptables-save` and `iptables-restore` command provide a way of dumping and restoring a full ruleset at once
- There is also an `iptables-xml` utility which converts a ruleset in XML for whatever purposes it may have

# Up to now

## The end-to-end transparency

- Up to now, we assumed that the “any-to-any” principle of IP was respected
- All the IP addresses were assumed to be reachable via a number of routing hops
- A single packet, once built, was always delivered as-is , without any changes
- The end-to-end transparency of a communication was never questioned

# Address Translation

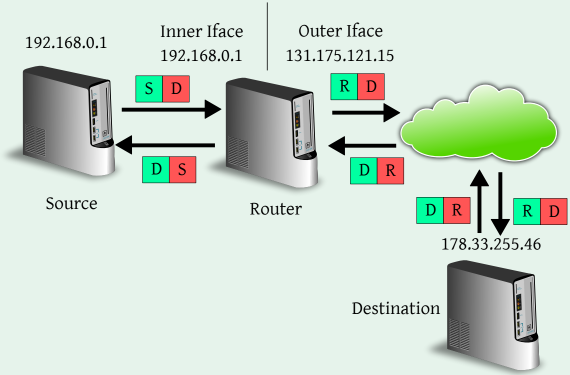
## Source NAT

- Although it raises some issues, it may be needed to mask a number of hosts under a single one
- Common when a LAN needs to access a public network but only one public IP address has been bought from IANA or the ISP
- Useful to "concentrate" accesses behind a single IP
- The best candidate to perform the packet mangling is the router

# Address Translation

## SNAT

The general structure of a source network address translation based architecture



# Address Translation

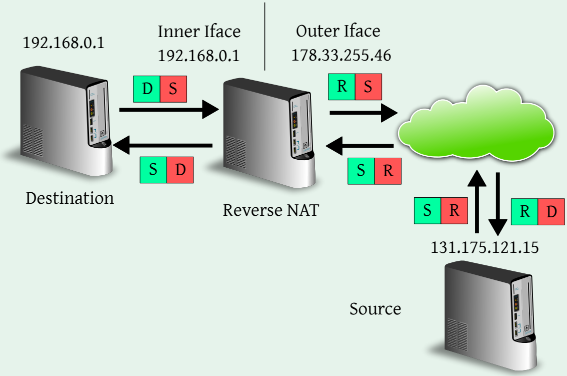
## Destination NAT

- Symmetrically, it may be helpful to split the network load managed by a server
- This can be done through dynamically modifying the destination of the communication
- The operation must be performed by the alleged target of the communications
- Bonus: it allows to replace machines behind the DNAT without interrupting a service

# Address Translation

## DNAT

The general structure of a destination network address translation based architecture



# NAT Features/Issues

## Opacity

- Once a NAT strategy is actuated, the IP domains on the two sides of the NAT are effectively split
- It is possible to mitigate the IPv4 address exhaustion
- The hosts behind a NAT are perfectly opaque[a]
- The host performing NAT must actively alter the packets, no end-to-end transparency

[a] almost perfectly actually

# NAT Strategy

## Address Translation Table

- In order to perform a correct NAT, a table containing all the connections must be kept
- Every time a new connection is requested, a line is added to the table
- The address translation mechanism will consistently map back the returning packets to the correct host
- Once a connection is torn down, the line in the mapping is removed

# NAT Issues

## Potholes

- Stateless protocols do not have a proper session
- The number of connections which can be opened between two hosts is lower than the one between *n* and one host
- Some upper level protocols contain redundant information on the network layer[a] which must be mangled too

[a] yes, this is a terrible practice

# NAPT

## Potholes

- The most straightfoward extension of the NAT mechanism involves also the mangling of the 4th level datagram
- The Network Address and Port Translation is employed when a protocol needs to communicate exactly on a port
- Destination NAPT is the most common form, in order to split the incoming communications on different servers according to the service needed
- Source NAPT is rather uncommon, as usually the source port is an ephemeral port with no particular meaning

# NAT: How?

## Overview

- The Netfilter infrastructure allows natively to perform [S|D]NA(P)T on all the connections
- The rules specifiying the NAT policies are inserted in the `nat` tables present on the `PREROUTING` and `POSTROUTING` hooks adding `-t nat` to the rule
- There is also a `nat` table in the `OUTPUT` hook, if you want to perform pre-output routing
- The connection state tables are automatically kept by the system

# Structure

## Overview

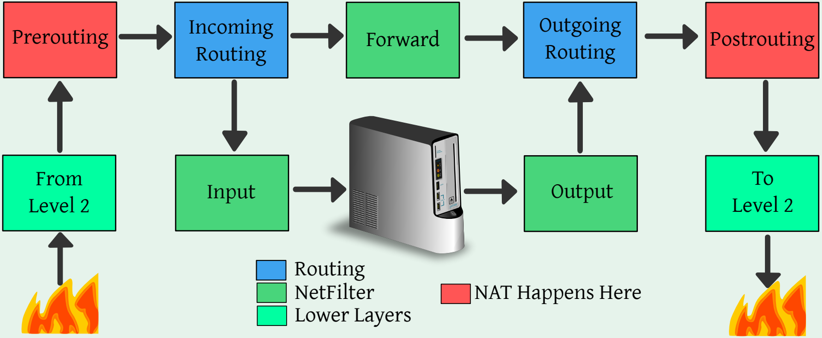



Figure: NAT communication and tables

# Source NAT

## Overview

- Source NAT is performed in the `POSTROUTING` hook, when the packet is about to leave
- The corresponding translation for the returning packet is automatically managed
- A simple `-t nat -A POSTROUTING -j SNAT --to <address>` rule sets all the packets matching it to be masked
- The output interface specifying option `-o` and comes in handy to specify which connection to mask
- The special target `-j MASQUERADE` instructs Netfilter to choose automatically the outgoing address according to the egress interface

# Destination NAT

## Overview

- Destination NAT is performed (symmetrically) in the `PREROUTING` hook, before anything is done to the packets
- The bidirectional communication of an established connection is also automatically managed
- The `-t nat -A PREROUTING -j DNAT --to-destination <address>` rule indicates the address where the packet should be redirected
- The input interface specifying option `-i` allows rough balancing in multi-interface routers
- Obviously, no automatic destination selection can be performed here

# Destination [S|D]NAPT

## Overview

- Both the Source and Destination NAT in NetFilter can be performed taking also into account ports
- The destination port of a NAT retargeted packet can simply be specified adding `:port` to the translated address
- A port range for both destination and source can be specified as `:port-port`
- By default the ports are mapped 1:1 on the range
- For privacy reasons, it is also possible to specify a `--random` option forcing the mapping to a random port for each connection

# Caveats

## Overview

- Do not set the policies of the `PREROUTING` and `POSTROUTING` hooks to anything but `ACCEPT`, filter later
- Remember that the packets will still pass through the `FORWARD` chain most of the times
- Take care that the DNAT-ed packets will flow through with a different destination IP and thus should be filtered accordingly
-

# Bidirectional traffic

## Overview

- NATs have the great advantage of being transparent to either the source or the destinations of the connection
- However, the main issue with NATs is that only one of the sides can start a connection.
- If two separate networks are required to communicate, regardless of the fact there are not enough public IP for all hosts tunnels can be used
- The general idea of a tunnel is to employ a connection as a virtual Level 2 link

# IP-over-IP tunnels

## Overview

- The simplest strategy is to encapsulate an IP datagram into another IP datagram
- The outer IP communication acts as the L2 link, while the actual IP communication is the one going on inside
- This methodology is described in RFC2003 and was the first proposal for tunnels
- It has a couple of issues, among which the bad handling of multicast connections

# GRE tunnels

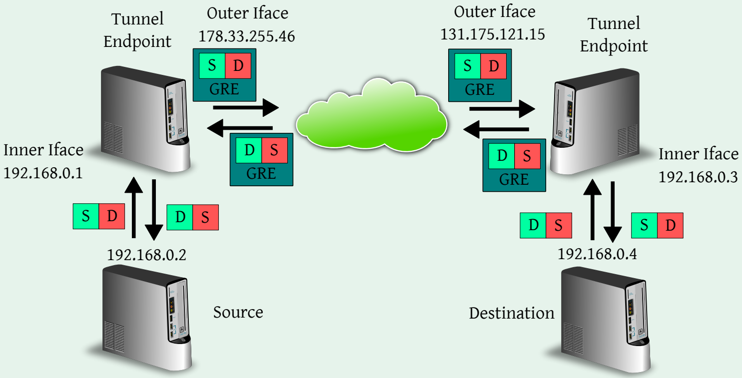
## Overview

- The Generic Routing Encapsulation protocol (GRE) was developed by Cisco as a replacement for IP-over-IP
- The protocol supports multicast messages, IPv4 and IPv6 payloads natively
- It has become the de-facto standard in tunneling
- It handles tunnel loops (the destination address of a tunneled datagram is through the tunnel itself)
- Coupled with IPSec , it forms the basic structure for the large majority of the VPNs around

# GRE tunnel

## DNAT

The general structure of typical GRE based tunnel



# iproute2 suite GRE tunnels

## How-To

- The `iproute2` suite provides also full support for tunnels
- Tunnels are treated as virtual, point-to-point, interfaces on which the host communicates
- Setting up a tunnel is as simple as : `ip tunnel add <interface> mode gre remote <endpoint> local <endpoint>`
- The same command, with swapped addresses should be employed on the other endpoint
- After the tunnel has been pulled up via `ip link <interface> up`, it is possible to route through it as a regular interface