



# Network Security

## Chapter 7 Middleboxes



### Overview

- ❑ Introduction
- ❑ Firewalls
- ❑ Application Proxies
- ❑ Networks Address Translators (NAT)
- ❑ Virtual Private Networks
- ❑ Case study: Linux Netfilter



### □ Introduction

- Firewalls
- Application Proxies
- Networks Address Translators
- Virtual Private Networks
- Case study: Linux Netfilter



- Definition:
  - *“A middlebox is defined as any intermediary device performing functions other than the normal, standard functions of an IP router on the datagram path between a source host and destination host.” [RFC3234]*
- The Internet was originally designed with the end-to-end connectivity principle
- However, in the meanwhile there are many devices on the datagram path that manipulate the IP packets
- [RFC3234] provides an overview of some commonly used middleboxes
  - e.g. firewalls, NATs, proxies, transcoders, load balancers, anonymisers
- In this chapter, we will restrict the discussion to some types of middleboxes that perform security-related manipulation of packets:
  - Firewalls, proxies, NATs, VPNs gateways

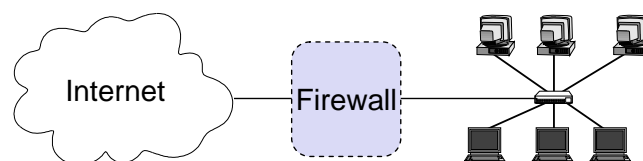


- Introduction
- **Firewalls**
- Application Proxies
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## Introduction to Network Firewalls (1)

- In building construction, a firewall is designed to keep a fire from spreading from one part of the building to another
- A network firewall, however, can be better compared to a moat of a medieval castle:
  - It restricts people to entering at one carefully controlled point
  - It prevents attackers from getting close to other defenses
  - It restricts people to leaving at one carefully controlled point
- Usually, a network firewall is installed at a point where the protected subnetwork is connected to a less trusted network:
  - Example: Connection of a corporate local area network to the Internet



- So, basically firewalls realize access control on the network level



## Introduction to Network Firewalls (2)

- What firewalls can do:
  - A firewall is a focus for security decisions
  - A firewall can enforce a security policy, i.e. concerning access control
  - A firewall can log Internet activity efficiently
  - A firewall can block unwanted traffic if the traffic can be characterized,
    - e.g. with an IP 5-tuple: IP source address, IP destination address, source port number, destination port number, transport protocol
  - A firewall can limit exposure to security problems in one part of a network



## Introduction to Network Firewalls (3)

- What firewalls can not do:
  - A firewall can't protect against malicious insiders
  - A firewall can't protect against connections that don't go through it
  - A firewall can't protect against completely new threats
  - A firewall can't fully protect against viruses,
    - e.g. if viruses are spread through emails, and the email service is allowed through the firewall, which is typically the case
  - A firewall does not perform cryptographic operations, e.g. message authentication  
(however, firewalls are often co-located with VPN end-points)
  - A firewall can't set itself up correctly ( $\Rightarrow$  cost of operation)



## Protocol Fields Important for Firewalls (1)

- Access Protocol:
  - Network Layer Protocol: IP, Appletalk, IPX (Novell), DecNet, etc.  
(Note: among these protocols nowadays, IP is nearly the only protocol that is being deployed)
  - Access Protocol Addresses: Ethernet MAC Address, E.164 Address, etc.
    - These addresses either refers to the final source / destination or the addresses of the intermediate nodes of this link
- IP:
  - Source address
  - Destination address
  - Flags, especially the indication of an IP fragment
  - Transport protocol type: TCP, UDP, ICMP, ...
  - Options:
    - E.g. source routing:
      - the sender explicitly specifies the route an IP packet will take
      - as this is often used for attacks most firewalls discard these packets
    - In general, IP options are rarely used



## Protocol Fields Important for Firewalls (2)

- TCP:
  - Source Port, Destination Port:
    - Evaluation of source and destination ports allow to determine (with a limited degree of confidence) the sending / receiving application, as most Internet services use well-known port numbers
  - Control:
    - ACK: this bit is set in every segment but the very first one transmitted in a TCP connection, it therefore helps to identify connection requests
    - SYN: this bit is only set in the first two segments of a connection, so it can be used to identify connection confirmations
    - RST: if set this bit indicates an ungraceful close of a connection, it can be used to shut peers up without returning helpful error messages
- Application Protocol:
  - In some cases a firewall might even need to peek into application protocol header fields
  - However, examination of application layer payloads is usually left to application proxies that are aware of the type of the application



## Two Fundamental Approaches Regarding Firewall Policy

- ❑ Default deny strategy:
  - *“Everything that is not explicitly permitted is denied”*
  - Examine the services the users of the protected network need
  - Consider the security implications of these services and how the services can be safely provided
  - Allow only those services that can be safely provided and for which there is a legitimate need
  - Deny any other service
- ❑ Default permit strategy:
  - *“Everything that is not explicitly forbidden is permitted”*
  - Permit every service that is not considered dangerous
  - Example:
    - Network file system (NFS) and X-Windows is not permitted across the firewall
    - Incoming telnet connections are only allowed to one specific host



## What Internet Services & Protocols should be Considered?

- ❑ Electronic mail: simple mail transfer protocol (SMTP)
- ❑ File exchange: file transfer protocol (FTP), network file system (NFS)
- ❑ Remote terminal access and command execution: telnet, rlogin, ssh
- ❑ Usenet news: network news transfer protocol (NNTP)
- ❑ World wide web: hypertext transfer protocol (HTTP)
- ❑ Information about people: finger
- ❑ Real-time conferencing services: CUseeMe, Netmeeting, Netscape conference, MBone tools, ...
- ❑ Name services: domain name service (DNS)
- ❑ Network management: simple network management protocol (SNMP)
- ❑ Time service: network time protocol (NTP)
- ❑ Window systems: X-Windows
- ❑ Printing systems: line printing protocols (LPR/LPD)



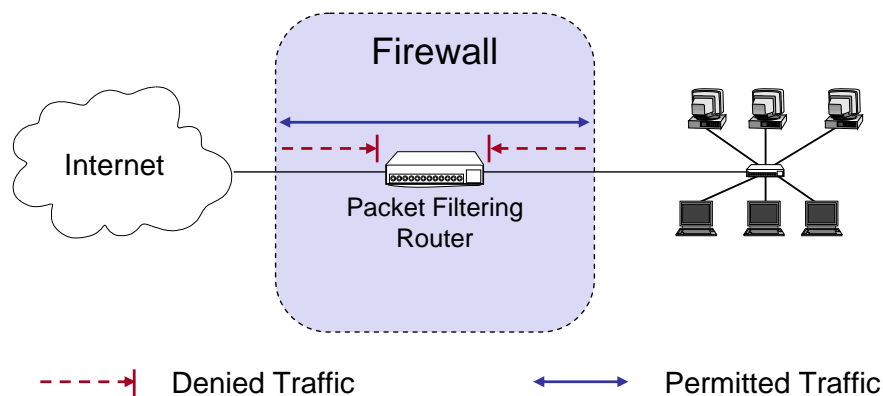
## Firewall Terminology & Building Blocks for Firewalls

- ❑ **Firewall:**
  - A component or a set of components that restricts access between a protected network and the Internet or between other sets of networks
- ❑ **Packet Filtering:**
  - The action a device takes to selectively control the flow of data to and from a network
  - Packet filtering is an important technique to implement **access control** on the subnetwork-level for packet oriented networks, e.g. the Internet
- ❑ **De-militarized zone (DMZ) :**
  - A subnetwork added between an external and an internal network, in order to provide an additional layer of security; also called **perimeter network**
- ❑ **Bastion Host:**
  - A computer that must be highly secured because it is more vulnerable to attacks than other hosts on a subnetwork
  - A bastion host in a firewall is usually the main point of contact for user processes of hosts of internal networks with processes of external hosts



## Firewall Architectures (1)

### The Simple Packet Filter Architecture

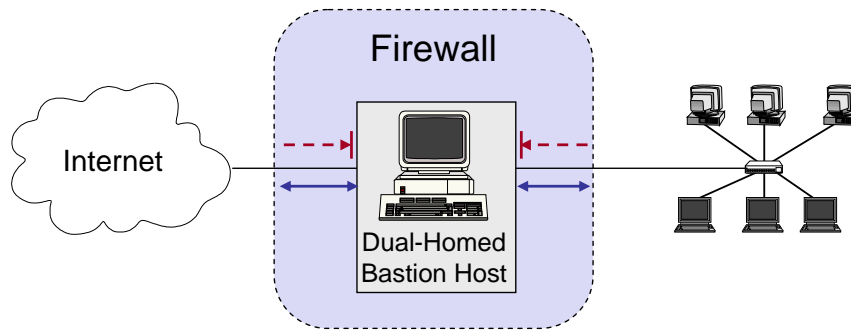


- ❑ The most simple architecture just consists of a packet filtering router
- ❑ It can be either realized with:
  - A standard workstation (e.g. Linux PC) with at least two network interfaces plus routing and filtering software
  - A dedicated router device, which usually also offers filtering capabilities



## Firewall Architectures (2)

### The Dual-Homed Host Architecture

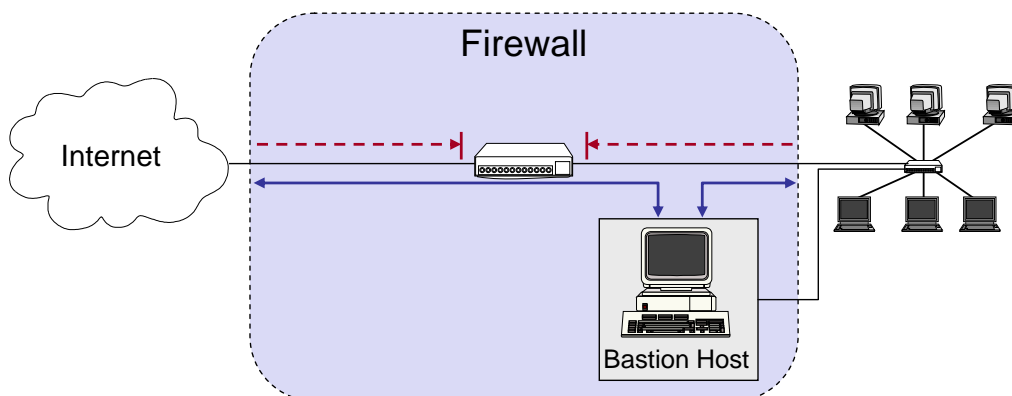


- ❑ The dual-homed host provides:
  - Proxy services to internal and / or external clients
  - Potentially additional packet filtering capabilities
- ❑ Properties of the dual-homed host:
  - It has at least two network interfaces
- ❑ Drawback: As all permitted traffic passes through the bastion host, this may introduce a performance bottleneck



## Firewall Architectures (3)

### The Screened Host Architecture



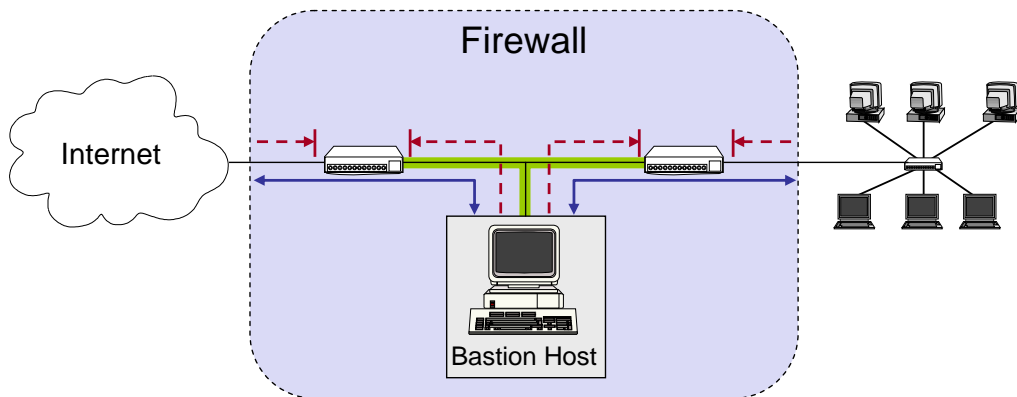
- ❑ The packet filter:
  - Allows permitted IP traffic between screened host and the Internet
  - Blocks direct traffic between other internal hosts and the Internet
- ❑ The screened host provides proxy services:
  - The screened host acts as a bastion host, being partially protected by the packet filter





## Firewall Architectures (4)

### The Screened Subnet Architecture

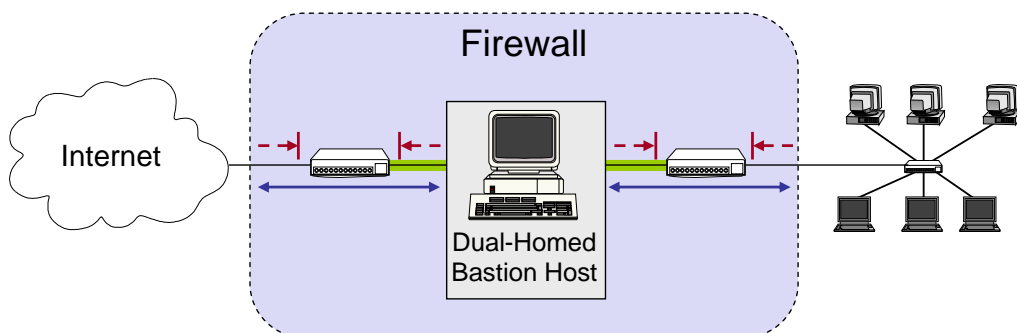


- ❑ A DMZ is created between two packet filters
- ❑ The inner packet filter serves for additional protection in case the bastion host is compromised:
  - This avoids a compromised bastion host to sniff internal traffic
- ❑ The DMZ (i.e., perimeter network) is also a good place to host a publicly accessible information server, e.g. a www-server



## Firewall Architectures (5)

### The Split Screened Subnet Architecture



- ❑ A dual-homed bastion host splits the perimeter network in two distinct networks
- ❑ This provides defense in depth, as:
  - The dual-homed bastion host provides finer control on the connections as his proxy services are able to interpret application protocols
  - The bastion host is protected from external hosts by an outer packet filter
  - The internal hosts are protected from the bastion host by an inner packet filter



## Packet Filtering (1)

- What can be done with packet filtering?
  - Theoretically speaking everything, as all information exchanged in a communication relation is transported via packets
  - In practice, however, the following observations serve as a guide:
    - Operations that require quite detailed knowledge of higher layer protocols are easier to realize in proxy systems
    - Operations that are simple but need to be done fast and on individual packets are easier to do in packet filtering systems
- Basic packet filtering enables to control data transfer based on:
  - Source IP Address
  - Destination IP Address
  - Transport protocol
  - Source and destination application port
  - Specific protocol flags (e.g. TCP's ACK- and SYN-flag)
  - The network interface a packet has been received on



## Packet Filtering (2)

- More elaborate packet filtering:
  - *Stateful or dynamic packet filtering:*
    - Example 1: *“Let incoming UDP packets through only if they are responses to outgoing UDP packets that have been observed”*
    - Example 2: *“Accept TCP packets with the SYN bit set only as part of TCP connection initiation”*
  - *Protocol checking:*
    - Example 1: *“Let in packets bound for the DNS port, but only if they are formatted like DNS packets”*
    - Example 2: *“Do not allow HTTP transfers to these sites”*
  - However, more elaborate packet filtering consumes more resources!
- Actions of a packet filter:
  - Pass the packet
  - Drop the packet
  - Eventually, log the passed or dropped packet (entirely or parts of it)
  - Eventually, pass an error message to the sender (may help an attacker!)



## Packet Filtering

- Specifying packet filtering rules:
  - As a packet filter protects one part of a network from another one, there is an implicit notion of the direction of traffic flow:
    - *Inbound*: The traffic is coming from an interface which is outside the protected network and its destination can be reached on an interface which is connected to the protected network
    - *Outbound*: the opposite of inbound
    - For every packet filtering rule this direction is specified as either “*inbound*”, “*outbound*”, or “*either*”
  - Source and destination address specifications can make use of wildcards, e.g. 125.26.\*.\* denotes all addresses starting with 125.26.
    - In our examples, we denote often simply denote addresses as “*internal*” or “*external*” when we want to leave exact network topology out of account
  - For source and destination ports we sometimes write ranges, e.g. “>1023”
  - We assume filtering rules to be applied in the order of specification, that means the first rule that matches a packet is applied



## An Example Packet Filtering Ruleset (1)

Rule	Direction	Src. Addr.	Dest. Addr.	Protocol	Src. Port	Dest. Port	ACK	Action
A	Inbound	External	Internal	TCP		25		Permit
B	Outbound	Internal	External	TCP		>1023		Permit
C	Outbound	Internal	External	TCP		25		Permit
D	Inbound	External	Internal	TCP		>1023		Permit
E	Either	Any	Any	Any		Any		Deny

- This ruleset 1 aims to specify that incoming and outgoing email should be the only allowed traffic into and out of a protected network
- Email is relayed between two servers by transferring it to an SMTP-daemon on the target server (server port 25, client port > 1023)
- Rule A allows incoming email to enter the network and rule B allows the acknowledgements to exit the network
- Rules C and D are analogous for outgoing email
- Rule E denies all other traffic



## An Example Packet Filtering Ruleset (2)

- ❑ Consider, for example, a packet which “wants” to enter the protected subnet and has a *spoofed* IP source address from the internal network:
  - As all allowed inbound packets must have external source and internal destination addresses (A, D) this packet is successfully blocked
  - The same holds for outbound packets with external source addresses (B, C)
- ❑ Consider now telnet traffic:
  - As a telnet server resides usually at port 23, and all allowed inbound traffic must be either to port 25 or to a port number > 1023, incoming packets to initiate an incoming telnet connection are successfully blocked
  - The same holds for outgoing telnet connections
- ❑ However, the ruleset is flawed as, for example, it does not block the X11-protocol for remote operation of X-Windows applications:
  - An X11-server usually listens at port 6000, clients use port numbers > 1023
  - Thus, an incoming X11-request is not blocked (D), neither is any answer (B)
  - This is highly undesirable, as the X11-protocol offers many vulnerabilities to an attacker, like reading and manipulating the display and keystrokes



## An Example Packet Filtering Ruleset (3)

Rule	Direction	Src. Addr.	Dest. Addr.	Protocol	Src. Port	Dest. Port	ACK	Action
A	Inbound	External	Internal	TCP	>1023	25		Permit
B	Outbound	Internal	External	TCP	25	>1023		Permit
C	Outbound	Internal	External	TCP	>1023	25		Permit
D	Inbound	External	Internal	TCP	25	>1023		Permit
E	Either	Any	Any	Any	Any	Any		Deny

- ❑ The flaw of ruleset 1 can be fixed in this updated ruleset 2 by including the source ports into the specification:
  - As now outbound traffic to ports >1023 is allowed only if the source port is 25 (B), traffic from internal X-clients or -servers (port >1023) will be blocked
  - The same holds for inbound traffic to ports >1023 (D)
- ❑ However, it can not be assumed for sure that an attacker will not use port 25 for his attacking X-client:
  - In this case the above filter will let the traffic pass



## An Example Packet Filtering Ruleset (4)

Rule	Direction	Src. Addr.	Dest. Addr.	Protocol	Src. Port	Dest. Port	ACK	Action
A	Inbound	External	Internal	TCP	>1023	25	Any	Permit
B	Outbound	Internal	External	TCP	25	>1023	Yes	Permit
C	Outbound	Internal	External	TCP	>1023	25	Any	Permit
D	Inbound	External	Internal	TCP	25	>1023	Yes	Permit
E	Either	Any	Any	Any	Any	Any	Any	Deny

- ❑ This problem can be addressed in ruleset 3 by also specifying TCP's ACK-flag in rules B and D:
  - As the ACK-flag is required to be set in rule B, it is not possible to open a new TCP connection in the outbound direction to ports >1023, as TCP's connect-request has the ACK-flag not set
  - The same holds for the inbound direction, as rule D requires the ACK-flag to be set
- ❑ As a basic rule, any filtering rule that permits incoming TCP packets for outgoing connections should require the ACK-flag to be set



## An Example Packet Filtering Ruleset (5)

Rule	Direction	Src. Addr.	Dest. Addr.	Protocol	Src. Port	Dest. Port	ACK	Action
A	Inbound	External	Bastion	TCP	>1023	25	Any	Permit
B	Outbound	Bastion	External	TCP	25	>1023	Yes	Permit
C	Outbound	Bastion	External	TCP	>1023	25	Any	Permit
D	Inbound	External	Bastion	TCP	25	>1023	Yes	Permit
E	Either	Any	Any	Any	Any	Any	Any	Deny

- ❑ If the firewall comprises a bastion host, the packet filtering rules should further restrict traffic flow (→ screened host architecture):
  - As in the modified rules above only traffic between the Internet and the bastion host is allowed, external attackers can not attack SMTP on arbitrary internal hosts any longer
- ❑ In a screened subnet firewall, two packet filtering routers are set up:
  - one for traffic allowed between the Internet and the bastion host, and
  - one for traffic allowed between the bastion host and the internal network



## Bastion Hosts (1)

- ❑ A bastion host is defined as a host that is more exposed to the hosts of an external network than the other hosts of the network it protects
- ❑ A bastion host may serve for different purposes:
  - Packet filtering
  - Providing proxy services
  - A combination of both
- ❑ The principles for building a bastion hosts are extensions of those for securing any mission critical host:
  - Keep it simple
  - Prepare for the bastion host to be compromised:
    - Internal hosts should not trust it more than necessary
    - If possible, it should be connected in such a way to the network that it can not sniff internal traffic
    - Provide extensive logging for incident detection / analysis, if possible such that it can not be easily tampered with even when the host is compromised



## Bastion Hosts (2)

- ❑ Further guidelines:
  - Make the bastion host unattractive:
    - Slower machines are less appealing targets and are less useful if compromised
    - However, if the bastion host offers some resource consuming service, e.g. WWW-service, it may be wiser not to make it too slow
    - The fewer tools are available on the bastion host, the less useful the machine is to an attacker
  - Get a reliable hardware configuration
  - The bastion host should be placed at a physically secure location
  - Disable any user accounts on the bastion host (e.g. only administrators can login to the Bastion host)
  - Secure the system logs (e.g. by writing them directly to a printer, or using the printer port to a dedicated PC which is not networked)
  - Do regular backups of the system logs and the configuration (using a dedicated backup device)
  - Monitor the machine closely (reboots, usage / load patterns, etc.)
  - If possible, restore the machine regularly from a prepared installation



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- *Proxy*:
  - A program that deals with external servers on behalf of internal clients
  - Proxies relay approved client requests to real servers and also relay the servers answers back to the clients
  - If a proxy interprets and understands the commands of an application protocol it is called an *application level proxy* (e.g. a Web proxy),
  - If it just passes the PDUs between the client and the server it is called a *circuit level proxy* (e.g. SOCKS proxy)
- Candidate services for proxying:
  - FTP, Telnet, DNS, SMTP, HTTP
- The use of a proxy service usually leads to the following situation:
  - The user of a proxy service has the illusion of exchanging data with the actual server host
  - The actual server has the illusion of exchanging data with the proxy host



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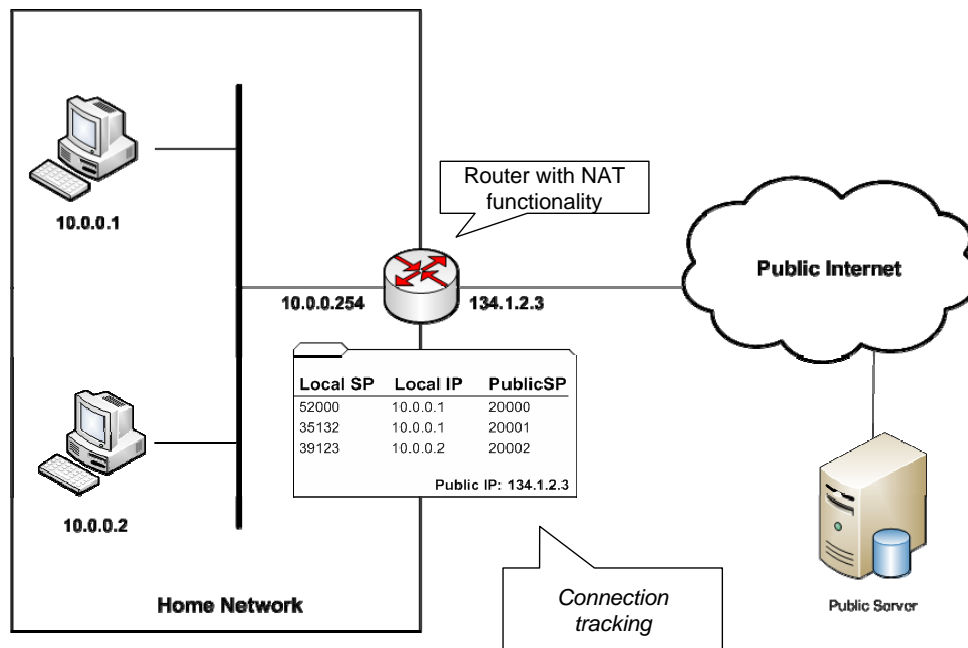
- *Network Address Translation (NAT):*
  - A procedure by which a router changes data in packets to modify the network addresses
- NATs were originally introduced due to the lack of IP addresses
- However, NATs are now also used to hide the internal topology of the network, and to limit connectivity to internal hosts
- NATs provide limited security
  - If a client behind a NAT is not directly reachable from the public Internet, the probability is lower that the client will be infected by a virus/worm that is spreading at the network layer
- However, for many applications, it is required that the client is reachable from the Internet,
  - e.g. Peer-to-Peer applications, Voice over IP (VoIP)





## Network Address Translation (NAT) (2)

### □ Example



- Local SP: Local Source Port;      Public SP: Public Source Port



## Network Address Translation (NAT) (3)

- NAT present a big burden in today's Internet applications
- One of the main problems is that the behavior of NATs is not properly standardized
  - It depends on the implementation of the NAT how the mapping between internal and external IP addresses and port numbers is performed



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- Various definitions of the term *virtual private network (VPN)*:
  - A virtual private network (VPN) is a network that **uses a public telecommunication infrastructure**, such as the Internet, to provide remote offices or individual users with secure access to their organization's network. An alternative to such a virtual private network is an expensive system of owned or leased lines that can be used only by a single organization. The goal of a VPN is to provide the organization with the same capabilities, but at a much lower cost. [SeSec08]
  - A communications environment in which **access is controlled** to permit peer connections only within a defined community of interest, and is constructed through **some form of partitioning** of a common underlying communications medium, where this underlying communications medium provides services to the network on a non-exclusive basis
  - A restricted-use, logical computer network that is constructed from the system resources of a relatively public, physical network (such as the Internet), often by using encryption, and often by tunneling links of the virtual network across the real network [RFC2828]



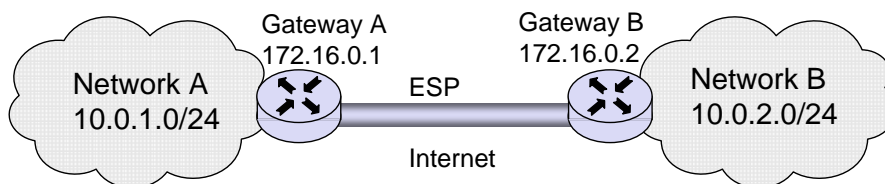
## Techniques for building Virtual Private Networks

- ❑ Make use of dedicated links
  - ATM or Frame Relay virtual connections
  - Multi-Protocol Over ATM (MPOA)
  - Multi-Protocol Label Switching (MPLS)
- ❑ *Controlled route leaking / route filtering:*
  - Basic idea: control route propagation to the point that only certain networks receive routes for other networks
  - This intends to realize “security by obscurity”
- ❑ *Tunneling:*
  - Generic routing encapsulation (GRE)
  - PPP / PPTP / L2TP
    - Note: PPTP was developed by Microsoft and used MS-CHAP (Microsoft Challenge-handshake Authentication Protocol) and MPPE (Microsoft Point-to-Point Encryption Protocol)
    - It is currently considered as inherently insecure, since messages can be easily spoofed
  - IPSec (See examples provided in Chapter 8)
  - SSL (e.g. OpenVPN is based on SSL/TLS)
  - SSH: OpenSSH offers also (since Version 4.3) a possibility for building VPNs



## Example: VPN with IPSec

- ❑ **ESP Tunnel** for VPN



- ❑ Configuration at Gateway A:
  - `spdadd 10.0.1.0/24 10.0.2.0/24 any -P out ipsec esp/tunnel/172.16.0.1-172.16.0.2/require ;`
  - `spdadd 10.0.2.0/24 10.0.1.0/24 any -P in ipsec esp/tunnel/172.16.0.2-172.16.0.1/require ;`

Note

  - protocol and port (any)
  - the policy to use (-P) specifying direction (in/out), action (ipsec/discard/none), the protocol (ah/esp), the mode (tunnel/transport), and the level (uses/require)
- ❑ Configuration at Gateway B:
  - `spdadd 10.0.2.0/24 10.0.1.0/24 any -P out ipsec esp/tunnel/172.16.0.2-172.16.0.1/require ;`
  - `spdadd 10.0.1.0/24 10.0.2.0/24 any -P in ipsec esp/tunnel/172.16.0.1-172.16.0.2/require ;`



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- Firewalls in Linux are implemented using the *Netfilter* architecture ([www.netfilter.org](http://www.netfilter.org))
  
- The Linux command „iptables“ is used to add firewalls rules, e.g.

```
# Allow port 22 (ssh) new TCP connection from  
# source IP address range 192.168.1.100/32  
iptables -A INPUT -p tcp -s 192.168.1.100/32 --dport 22 -m state --state NEW -j ACCEPT
```

-A INPUT: append new rule to rule chain INPUT

-m (match)

-m state --state: NEW/ESTABLISHED/RELATED

-j (jump): ACCEPT/DROP



## Netfilter Chains (1)

- ❑ The packets are processed in so-called „**chains**“
- ❑ A “chain” is a checklist of rules
- ❑ Each incoming or outgoing packet is sequentially checked against these rules
- ❑ Each rule says “if the packet header looks like this, then here's what to do with the packet”, e.g. drop or accept
- ❑ Firewall functionality is implemented using 3 chains
  - The „**input**“ chain: for processing packets addressed to this host
  - The „**output**“ chain: for processing packets coming from local processes and leaving this host
  - The „**forward**“ chain: for processing packets that are traversing this host. If a Linux machine is used as a router, this chain will be frequently used. If a Linux machine is used as an end-host and not as a Linux router, this chain will not be used

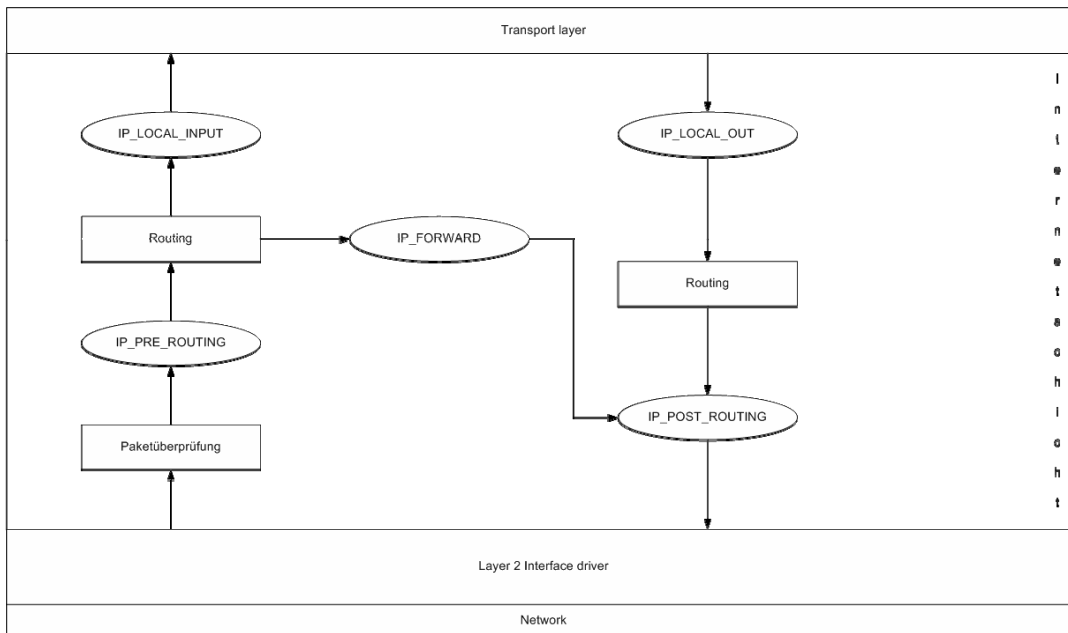


## Netfilter Chains (2)

- ❑ Additionally, two chains are used for NAT functionality
  - „**Pre-Routing**“: here packets are processed before a routing decision is taken
    - ➔ If the destination IP address needs to be modified, an appropriate rule is required here
  - “**Post-routing**“: here packets are processed after a routing decision has been taken
    - ➔ The destination IP address can not be modified here.

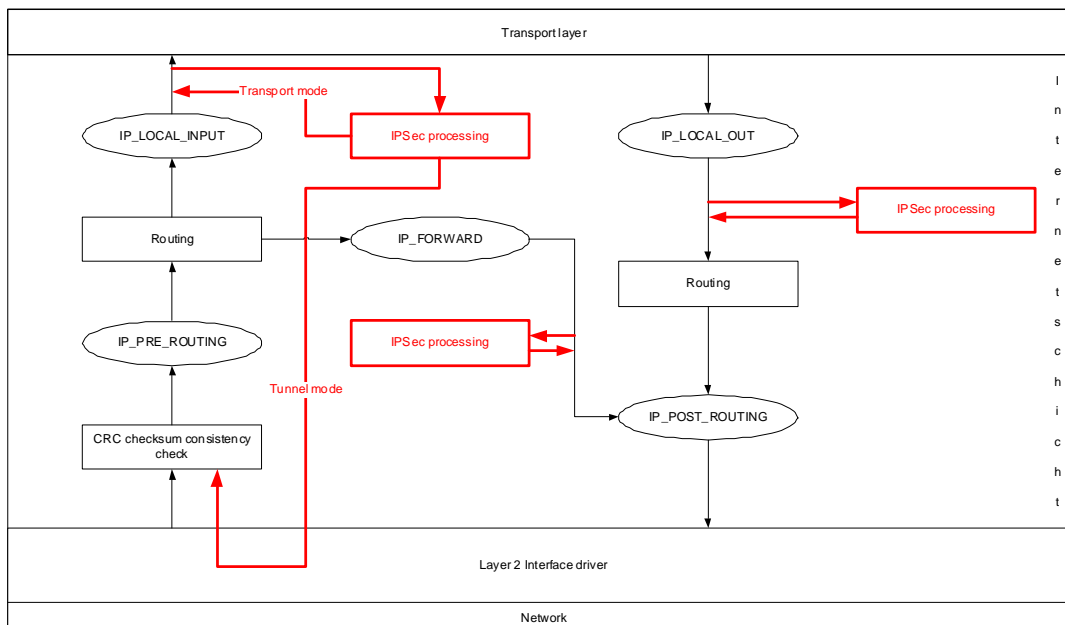


# Netfilter Chains



# Native IPsec Support

- In Linux 2.6, native support for IPsec processing is integrated with the netfilter architecture





## Additional References

- [netfi08] “Netfilter Online Documentation”,  
<http://www.netfilter.org/documentation/HOWTO//packet-filtering-HOWTO.html>
- [Sem96a] C. Semeria. *Internet Firewalls and Security*. 3Com Technical Paper, 1996.
- [Wack95a] J. P. Wack, L.J. Carnahan. *Keeping Your Site Comfortably Secure: An Introduction to Internet Firewalls*. NIST Special Publication 800-10, 1995.
- [Zwi00a] E. Zwicky, S. Cooper, B. Chapman. *Building Internet Firewalls*. Second Edition, O'Reilly, 2000.
- [SeSec08] “SearchSecurity.com Definitions; virtual private network”  
[http://searchsecurity.techtarget.com/sDefinition/0,,sid14\\_gci213324,00.html](http://searchsecurity.techtarget.com/sDefinition/0,,sid14_gci213324,00.html)