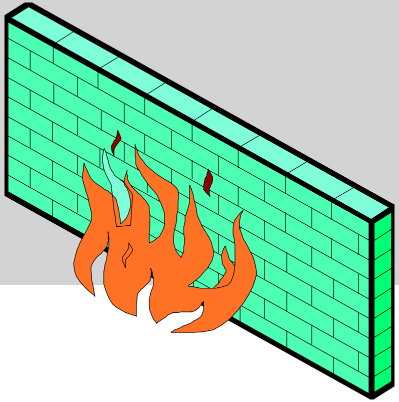
Firewalls



Chapter 21.1

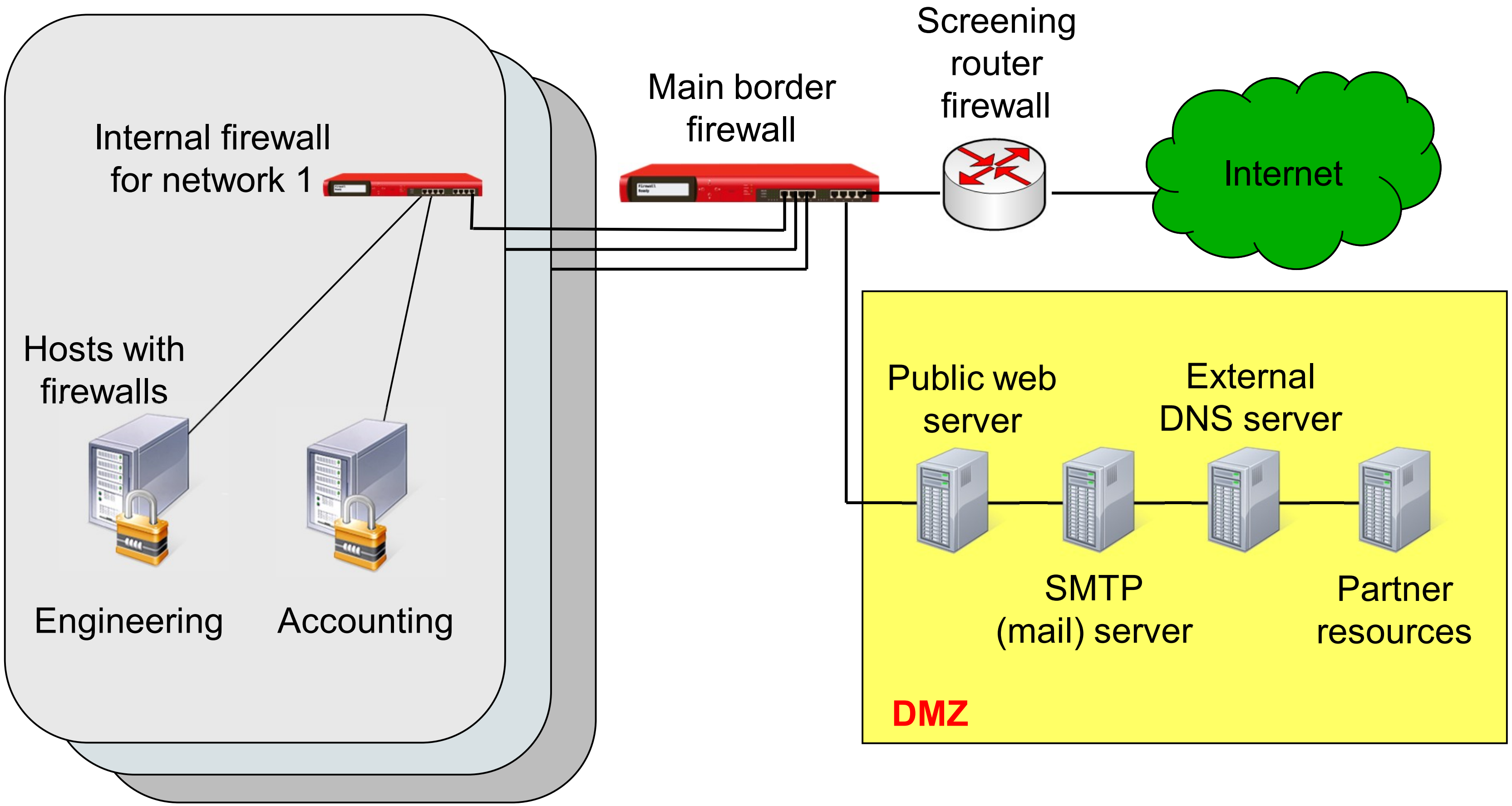
The danger of overload

- The firewall …
  - Can be a dedicated box, a router, a PC or a collection of hosts
  - You get what you pay for – cost from 10,000 SEK to 1,000,000 and even more
- If a firewall is overloaded and cannot handle the traffic,
  it must drop unprocessed packets
  - What would the alternative be?
  - This results in denial of service to its users
- Many solutions are designed to handle normal traffic but not heavy loads/attacks
  - Logging could be one problem
  - Suppose it is configured to send an email message for each suspect packet…
- Firewalls must have the capacity to handle all potential traffic peaks
  - Must be able to work at wire speed
  - Logs and alarms must be configured accordingly

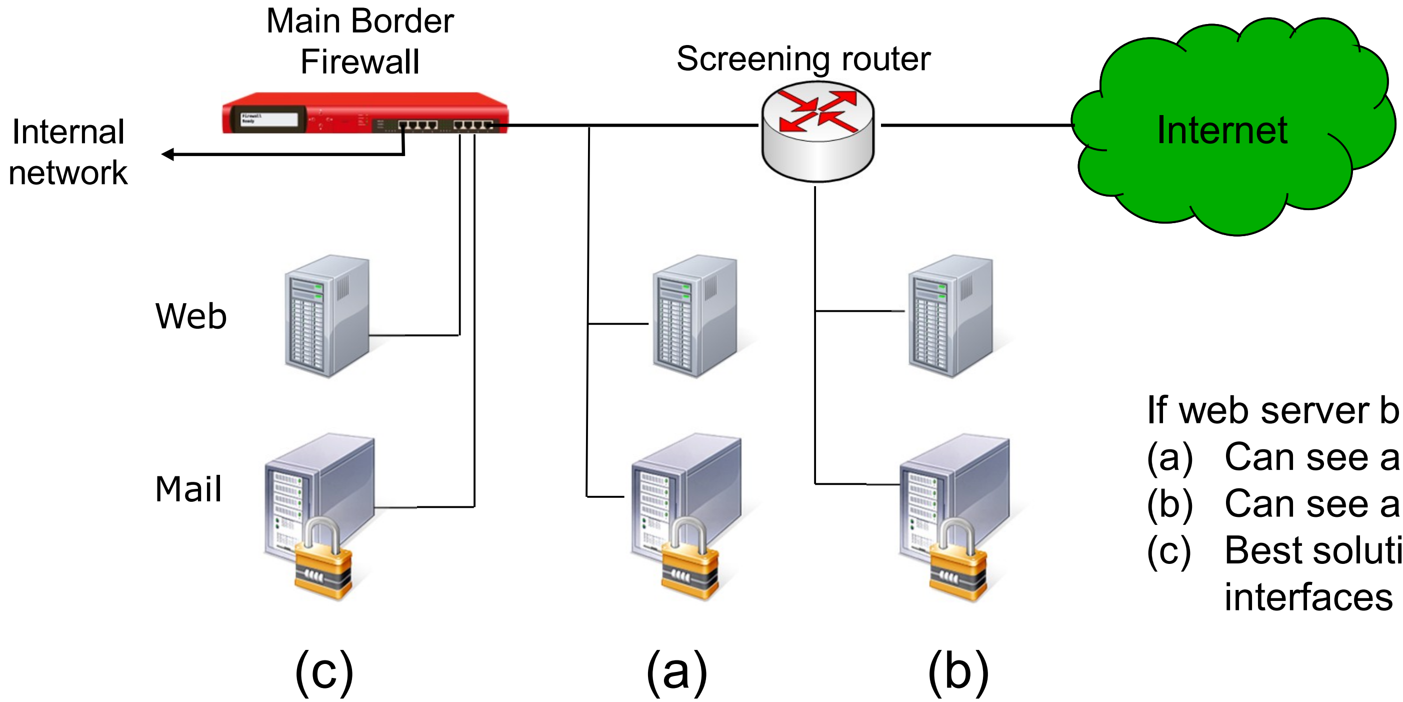
What level(s) to inspect?

- Application Level
  - Number of attacks at the application level is increasing
  - Application-level firewalls inspect and understand application level protocols such as FTP, HTTP, SMTP, etc.
  - Can do virus/worm/Trojan filtering (i.e. malware filtering)
- Transport and Network Level
  - Attacks and therefore firewalls started here
  - Most firewalls focus on this level (TCP, UDP, IP)
- Data-link Level
  - Usually no or little protection, although attacks can occur here
  - However, attacker must have access to the local network
- Physical Level
  - No protection

In-depth security is important



Protecting the DMZ



If web server breached:

(a) Can see all in- and outgoing traffic

(b) Can see all email traffic

(c) Best solution if firewall has enough interfaces

Multiple layers of DMZ and firewalls

- How can switches prevent sniffing?

  More in link-level security lecture

- More than one DMZ can be built

- Multiple firewalls:
  - May offload each other from work
  - May catch problems if one is mis-configured (trigger alarms)

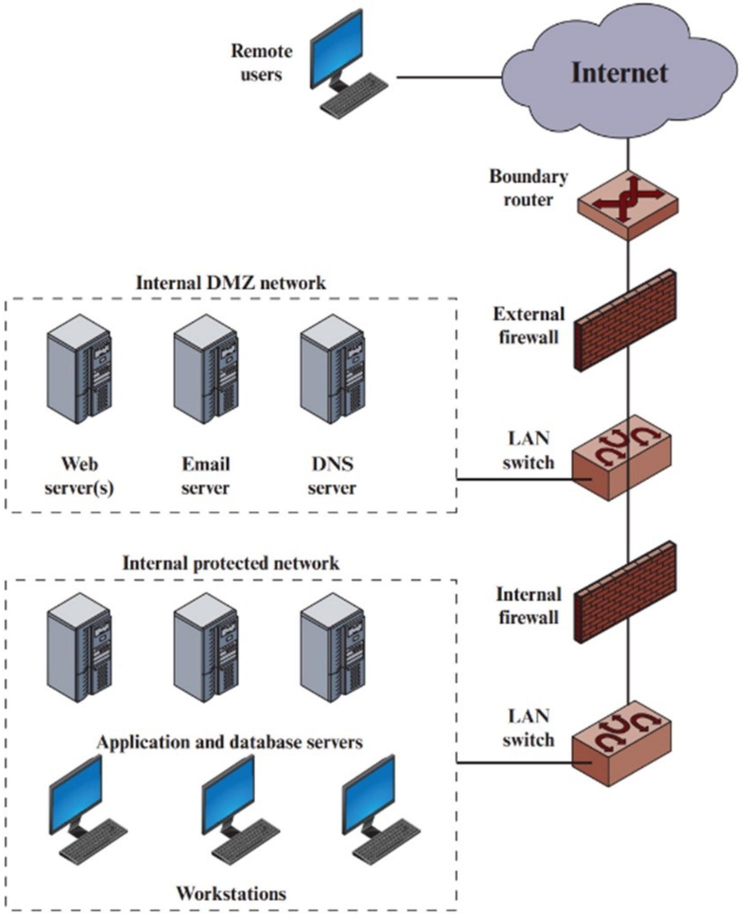
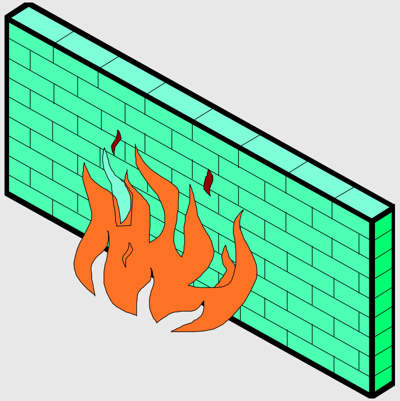


Figure 21.3 Example Firewall Configuration



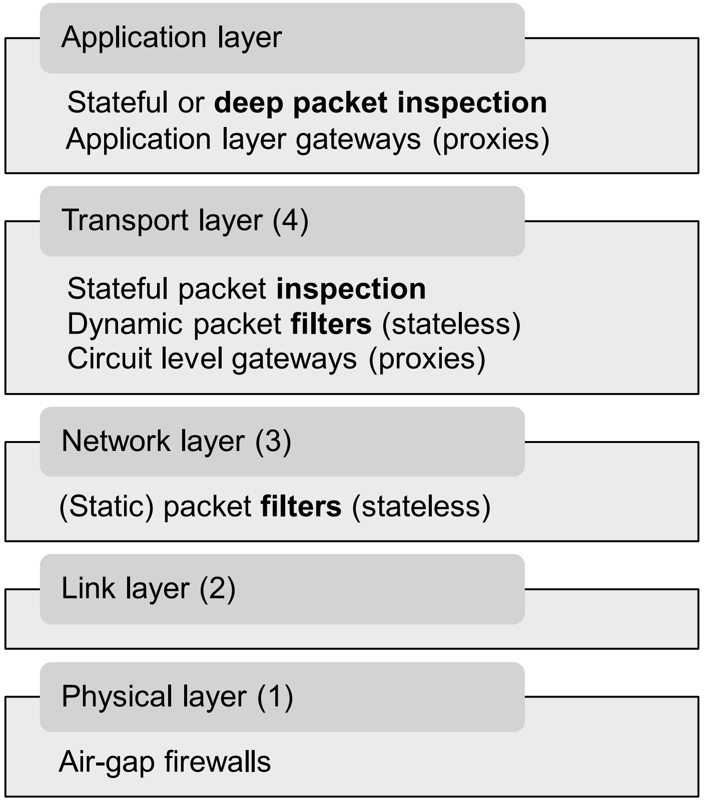
Types of firewalls

Chapter 23.3

Firewall history

- Routers to prevent own network problems to spread (segmentation) [~1980]
- Routers with static packet filters (stateless) removing unwanted traffic [~1990]
  - Table with block/allow consulted for each packet
  - Goal: to build a wall around the own network
- Bastion hosts
  - Specially hardened hosts (proxies) taking care of a few necessary services
  - Approx. the same as “Application layer gateways”
  - May support user authentication
- Stateful (packet) inspection [1994]
  - Technique becoming more and more sophisticated
  - Each packet is investigated, states are kept
- Application-level inspection (“deep” packet inspection)
  - Over time, inspection has moved upwards in the OSI model
  - One inspection module needed for each protocol to be analyzed
- Firewalls for internal networks and built-in host-based personal firewalls [~2000]

Types of firewalls, overview



Application layer

Stateful or **deep packet inspection**
Application layer gateways (proxies)

Transport layer (4)

Stateful packet **inspection**
Dynamic packet **filters** (stateless)
Circuit level gateways (proxies)

Network layer (3)

(Static) packet **filters** (stateless)

Link layer (2)

Physical layer (1)

Air-gap firewalls

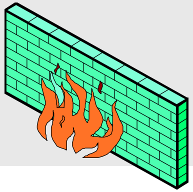
Packet inspection is more powerful than packet filters

Stateful normally means that the full protocol is understood. But terminology may vary.

Firewalls are normally multi-layer: inspects up to the indicated layer

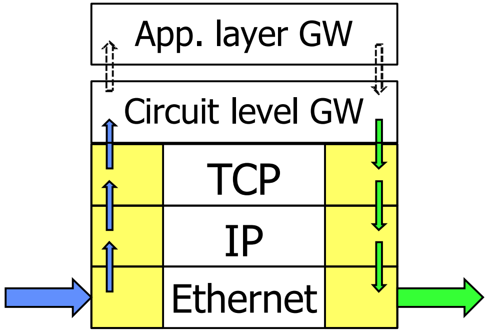
Types of firewalls

Note: There exist many hybrid solutions. Vendors may use different terminologies

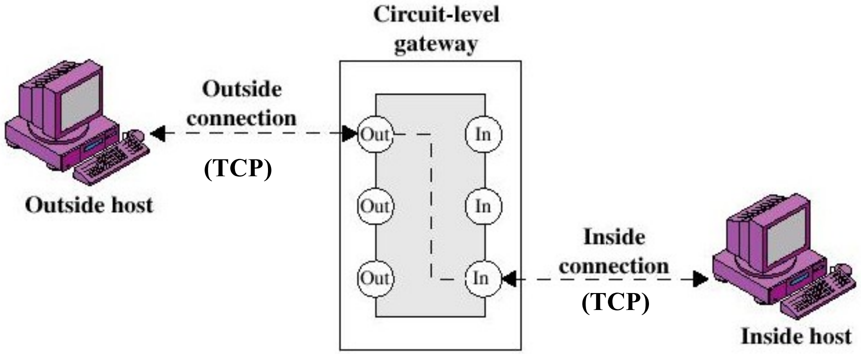


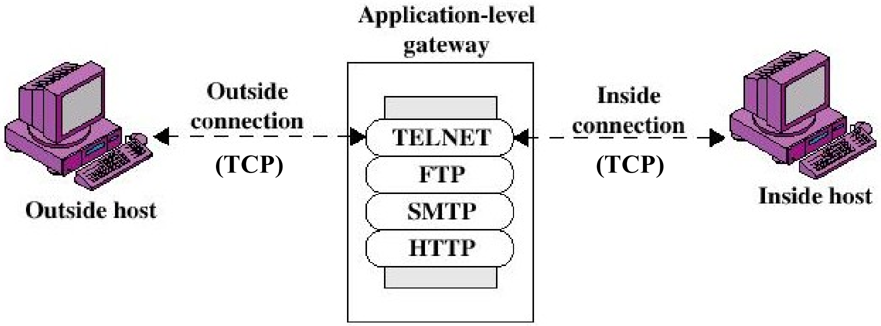
- (Static) Packet **filter** firewalls [OSI 3]
  - Stateless. Does not understand TCP
  - Compares IP addresses and port numbers with an access control list
  - IP address spoofing can be detected
  - Fast and cheap, often part of a router
  - Only a complement to a "real" firewall
- Dynamic (self-modifying) packet **filters** [OSI 4]
  - Rules may be changed dynamically by the filter itself to understand SYN – SYN/ACK – ACK sequences
  - Still does not really understand TCP
- Stateful packet **inspection**, SPI [OSI 4+]
  - ACL lists consulted at connection establishment; a state table is used for established connections
  - State aware = knows about TCP states
  - Most SPI firewalls can also inspect some application-level protocols
- Circuit-level gateways (generic **proxies**) [OSI 4]
  - Relays connections on TCP level: unpacks TCP contents and repacks it for the other side
  - Hides internal structure
  - May perform authentication
- Application level (or layer) gateways (application **proxies**, bastion hosts) [OSI 7]
  - Designed for one application (FTP, HTTP, …)
  - Unpacks application data and repacks it for the other side
  - May perform authentication
- Stateful application-level packet inspection (or **deep packet inspection**) [OSI 7]
  - Inspects several application layer protocols
  - Can have signatures for known problems (IDS), detect Ping-of-death attacks, nonstandard commands in FTP, etc.
  - May require special hardware for performance
- **Air-Gap** Firewalls (special-purpose)

Proxies (or Gateways)

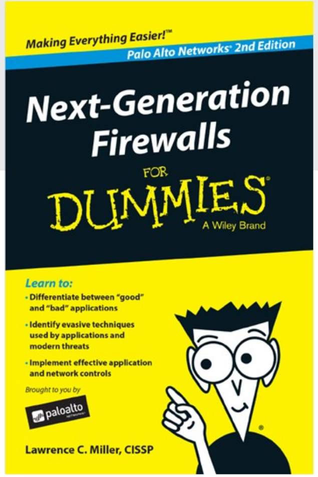


All headers are removed, data is extracted and inspected. If Ok, new headers are created by the proxy.





“Next Generation” Firewalls (NGFW)


Making Everything Easier!™
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Next-Generation Firewalls
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Learn to:
• Differentiate between “good” and “bad” applications
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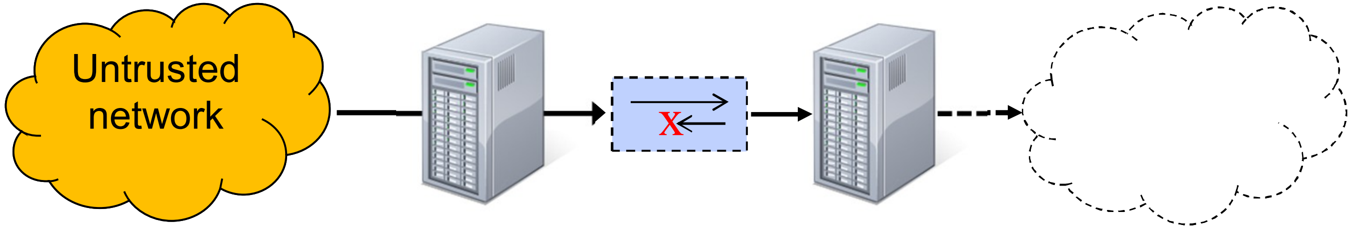
2nd ed. 2016

- Not as new as the name implies, concept introduced around 2010
- Deep packet inspections with support for NAT, VPN, QoS (limit or prioritize some types of traffic)
- Reputation based malware detection and URL filters/blocks
- Main “new” feature: moving from “port based” to “application aware” firewalls
- Application aware = knows what application is in charge:
  - Understands application behavior (ports, protocols, expected behavior, contents, …)
  - Example: text editor starts to send http or UDP messages
  - Traffic on port 80 is not just surf (games, file transfers, VPN, ...) – better control needed
  - May be self-learning and detect changed behavior
  - May be aware of user-IDs and groups and their behavior
- Inspection is done just once for each packet
  - Not separate modules repeating the inspection

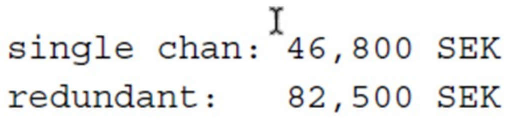
Air-gap “firewalls”

- Air-gap “firewalls” work on the physical layer
  - Isolates computers more or less from the Internet
  - Still not 100% secure
- Offers one-way communication between two hosts
  - No traditional physical network connections work: no TCP, IP, …
  - Example: relays for mail traffic, input to control system, etc.



- Optical fiber with only one transmitter (data in one direction only)
- Ethernet cable with receive cable removed

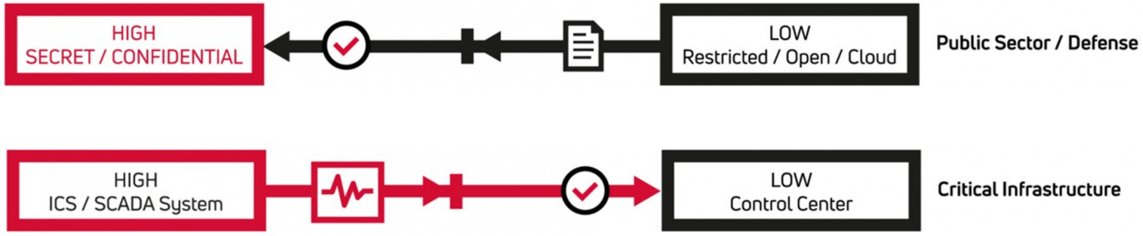
Air-gap firewall (“data diode”)

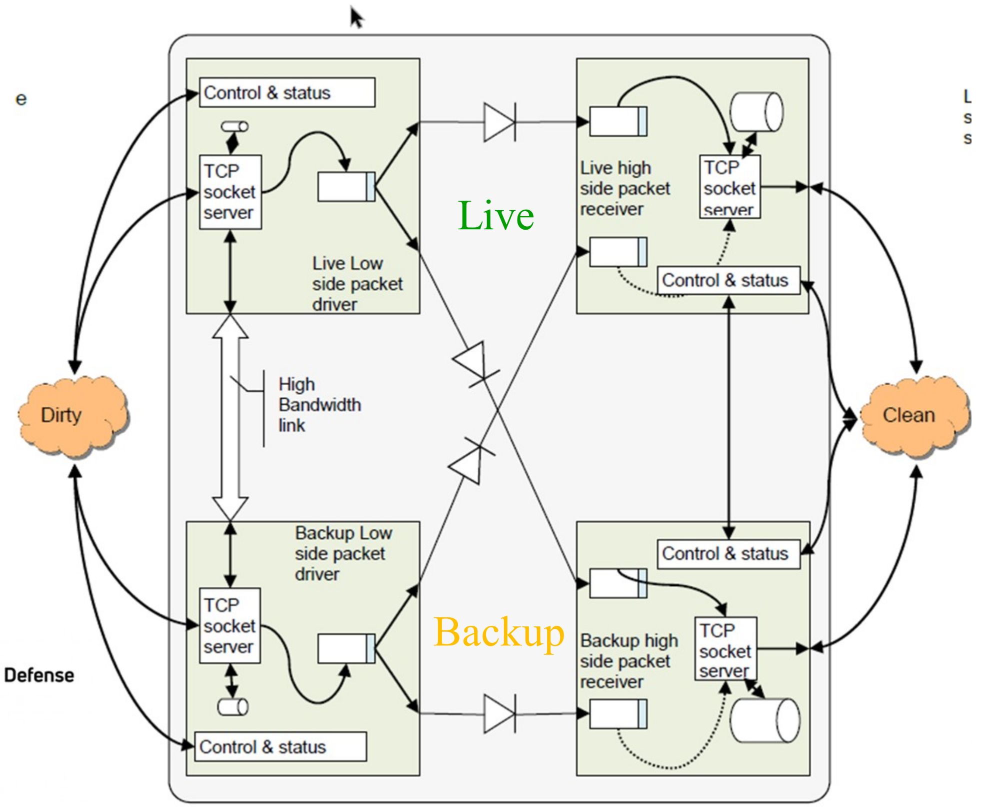


```
single chan:  46,800 SEK
redundant:    82,500 SEK
```

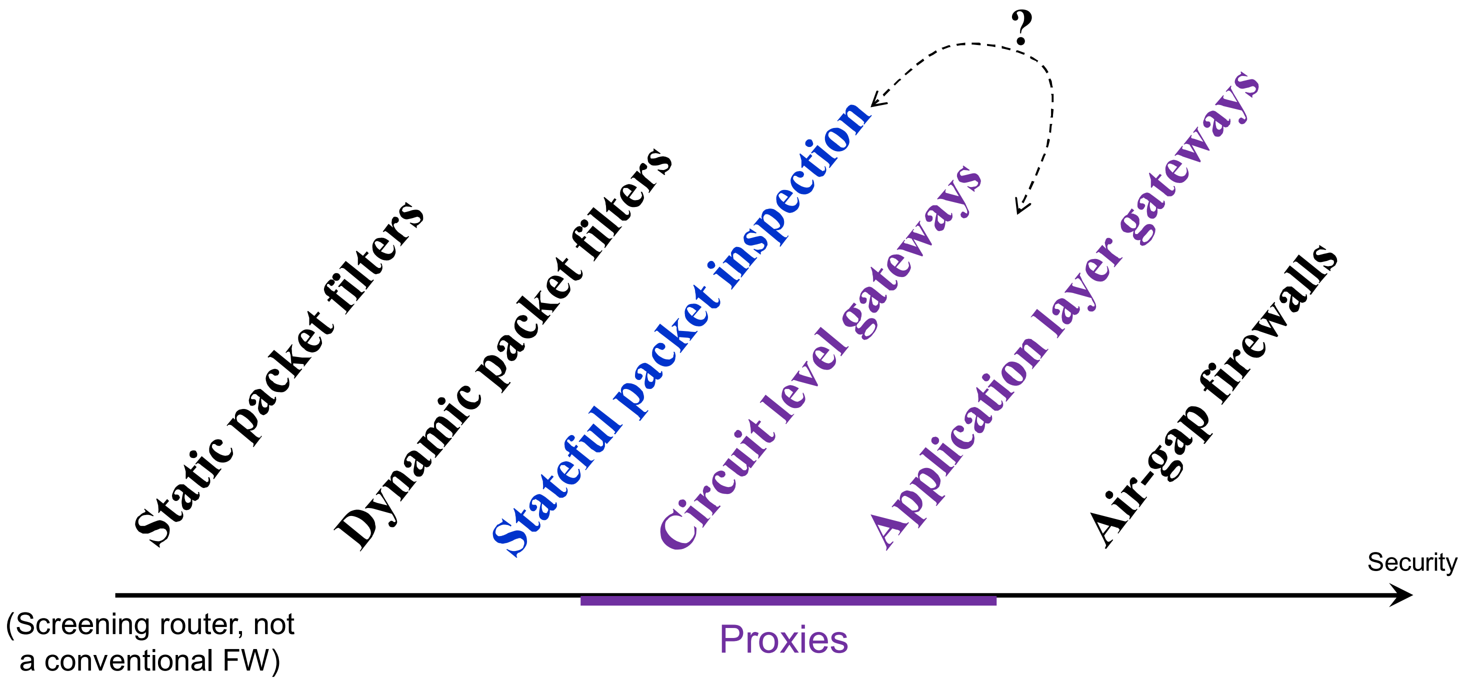
Physical data separation is maintained by use of independent data paths connected only by single one-way optical links.

Operates on the principle of a unidirectional stream of data. This stream of data is fed on the low security side through a TCP/IP Socket connection.





Firewall technology and security

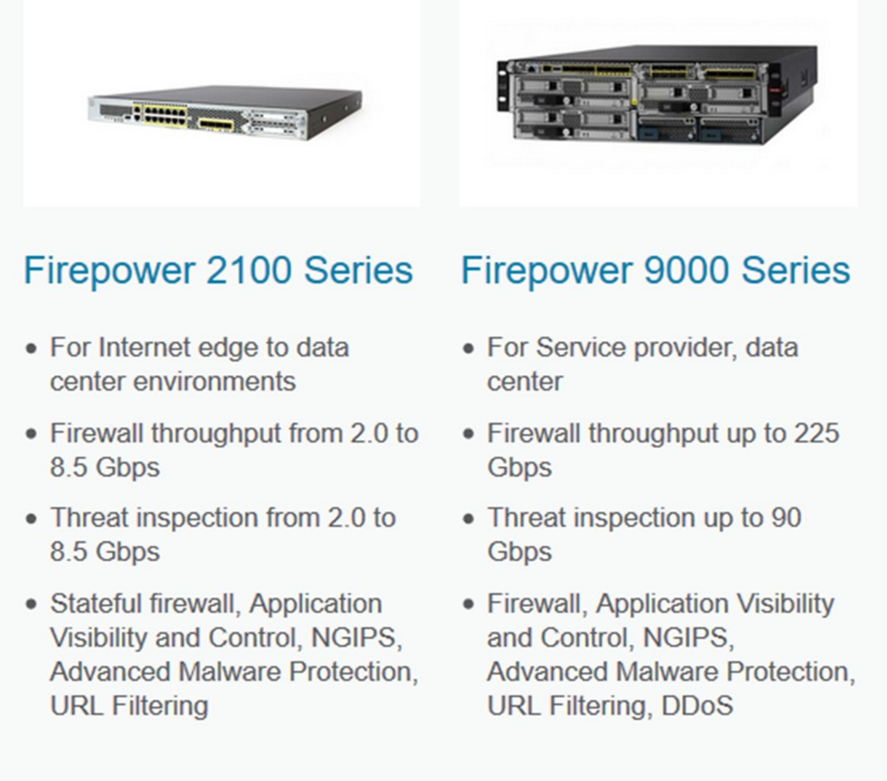


Note: The achieved level of security depends on selecting the right technology for the problem. High-security firewalls are often based on proxy technology.

Industrial strength vs. mainstream products

- Logging and notification ability
  - Good logging ≠ logging everything: too much data or unstructured data does not help understanding
  - Support for SMNP, syslog, etc. and central management
  - A centralized logging system may be designed to receive > 100,000 events per second
- Protocol support
  - Number of supported protocols may vary
  - Good FWs allow us to define rules per interface
- High-volume packet inspection
  - Must be able to handle the traffic in wire speed
  - Application-level protocol inspection requires processing power or hardware (ASICs)
- Device security and redundancy important
  - Underlying system (e.g. Linux) in FW must be secure enough
  - Redundancy (if one device fails, another continues)
- Multiple network interfaces, network throughput, multi-protocol support, advanced rule syntax, QoS functions, VPN performance, user authentication, VLAN support, SNMP, IDS functionality, clustering, redundancy, logging and report functions, ...

More firewall examples (Cisco, Checkpoint)

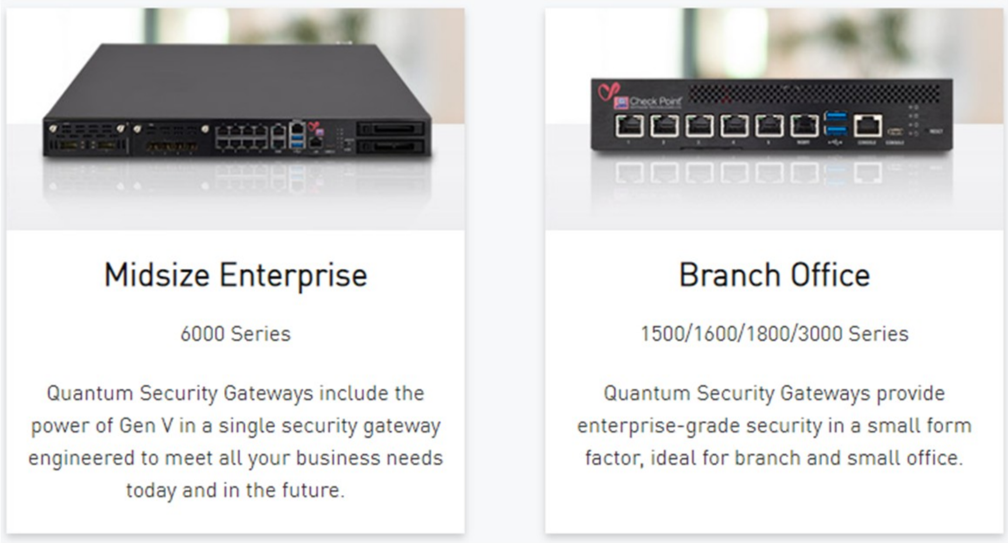


Firepower 2100 Series

- For Internet edge to data center environments
- Firewall throughput from 2.0 to 8.5 Gbps
- Threat inspection from 2.0 to 8.5 Gbps
- Stateful firewall, Application Visibility and Control, NGIPS, Advanced Malware Protection, URL Filtering

Firepower 9000 Series

- For Service provider, data center
- Firewall throughput up to 225 Gbps
- Threat inspection up to 90 Gbps
- Firewall, Application Visibility and Control, NGIPS, Advanced Malware Protection, URL Filtering, DDoS



Midsize Enterprise

6000 Series

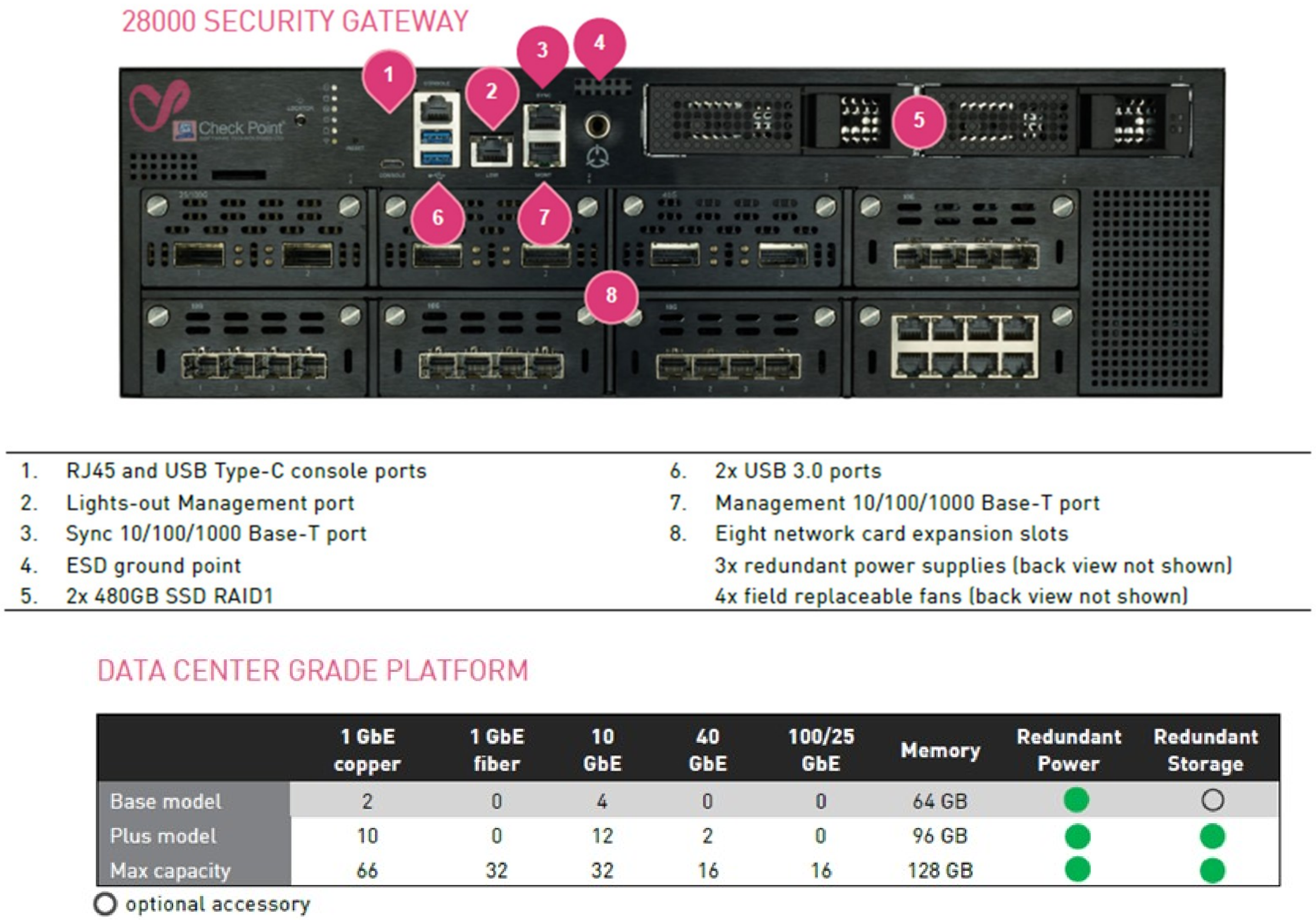
Quantum Security Gateways include the power of Gen V in a single security gateway engineered to meet all your business needs today and in the future.

Branch Office

1500/1600/1800/3000 Series

Quantum Security Gateways provide enterprise-grade security in a small form factor, ideal for branch and small office.

Example



28000 SECURITY GATEWAY

1. RJ45 and USB Type-C console ports
2. Lights-out Management port
3. Sync 10/100/1000 Base-T port
4. ESD ground point
5. 2x 480GB SSD RAID1
6. 2x USB 3.0 ports
7. Management 10/100/1000 Base-T port
8. Eight network card expansion slots

   3x redundant power supplies (back view not shown)

   4x field replaceable fans (back view not shown)

DATA CENTER GRADE PLATFORM

	1 GbE copper	1 GbE fiber	10 GbE	40 GbE	100/25 GbE	Memory	Redundant Power	Redundant Storage
Base model	2	0	4	0	0	64 GB	●	○
Plus model	10	0	12	2	0	96 GB	●	●
Max capacity	66	32	32	16	16	128 GB	●	●

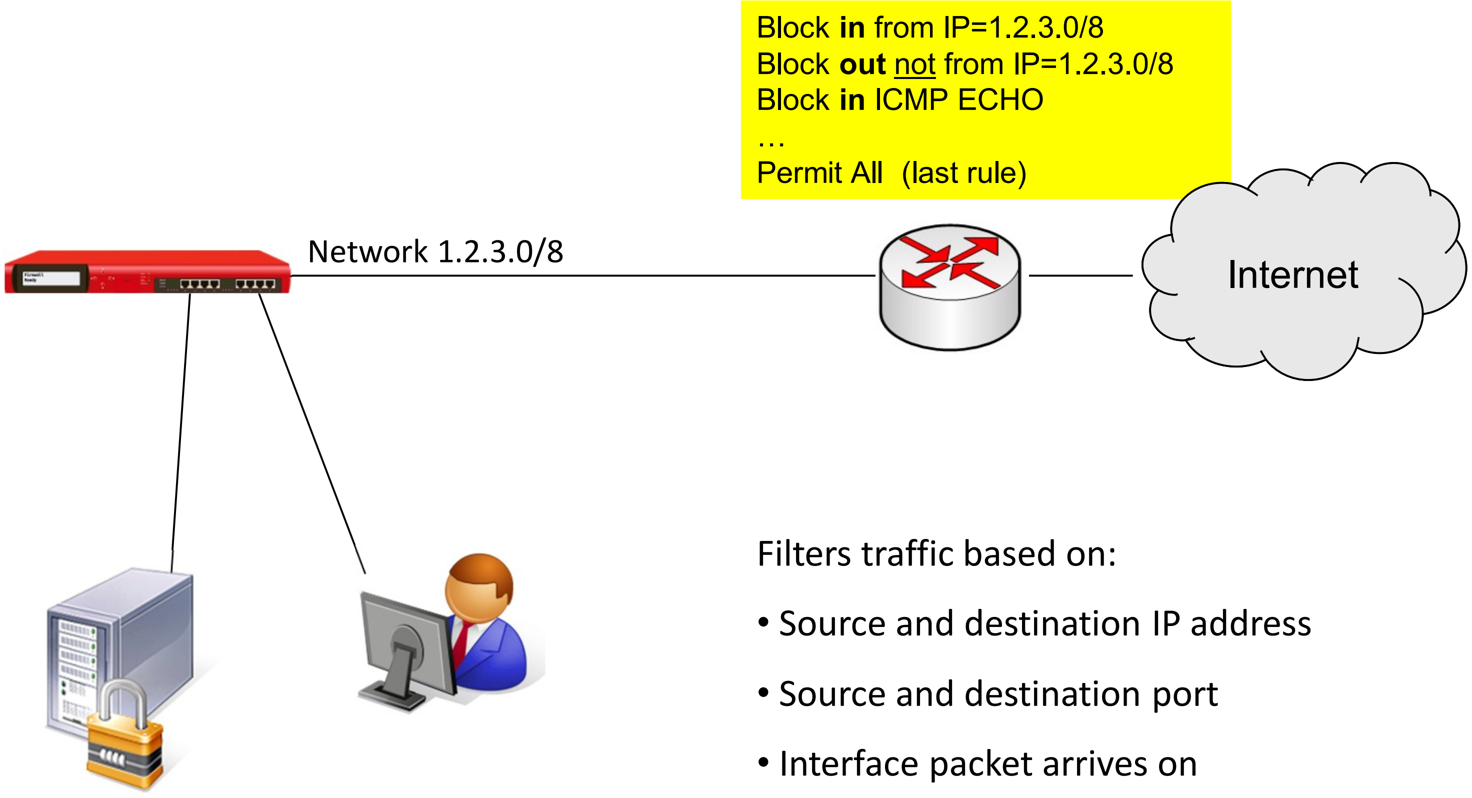
○ optional accessory

List price: from $250,000

Screening Routers

Normally Static Packet Filters (stateless)

Screening Routers



Block **in** from IP=1.2.3.0/8
Block **out** not from IP=1.2.3.0/8
Block **in** ICMP ECHO
…
Permit All (last rule)

Filters traffic based on:

- Source and destination IP address
- Source and destination port
- Interface packet arrives on

Screening Routers

- Screening Router – our first defense firewall
  - Normally done by adding filter rules in the border router
  - Reduces the load on the main border firewall
  - Good location for Ingress and Egress Filtering
  - Filters out many high-frequency, low-complexity attacks (i.e. garbage)
  - Normally filters on source and destination address, TCP and UDP ports and ICMP message type
- Also reduces risk if main firewall erroneously configured
- Uses Static Packet Filtering (stateless)
  - Fast processing at a competitive price
  - Packets examined one at a time in isolation – this misses many attacks

Ingress and Egress filters [RFC 3704]

[Private RFC1918 addresses – should never be forwarded by border router]

```
source_addr = 10.*.*.*, DROP
source_addr = 172.16.*.* to 172.31.*.*, DROP
source_addr = 192.168.*.*, DROP
source_addr = 169.254.*.*, DROP                         // Auto-configuration addr.
```

[Reserved IP addresses]

```
source_addr = 0.*.*.*,  DROP
source_addr = 127.*.*.*,  DROP                          // localhost – loopback interface
source_addr = 240.*.*.* to 255.255.255.255,  DROP       // reserved (today)
```

[Broadcast and TCP multicast]

```
source_addr = 111.222.255.255,  DROP                    // Our broadcast address (or addresses)
source_addr = 224.*.*.* to 239.*.*.*,  DROP             // Multicast address as source
dest_addr = 224.*.*.* to 239.*.*.*  proto TCP,  DROP    // TCP is not multicast
```

[Malformed packets]

```
TCP SYN=1 AND FIN=1, DROP                               // packet makes no sense (example)
tiny_fragment, DROP                                     // fragment overwriting TCP or application layer headers (e.g. HTTP)
…
```

Ingress Filters (incoming traffic)

[Internal addresses in incoming traffic]

```
source_addr = 111.222.*.*,  DROP     // internal IP address range
```

[ICMP messages – guidelines only]

```
ICMP Type = 0, PASS             // incoming “echo reply”
ICMP Type = 3, PASS             // destination unreachable: net/host/port, Fragmentation needed
ICMP Type = 4, DROP             // “source quench” messages   [depreciated RFC 6633 but may be transmitted]
ICMP, DROP                      // drop all other incoming ICMP packets??
```

[Other traffic]

```
PASS ALL                        // leave rest for main border firewall
```

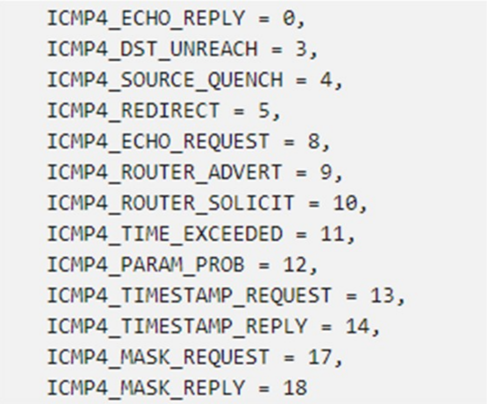
Egress filters (outgoing traffic)

[Check that source addresses belong to us – anti-spoofing]

source_addr NOT 111.222.*.*, DROP // Not our own address as source

[ICMP – guidelines only]

ICMP Type = 8, PASS // Allow outgoing echo messages (ping)
ICMP Type = 3, DROP // Host/net/port unreachable, … (prevent remote scanning)
ICMP Type = 11, DROP // TTL exceeded (prevent remote scanning)
ICMP, DROP // Most not needed but more thought needed → → →



```
ICMP4_ECHO_REPLY = 0,
ICMP4_DST_UNREACH = 3,
ICMP4_SOURCE_QUENCH = 4,
ICMP4_REDIRECT = 5,
ICMP4_ECHO_REQUEST = 8,
ICMP4_ROUTER_ADVERT = 9,
ICMP4_ROUTER_SOLICIT = 10,
ICMP4_TIME_EXCEEDED = 11,
ICMP4_PARAM_PROB = 12,
ICMP4_TIMESTAMP_REQUEST = 13,
ICMP4_TIMESTAMP_REPLY = 14,
ICMP4_MASK_REQUEST = 17,
ICMP4_MASK_REPLY = 18
```

[Black-listed ports – may be needed at times]

TCP source_port = …., DROP // e.g. Trojan “phone home” port…

[Other traffic]

PASS ALL // What is not explicitly forbidden will be accepted !

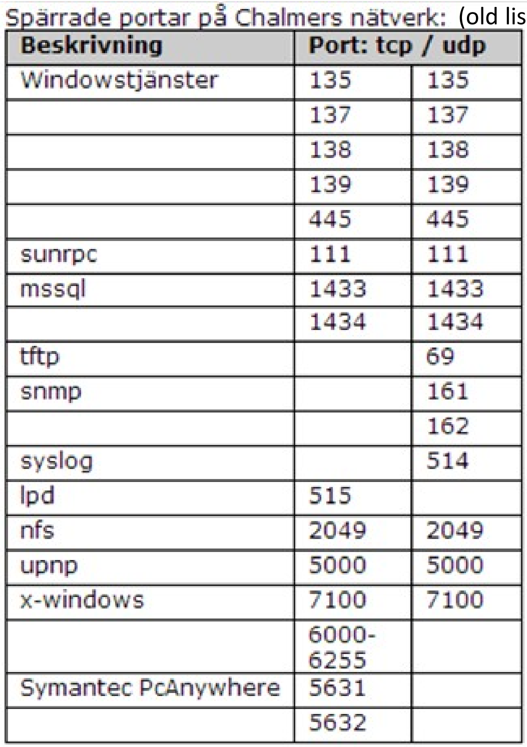
Other services to consider

Details not important

- Microsoft RPC TCP + UDP 135
  NetBIOS TCP + UDP 137-139
  SMB file sharing TCP 445
  - Used for many Windows services: file sharing, RPC, …
  - Probably no reason for them to traverse the firewall
- Simple Network Management Protocol – SNMP UDP 161-162
- Allow SMTP from all internal IP's but only to our mail server TCP 25
  - To prevent systems from sending spam
  - Drawback: users cannot connect to other mail servers (good?)

SGS student home network, possible to choose Open (no protection), Normal or Protected (no incoming connections allowed).

Normal profile inbound filter:
TCP: 21 (FTP), 23 (Telnet), 25, 53 (DNS), 80, 111, 137-139, 443
UDP: 53, 137-139, 161-162 (SNMP), 1900 (UpNp), 5351 (NAT)
Outbound filter:
TCP 137-139



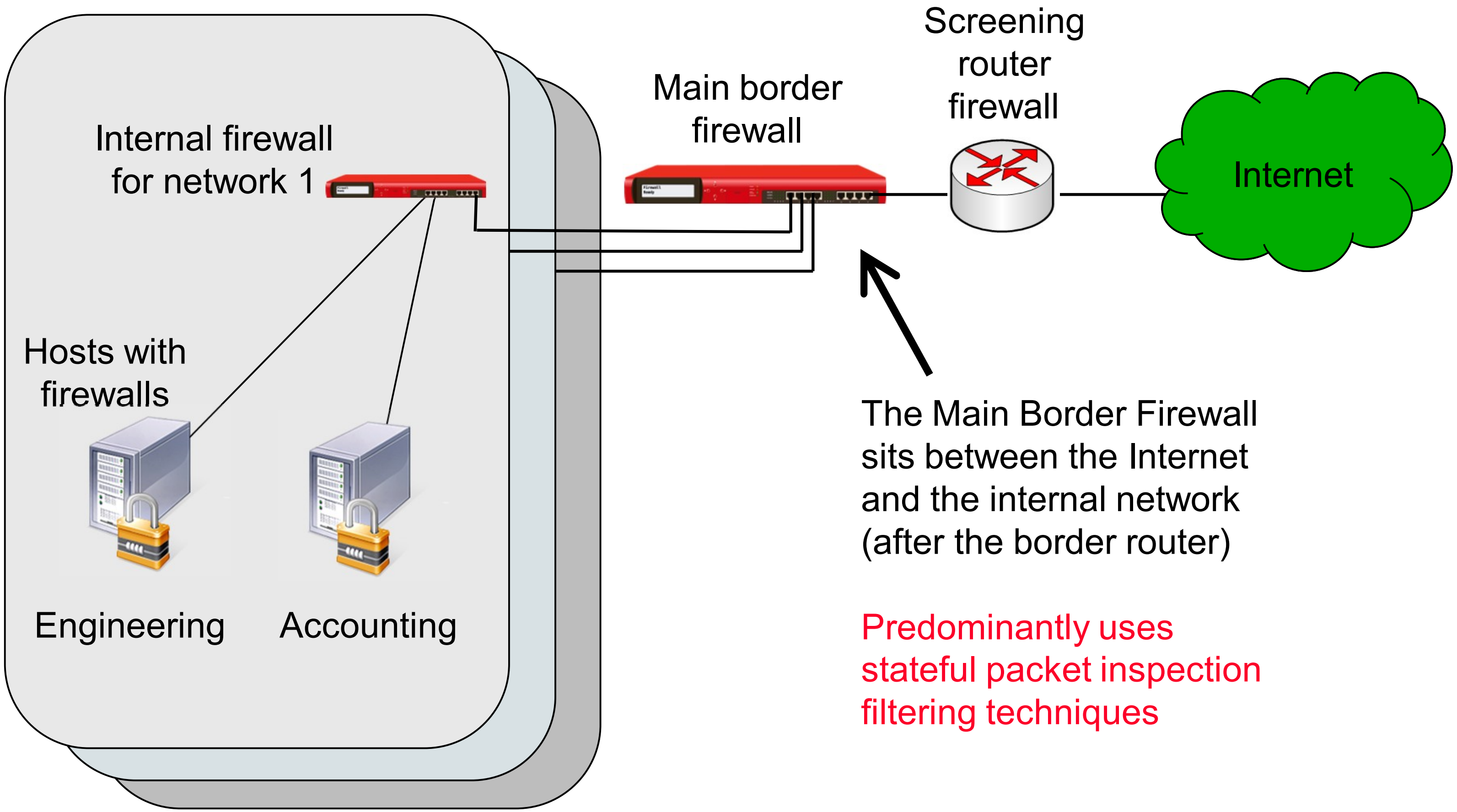
Spärrade portar på Chalmers nätverk: (old list)

Beskrivning	Port: tcp / udp	
Windowstjänster	135	135
	137	137
	138	138
	139	139
	445	445
sunrpc	111	111
mssql	1433	1433
	1434	1434
tftp		69
snmp		161
		162
syslog		514
lpd	515	
nfs	2049	2049
upnp	5000	5000
x-windows	7100	7100
	6000-6255	
Symantec PcAnywhere	5631	
	5632	

Main Border Firewalls

Normally achieved by Stateful Packet Inspection (SPI) firewalls

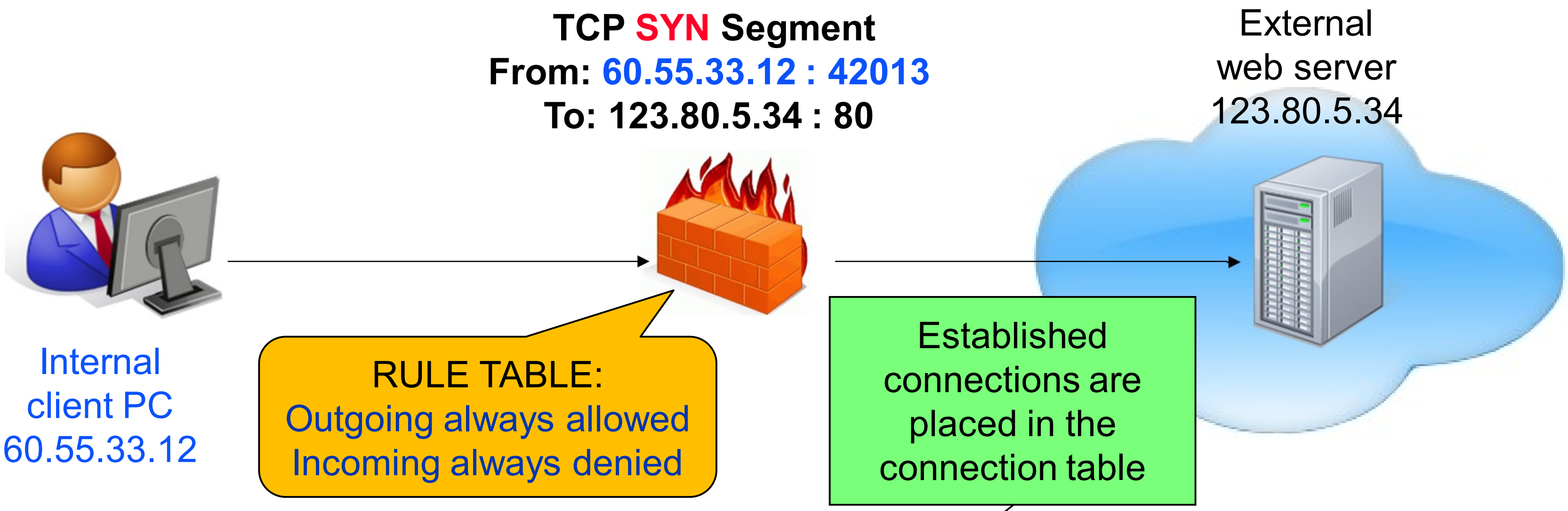
The Main Border Firewall



The Main Border Firewall sits between the Internet and the internal network (after the border router)

Predominantly uses stateful packet inspection filtering techniques

Stateful Packet Inspection (step 1)



TCP SYN Segment
From: 60.55.33.12 : 42013
To: 123.80.5.34 : 80

External
web server
123.80.5.34

Internal
client PC
60.55.33.12

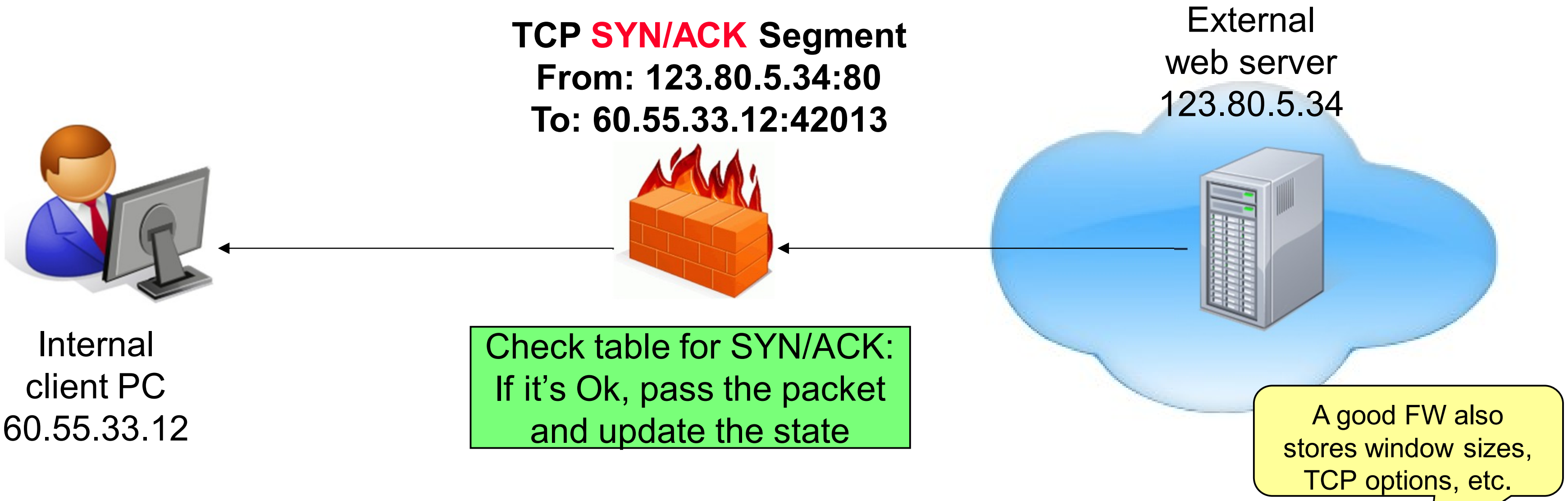
RULE TABLE:
Outgoing always allowed
Incoming always denied

Established connections are placed in the connection table

CONNECTION TABLE (or state table):

Type	Internal IP	Internal Port	External IP	External Port	State	Seq. number incoming	Seq. number outgoing
TCP	60.55.33.12	42013	123.80.5.34	80	SYN sent	--	1,324,125,328

Stateful Packet Inspection (step 2)



TCP SYN/ACK Segment
From: 123.80.5.34:80
To: 60.55.33.12:42013

External
web server
123.80.5.34

Internal
client PC
60.55.33.12

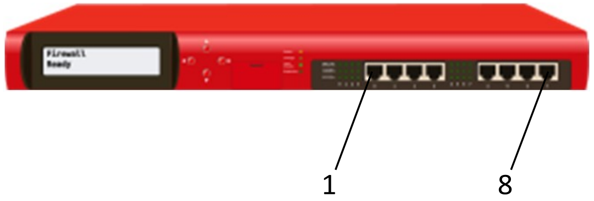
Check table for SYN/ACK:
If it's Ok, pass the packet
and update the state

A good FW also
stores window sizes,
TCP options, etc.

CONNECTION TABLE (or state table):

Type	Internal IP	Internal Port	External IP	External Port	State	Seq. number incoming	Seq. number outgoing
TCP	60.55.33.12	42013	123.80.5.34	80	SYN rec'd	387 824 116	1 324 125 328

Multiple interfaces



- Most firewalls allow interfaces in ACLs
  - With two interfaces, rules for ”in” and ”out” works
  - With more interfaces, they must be numbered or named

- Example:
  block in log on EXTERNAL {10.0.0.0/8} to any
  Rule blocks and logs incoming packets from 10.* network if received on interface EXTERNAL

- The connection table needs to contain information about interfaces:

Proto	Inter-face	IP	Port	Inter-face	IP	Port	State, seq. no, etc.
TCP	1 (ext)	60.55.33.12	42013	3	10.3.1.34	80	...
TCP	2	10.2.2.32	2313	3	10.3.1.34	80	...

UDP and Stateful Packet Inspection

- For UDP: store IP addresses and port numbers in the connection table
- Store a timeout value for the entry
- Note: during this time period, the firewall is open for external traffic to the host
  - Attacker needs to know both IP address and port number to succeed
  - It may be possible to guess this? Perhaps to constantly send faked DNS responses to an internal system waiting for the window to open ??

Type	Internal IP	Internal Port	External IP	External Port	State
TCP	60.55.33.12	42013	123.80.5.34	80	…
UDP	60.55.33.12	42111	1.8.33.4	53	Time=10s

Firewall principles

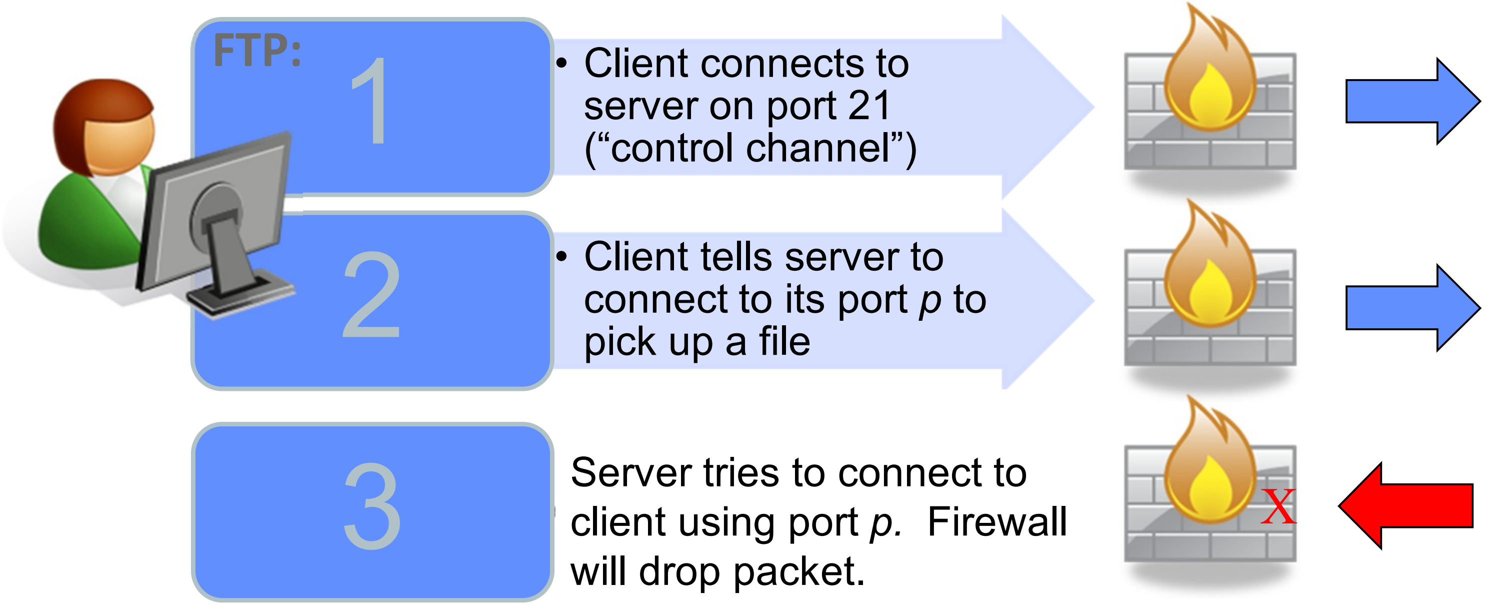
- Incoming packets:
  1. Check connection (state) table
  2. If not found, check the rule table (ACL list)
  3. If ok, pass the packet and update the state in connection table

- The rule table is normally evaluated in order: top → down
  - First match stops evaluation
  - Last rule in the main border firewall is always “Drop All”

- Each application-level protocol to inspect requires a module
  - More protocols → more processing power →may need dedicated hardware
  - Can detect that traffic is not legitimate
  - Example: lots of non-web traffic uses port 80 to become “firewall friendly”
  - Solution: do HTTP content filtering

Problems with FTP-like protocols

- Protocols that dynamically open new ports are problematic. Avoid them!



FTP:

1

- Client connects to server on port 21 (“control channel”)

2

- Client tells server to connect to its port *p* to pick up a file

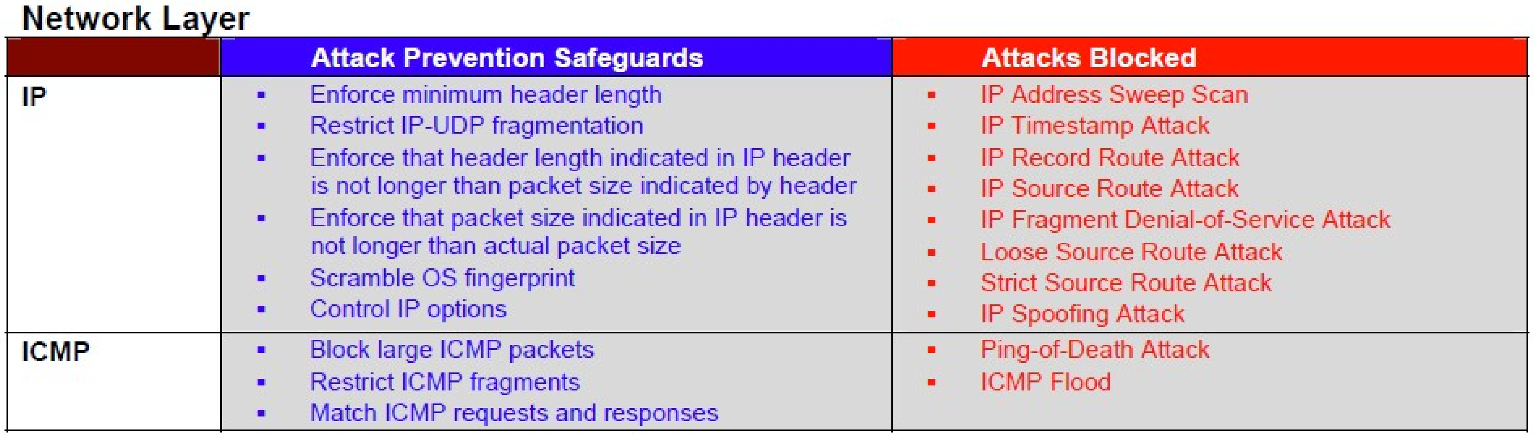
3

Server tries to connect to client using port *p*. Firewall will drop packet.

SPI Firewalls – Summary

- Dominating technique for Main Border Firewalls
- Security
  - Very flexible – can handle almost any TCP/UDP/ICMP flow
  - Probably best choice if only one FW is used
- Can do some application-level filtering
  - Other important protocols: FTP, HTTP, DNS, …
- Simple and can therefore be rather cheap
  - Rules could be complex (good)
  - Checking ongoing connections is simple and fast
  - But if connection table grows very large → takes longer time
- Stateful inspection is cost effective
  - Many firewalls run on standard operating systems
  - Hardened system with special packet handling software

Example: FW-1 firewall features

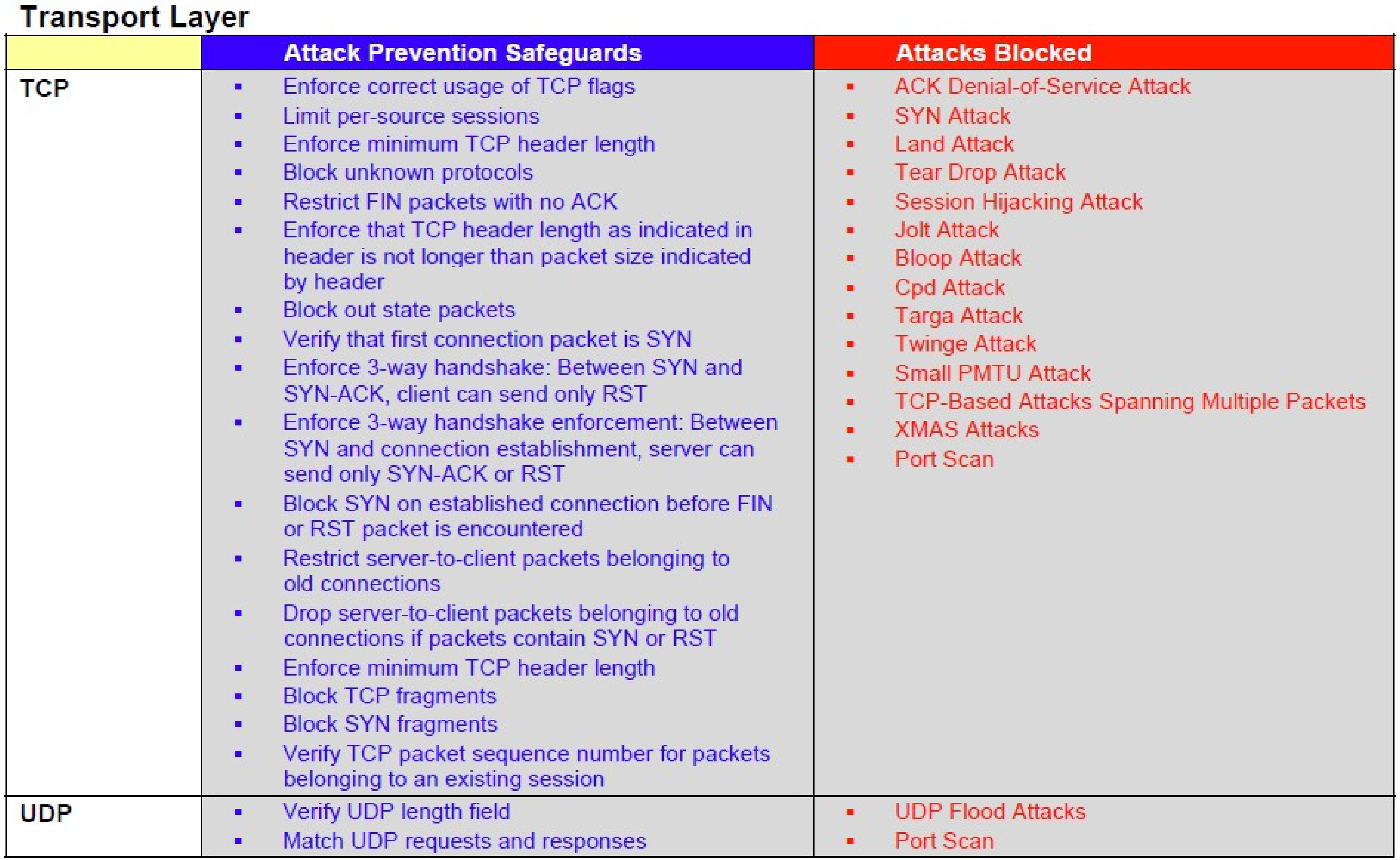


Network Layer

	Attack Prevention Safeguards	Attacks Blocked
IP	▪ Enforce minimum header length ▪ Restrict IP-UDP fragmentation ▪ Enforce that header length indicated in IP header is not longer than packet size indicated by header ▪ Enforce that packet size indicated in IP header is not longer than actual packet size ▪ Scramble OS fingerprint ▪ Control IP options	▪ IP Address Sweep Scan ▪ IP Timestamp Attack ▪ IP Record Route Attack ▪ IP Source Route Attack ▪ IP Fragment Denial-of-Service Attack ▪ Loose Source Route Attack ▪ Strict Source Route Attack ▪ IP Spoofing Attack
ICMP	▪ Block large ICMP packets ▪ Restrict ICMP fragments ▪ Match ICMP requests and responses	▪ Ping-of-Death Attack ▪ ICMP Flood

Firewall-1 was selected here because of a nice table. Other firewalls have similar features.

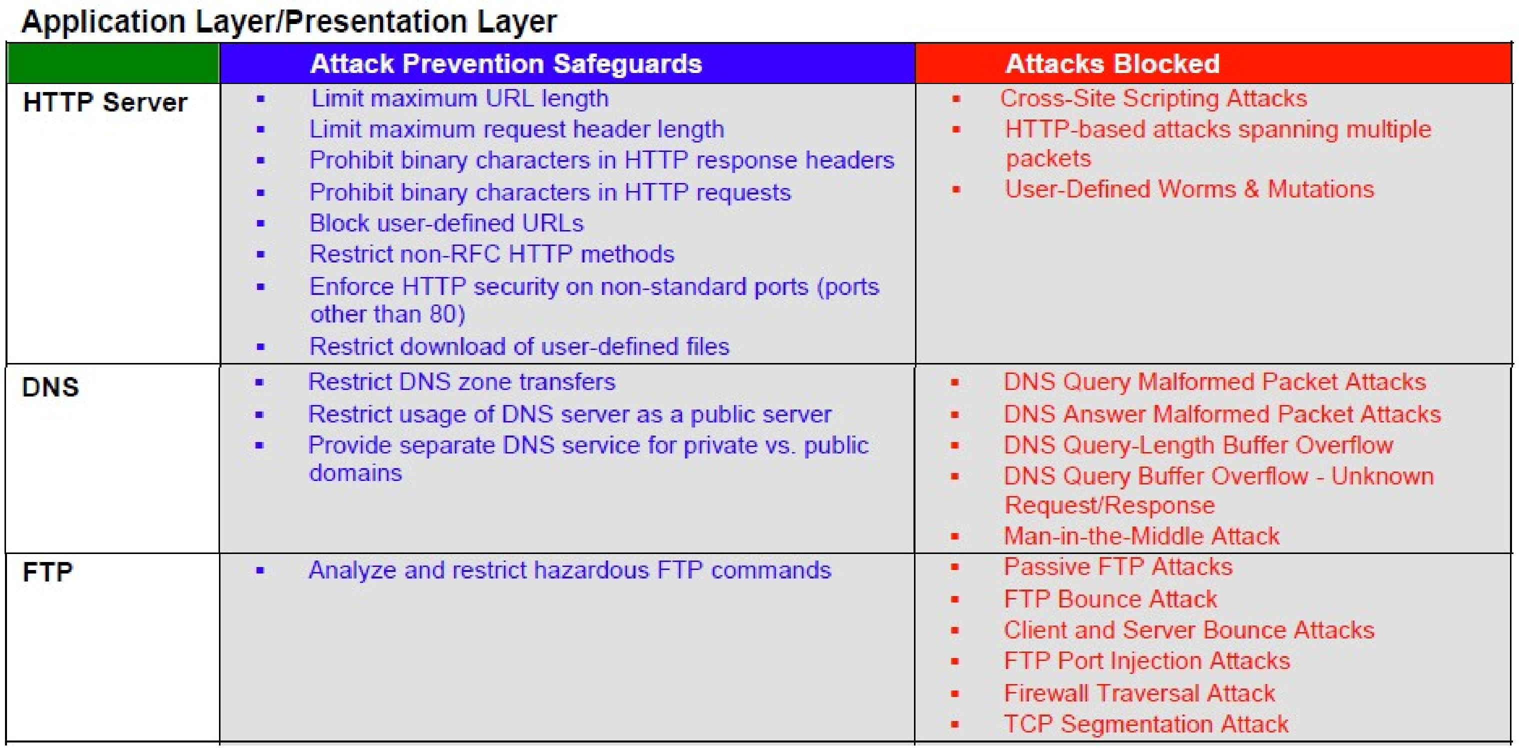
Example: FW-1 firewall features



Transport Layer

	Attack Prevention Safeguards	Attacks Blocked
TCP	▪ Enforce correct usage of TCP flags ▪ Limit per-source sessions ▪ Enforce minimum TCP header length ▪ Block unknown protocols ▪ Restrict FIN packets with no ACK ▪ Enforce that TCP header length as indicated in header is not longer than packet size indicated by header ▪ Block out state packets ▪ Verify that first connection packet is SYN ▪ Enforce 3-way handshake: Between SYN and SYN-ACK, client can send only RST ▪ Enforce 3-way handshake enforcement: Between SYN and connection establishment, server can send only SYN-ACK or RST ▪ Block SYN on established connection before FIN or RST packet is encountered ▪ Restrict server-to-client packets belonging to old connections ▪ Drop server-to-client packets belonging to old connections if packets contain SYN or RST ▪ Enforce minimum TCP header length ▪ Block TCP fragments ▪ Block SYN fragments ▪ Verify TCP packet sequence number for packets belonging to an existing session	▪ ACK Denial-of-Service Attack ▪ SYN Attack ▪ Land Attack ▪ Tear Drop Attack ▪ Session Hijacking Attack ▪ Jolt Attack ▪ Bloop Attack ▪ Cpd Attack ▪ Targa Attack ▪ Twinge Attack ▪ Small PMTU Attack ▪ TCP-Based Attacks Spanning Multiple Packets ▪ XMAS Attacks ▪ Port Scan
UDP	▪ Verify UDP length field ▪ Match UDP requests and responses	▪ UDP Flood Attacks ▪ Port Scan

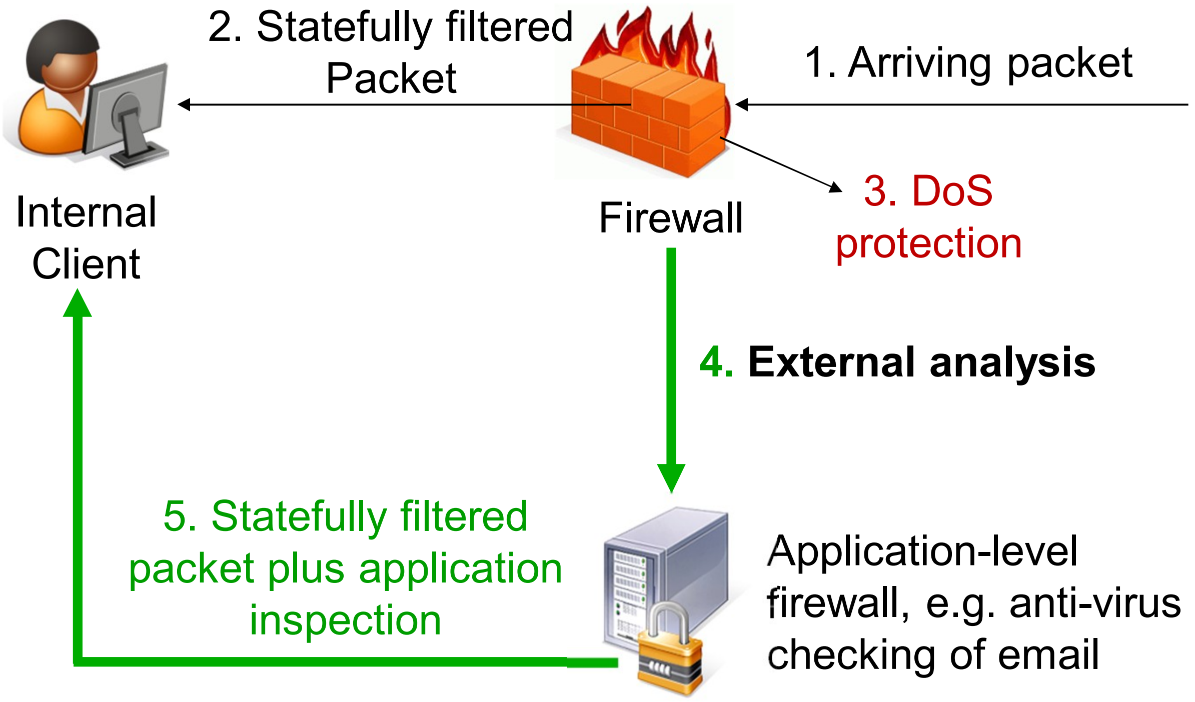
Example: FW-1 firewall features



Application Layer/Presentation Layer

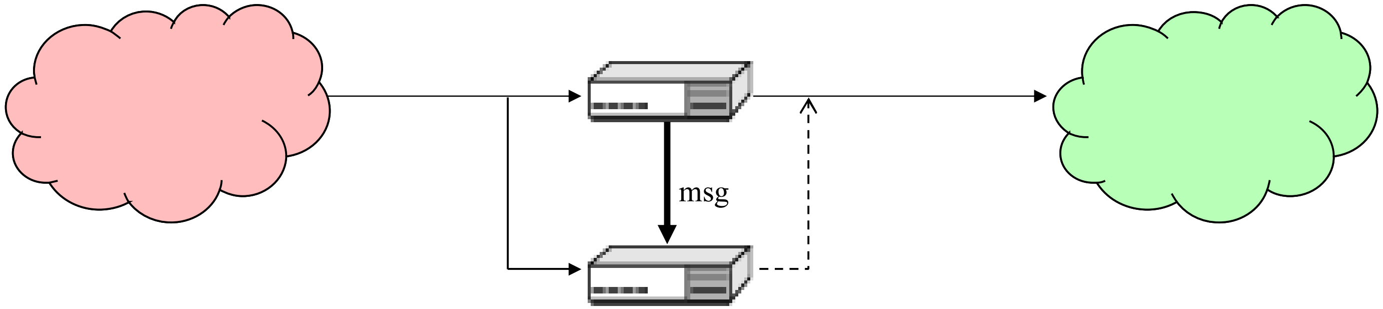
	Attack Prevention Safeguards	Attacks Blocked
HTTP Server	▪ Limit maximum URL length ▪ Limit maximum request header length ▪ Prohibit binary characters in HTTP response headers ▪ Prohibit binary characters in HTTP requests ▪ Block user-defined URLs ▪ Restrict non-RFC HTTP methods ▪ Enforce HTTP security on non-standard ports (ports other than 80) ▪ Restrict download of user-defined files	▪ Cross-Site Scripting Attacks ▪ HTTP-based attacks spanning multiple packets ▪ User-Defined Worms & Mutations
DNS	▪ Restrict DNS zone transfers ▪ Restrict usage of DNS server as a public server ▪ Provide separate DNS service for private vs. public domains	▪ DNS Query Malformed Packet Attacks ▪ DNS Answer Malformed Packet Attacks ▪ DNS Query-Length Buffer Overflow ▪ DNS Query Buffer Overflow - Unknown Request/Response ▪ Man-in-the-Middle Attack
FTP	▪ Analyze and restrict hazardous FTP commands	▪ Passive FTP Attacks ▪ FTP Bounce Attack ▪ Client and Server Bounce Attacks ▪ FTP Port Injection Attacks ▪ Firewall Traversal Attack ▪ TCP Segmentation Attack

Other systems can help the firewall


2. Statefully filtered Packet
1. Arriving packet
Internal Client
Firewall
3. DoS protection
4. External analysis
5. Statefully filtered packet plus application inspection
Application-level firewall, e.g. anti-virus checking of email

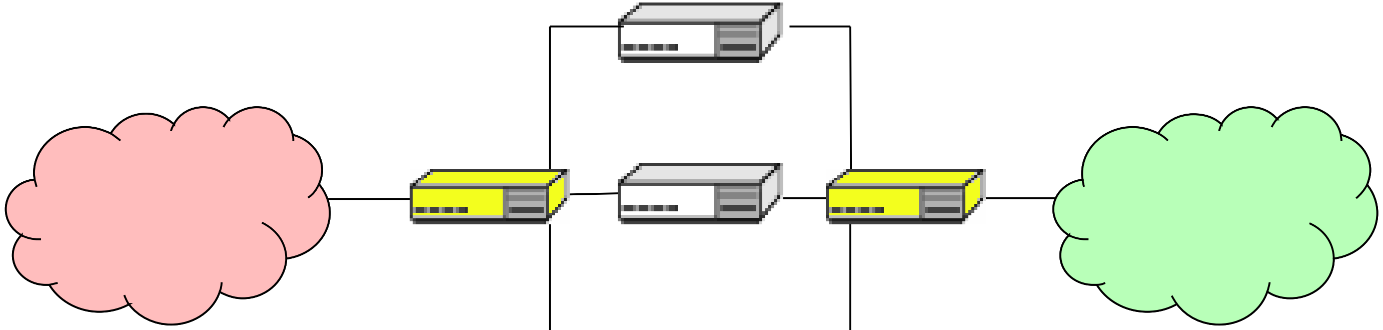
Clustering for Redundancy

- It is possible to use multiple firewalls (clustering) to achieve higher availability
- All firewalls in the cluster must have the same state information
  - They communicate via a private network connection
- One method:
  - Both FWs listen to network traffic but only the master forwards traffic
  - The slave gets periodic messages from the master ("I'm alive")
  - If messages cease, slave immediately takes over and forwards packets



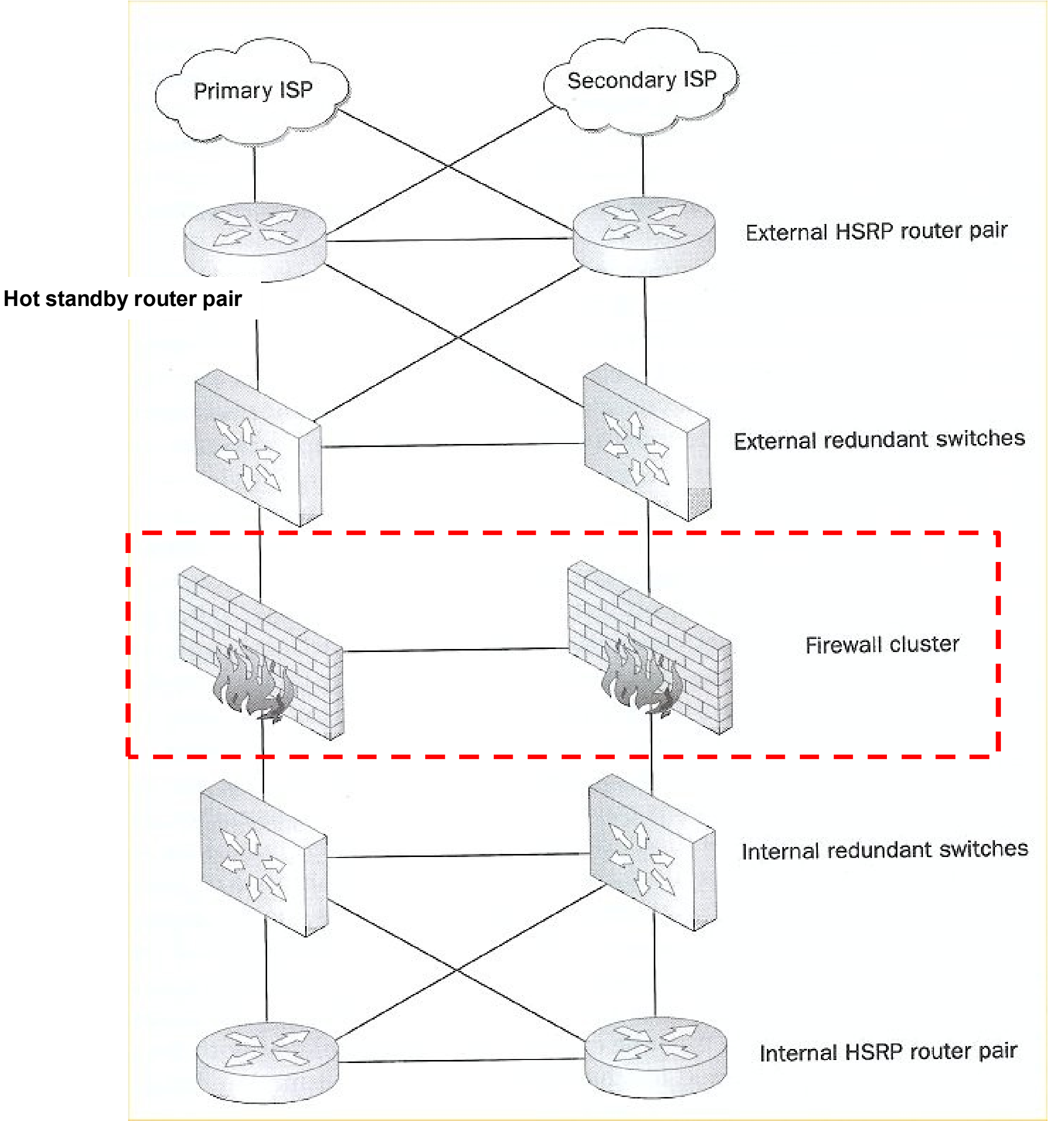
Clustering for load sharing

- Front-end load balancers distribute traffic
  - Same firewall always handles one traffic flow
  - State not shared between firewalls
- If a firewall dies, its connections are broken
- But if the load balancer dies? More complex solutions needed, next slide



Clustering for redundancy and load sharing

Takeaway: it is complicated to make it truly redundant


Primary ISP
Secondary ISP
External HSRP router pair
Hot standby router pair
External redundant switches
Firewall cluster
Internal redundant switches
Internal HSRP router pair

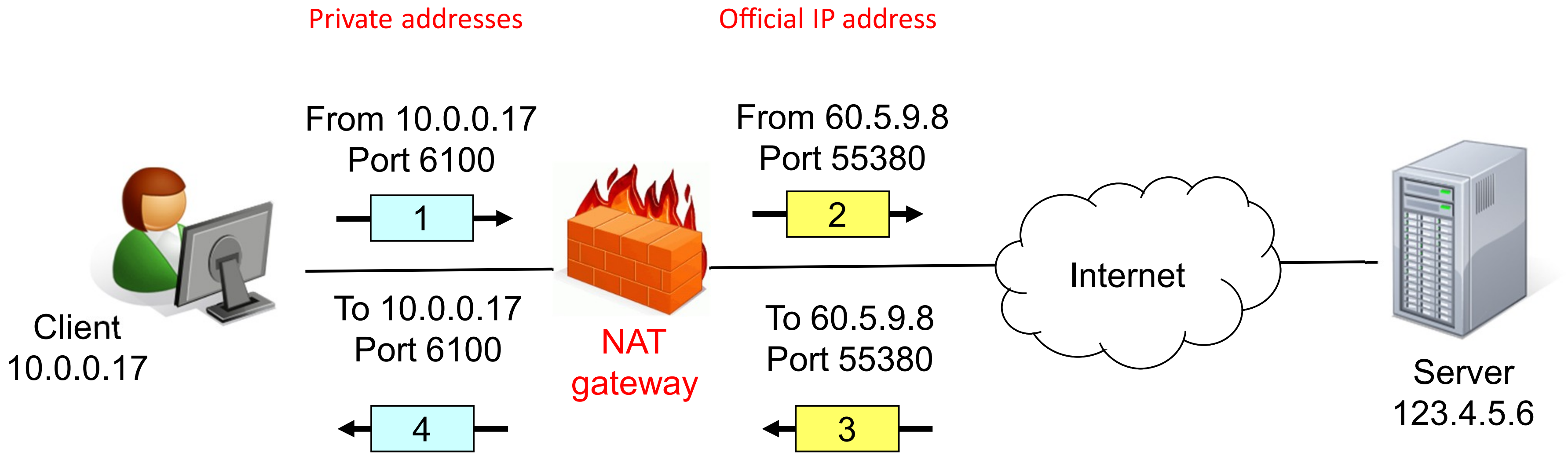
Network Address Translation (NAT)

Can be used as a firewall – it blocks external connections to the network

Network Address Translation (NAT)

- Internal IP addresses to one or more official addresses (RFC 2663)
  - Can use private (RFC 1918) addresses internally
- NAPT – Network Address Port Translation is what most consider as NAT ("Traditional NAT" – RFC 3022)
- Translates [IP_address, port_number] on internal hosts to an official IP address and another port number
  - Dynamic: translation is done per connection and only when needed
  - An organization may have a limited number of public IP addresses
  - Can have thousands of internal IP addresses for each public IP address
  - Each external IP address can have one connection per port number (i.e. 65,535 active connections)
  - Multiple external IP addresses can be used if one is not enough
- Clients can request NAT device to open ports – Port Control Protocol (PCP – RFC7843)
  - Typically used for home users
  - Part of Universal Plug and Play (UPnP) for Internet Gateway Devices
  - UDP port 5350 (client) and 5351 (server)

Network Address Translation (NAT)



Translation Table

Internal		External	
IP Addr	Port	IP Addr	Port
10.0.0.17	6100	60.5.9.8	55380
. . .	. . .	. . .	. . .

Information stored by NAT gateways

- TCP and UDP:
  - Source and dest IP addresses
  - Source and dest ports
- ICMP:
  - Source and dest IP addresses
  - ICMP query ID
  - IP address in the actual reply must also be modified by NAT gateway
- All other (if supported):
  - Source and dest IP addresses
  - protocol field in IP header
- Session termination [more details in RFC 2663]
  - NAT gateway cannot assume that FIN or RSTs will be delivered to hosts
  - Timeout since last seen activity, device dependent
  - For TCP typically 4 minutes after FIN messages

Security benefits with NAT

- Hides internal IP addresses and port numbers
  - Externally only translated addresses and port numbers visible
  - Much harder to identify individual hosts
  - External attackers cannot create connections to internal computers
- Attackers can only spoof packets for open connections
  - Ports on internal machines are invisible
  - Sniffers can read stand-in IP addresses and port numbers
  - ACK scans possible for open connections
- Good complement to a stateful firewall
  - Normally implemented in the border (screening) router
  - Or in the firewall itself if no screening router used
- No active clients → translation table empty → no incoming traffic allowed

NAT disadvantages

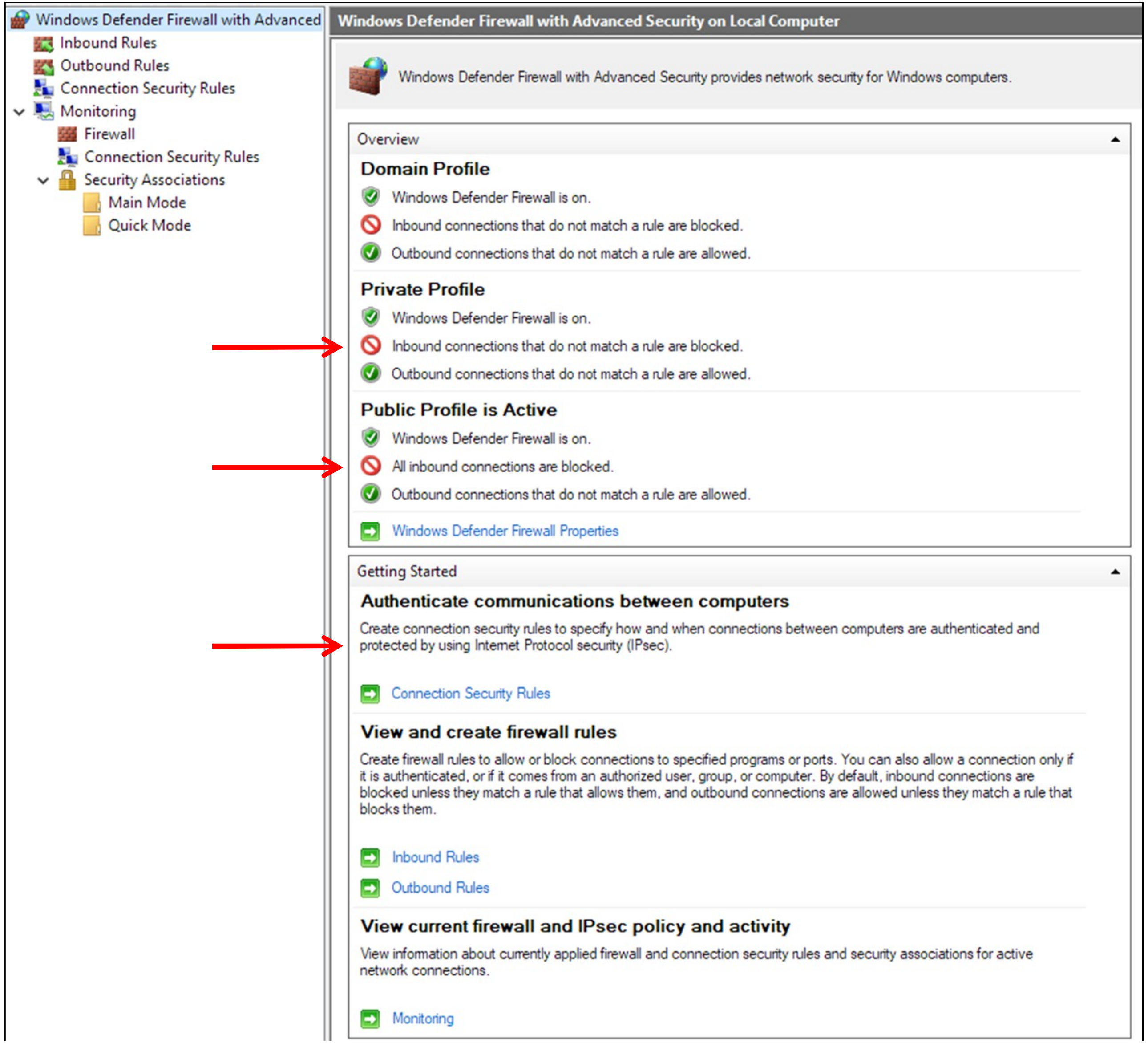
- No inspection of packet contents
- NAT gateways need to reassemble IP fragments before forwarding
  - TCP header only present in first fragment – needed to look up entry in table
  - Fragments can be forwarded but it must at least do “virtual” fragmentation
  - Keep state? Drop?
- Problems with protocols relying on clients’ IP addresses
  - Applications sending client IP-addresses will not work (IPsec, VoIP, SIP, …)
  - Protocols requesting the external party to connect back will not work (FTP)
  - Good from a security point of view, but…
- Examples of problematic protocols:
  - Virtual private networks (VPN) using IPsec
  - VoIP, h323, FTP, P2P, IRC
  - Mobile IP, …
- Authorizing users based on the IP address from a NATed site will fail
  - All users seem to originate from the same computer
  - Never offer services that rely only on the IP addresses!

Host-based / personal firewalls

Windows

- Stateful firewall introduced with Windows Vista 2007 which was enabled by default
  - GUI for user interaction
  - Domain users can have remote configured firewalls
  - Few users know what is legitimate traffic
- Different profiles can be active based on location
  - Home, domain and public
  - A profile can be associated with a network interface
- Possible to control which application can use a port (i.e. to be a service)
  - Can notify user if a program is blocked
  - Linux similar functionality: AppArmor kernel security module
- Possible to control what interface rule applies to
  - May be different rules for LAN, WLAN, 3G, ...
- Possible to allow connection from a host only if IPsec (encrypted IP) is used

Windows defender firewall profiles


Windows Defender Firewall with Advanced
Inbound Rules
Outbound Rules
Connection Security Rules
Monitoring
Firewall
Connection Security Rules
Security Associations
Main Mode
Quick Mode

Windows Defender Firewall with Advanced Security on Local Computer

Windows Defender Firewall with Advanced Security provides network security for Windows computers.

Overview

Domain Profile

- ✓ Windows Defender Firewall is on.
- ⊘ Inbound connections that do not match a rule are blocked.
- ✓ Outbound connections that do not match a rule are allowed.

Private Profile

- ✓ Windows Defender Firewall is on.
- ⊘ Inbound connections that do not match a rule are blocked.
- ✓ Outbound connections that do not match a rule are allowed.

Public Profile is Active

- ✓ Windows Defender Firewall is on.
- ⊘ All inbound connections are blocked.
- ✓ Outbound connections that do not match a rule are allowed.

Windows Defender Firewall Properties

Getting Started

Authenticate communications between computers

Create connection security rules to specify how and when connections between computers are authenticated and protected by using Internet Protocol security (IPsec).

Connection Security Rules

View and create firewall rules

Create firewall rules to allow or block connections to specified programs or ports. You can also allow a connection only if it is authenticated, or if it comes from an authorized user, group, or computer. By default, inbound connections are blocked unless they match a rule that allows them, and outbound connections are allowed unless they match a rule that blocks them.

Inbound Rules

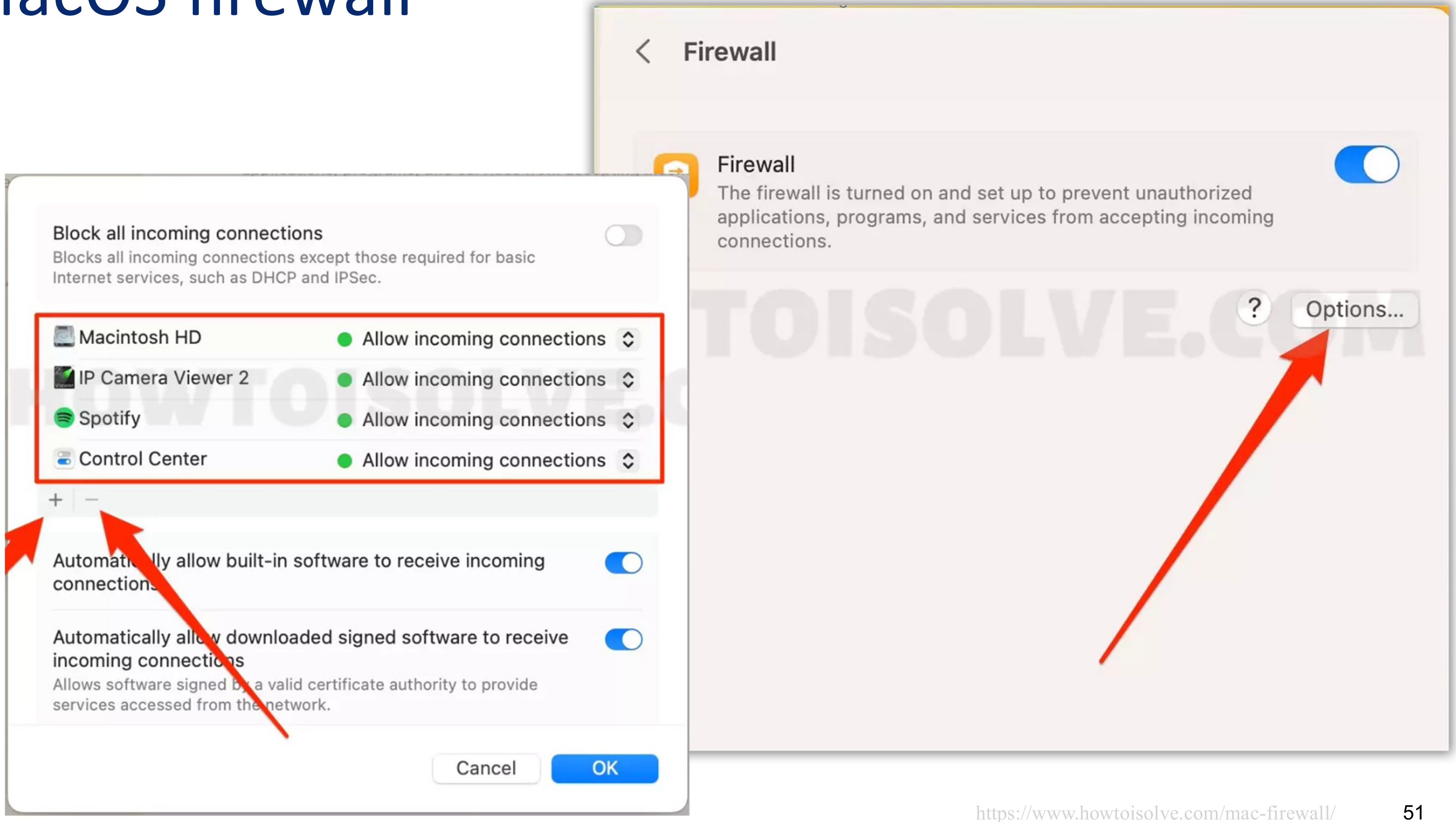
Outbound Rules

View current firewall and IPsec policy and activity

View information about currently applied firewall and connection security rules and security associations for active network connections.

Monitoring

MacOS firewall



Firewall

Firewall

The firewall is turned on and set up to prevent unauthorized applications, programs, and services from accepting incoming connections.

Block all incoming connections

Blocks all incoming connections except those required for basic Internet services, such as DHCP and IPSec.

Macintosh HD	● Allow incoming connections
IP Camera Viewer 2	● Allow incoming connections
Spotify	● Allow incoming connections
Control Center	● Allow incoming connections

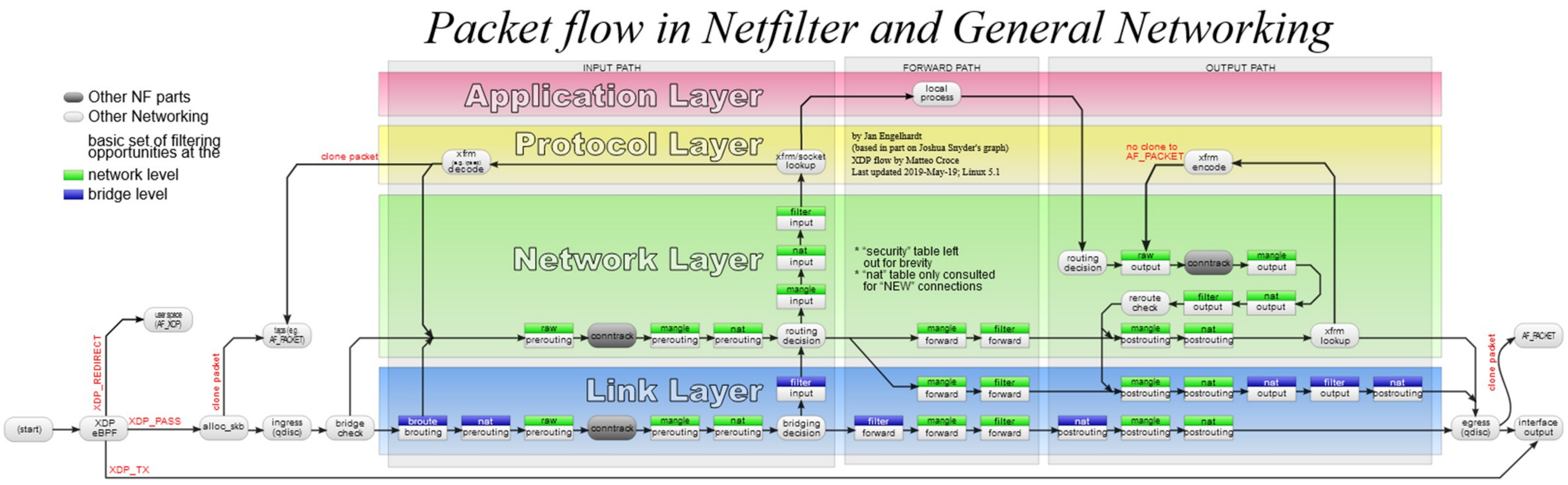
Automatically allow built-in software to receive incoming connections

Automatically allow downloaded signed software to receive incoming connections

Allows software signed by a valid certificate authority to provide services accessed from the network.

https://www.howtoisolve.com/mac-firewall/

Linux iptables / Netfilter

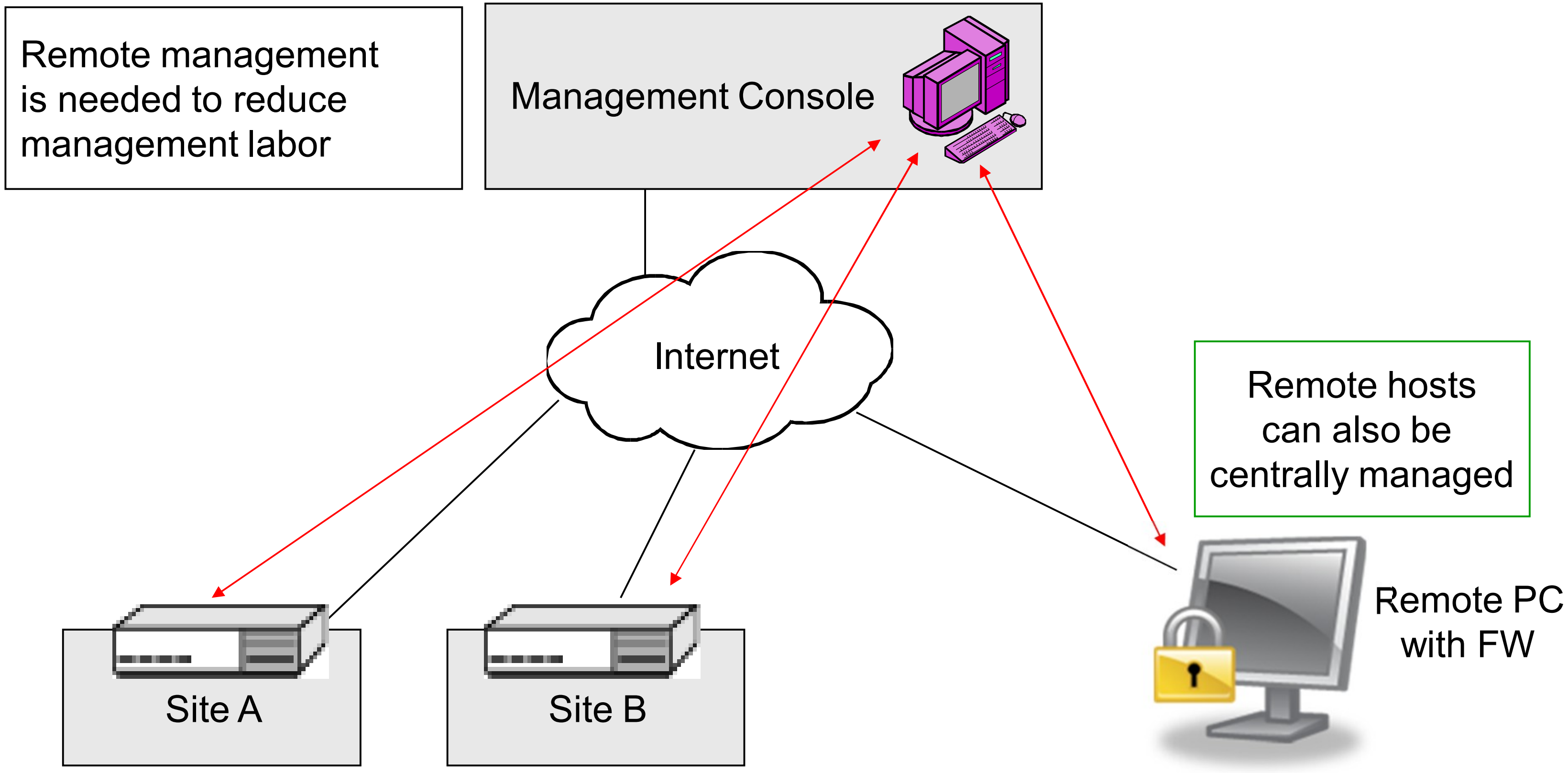


by Jan Engelhardt
(based in part on Joshua Snyder's graph)
XDP flow by Matteo Croce
Last updated 2019-May-19; Linux 5.1

- "security" table left out for brevity
- "nat" table only consulted for "NEW" connections

https://en.wikipedia.org/wiki/Netfilter

Centralized Firewall Management



Remote management is needed to reduce management labor

Management Console

Remote hosts can also be centrally managed

Summary

- Firewall types
  - Static and dynamic (stateless) filters
  - Stateful packet inspection (transport and/or application layer)
  - Circuit-level gateways and application proxies
- Use screening router + main border firewall
  - Screening router removes all obvious garbage and does ingress and egress filtering
  - Main border firewall performs deeper inspection
- Internal firewalls for segmentation
  - Many layers of defense
- NAT for security
- Host-based (personal) firewalls on clients and servers
  - Remote clients’ only defense, e.g. on guest networks
  - Also final outpost if problems occur on internal networks