

Network Flow Control

Segurança em Redes de Comunicações
Mestrado em Cibersegurança
Mestrado em Engenharia de Computadores e
Telemática
DETI-UA

Network Security Systems

- Firewall
- Intrusion Prevention System (IPS)
 - ◆ Performs deep-packet inspection
- Intrusion Detection Systems (IDS)
 - ◆ Performs deep-packet (DPI) and shallow-packet inspection (SPI)
- Security Appliance
 - ◆ Unified communications security
 - ◆ Firewall services
 - ◆ Real-time threat defense
 - ◆ Secure remote access
 - ◆ Secure communications services
 - ◆ Content security





Firewalls

- A firewall provides a single point of defense between networks and protects one network from the others-
- It is a system or group of systems that enforces a control policy between two or more networks (access control, flow control and content control).
- It is a network gateway that enforces the rules of network security.
- Minimizes local vulnerabilities.
- Evaluates each network packet against the policies of network security.
- Can monitor all the network traffic and alert to any attempts to bypass security or to any patterns of inappropriate use.
- Can be hardware or software based.



Firewalls Security/Network Services

- NAT (Network Address Translation).
- Authorization
 - ♦ Flows (packet filtering).
 - ♦ Users (application and circuit level).
- Redirecting.
 - ♦ To specif machines.
 - ♦ Proxing.
- Content analysis.
- Secure communication.
 - ♦ Site-to-site VPN.
 - IPsec.
 - ♦ Remote-access VPN.
- DoS and DDoS detection and defense.





Types of Firewalls

- Network-Level Firewalls (L2/L3)

- ◆ Packet filtering
- ◆ Inspecting packet headers and filtering traffic based on
 - the IP address of the source and the destination, the port and the service (L3)
 - source and the destination MAC addresses (L2)

- Circuit-Level Firewalls (L4)

- ◆ Monitor TCP handshaking between packets to make sure a session is legitimate
- ◆ Traffic is filtered based on specified session rules

- Application-Level Firewalls (L4+)

- ◆ Application-level firewalls are sometimes called proxies
- ◆ Looking more deeply into the application data
- ◆ Consider the context of client requests and application responses
- ◆ Attempt to enforce correct application behavior and block malicious activity
- ◆ Application-level filtering may include protection against Spam and viruses as well, and block undesirable Web sites based on content rather than just their IP address
- ◆ Slow and resources consuming tasks

- Stateful Multi-level Firewalls (L*)

- ◆ Filter packets at the network level and they recognize and process application-level data
- ◆ Since they don't employ proxies, they have reasonably good performance even performing deep packet analysis

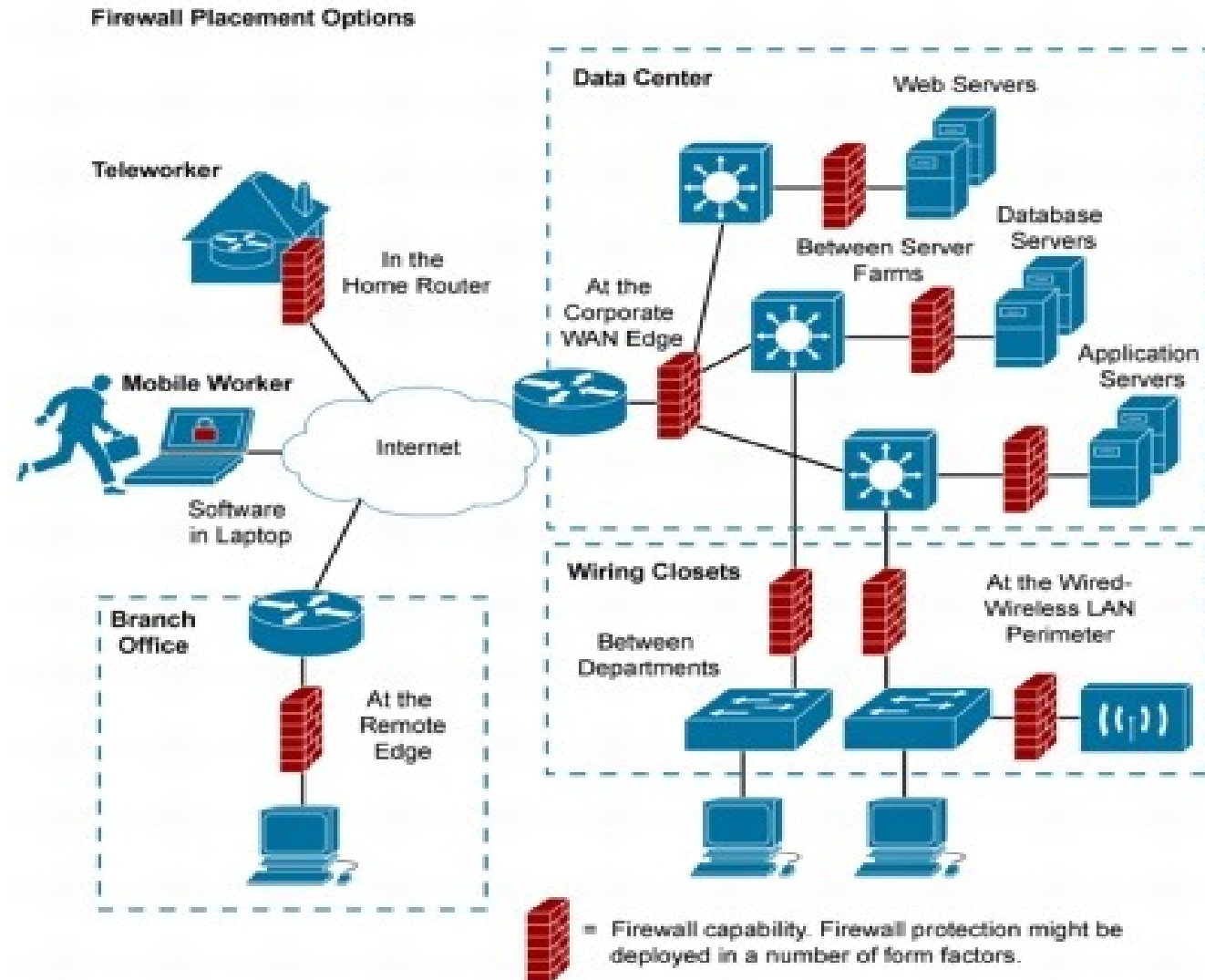
- Host Level / Personal Firewalls

- ◆ Act only within a specif host
- ◆ Filter all communication layers
- ◆ Control OS processes/applications



Deploying Firewalls

- Network must be protected at multiple levels and locations





Stateful vs. Stateless Firewalls

- Stateless firewalls

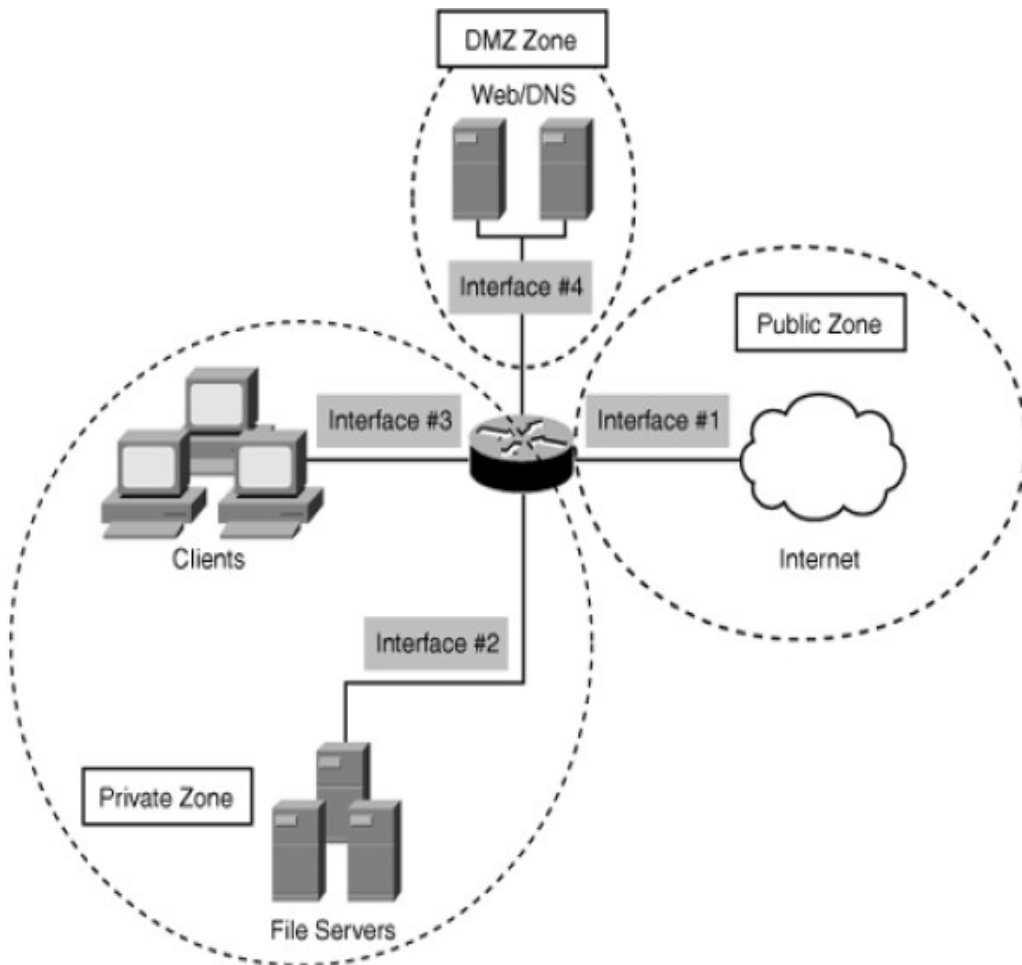
- ◆ Controls traffic by applying rules to single frames/packets
 - Does not need to track traffic flows/sessions.
- ◆ Rules based on specific values on frames/packet available headers.
 - Set of basic permit/deny actions for input and output based on IP addresses, UDP/TCP ports, etc...
 - Usually called ACL (Access List).
- ◆ They are fast and consume very low computing resources.
 - Perform well under heavy traffic load.
 - Ideal to defense against DDoS attacks in the first line of network defense.
 - Cost-effective compared with stateful firewall types.

- Stateful firewalls

- ◆ Monitor all traffic flows/sessions.
- ◆ Controls traffic based on the connection state of a flow/session.
 - Automatic bidirectional rules (reflexive rules).
- ◆ Connection state is maintained in a state table.
 - State tables must be synchronized with other firewalls when in a redundant scenario (load balancing) or high-availability scenario (backup upon failure).



Firewall Zones/Group



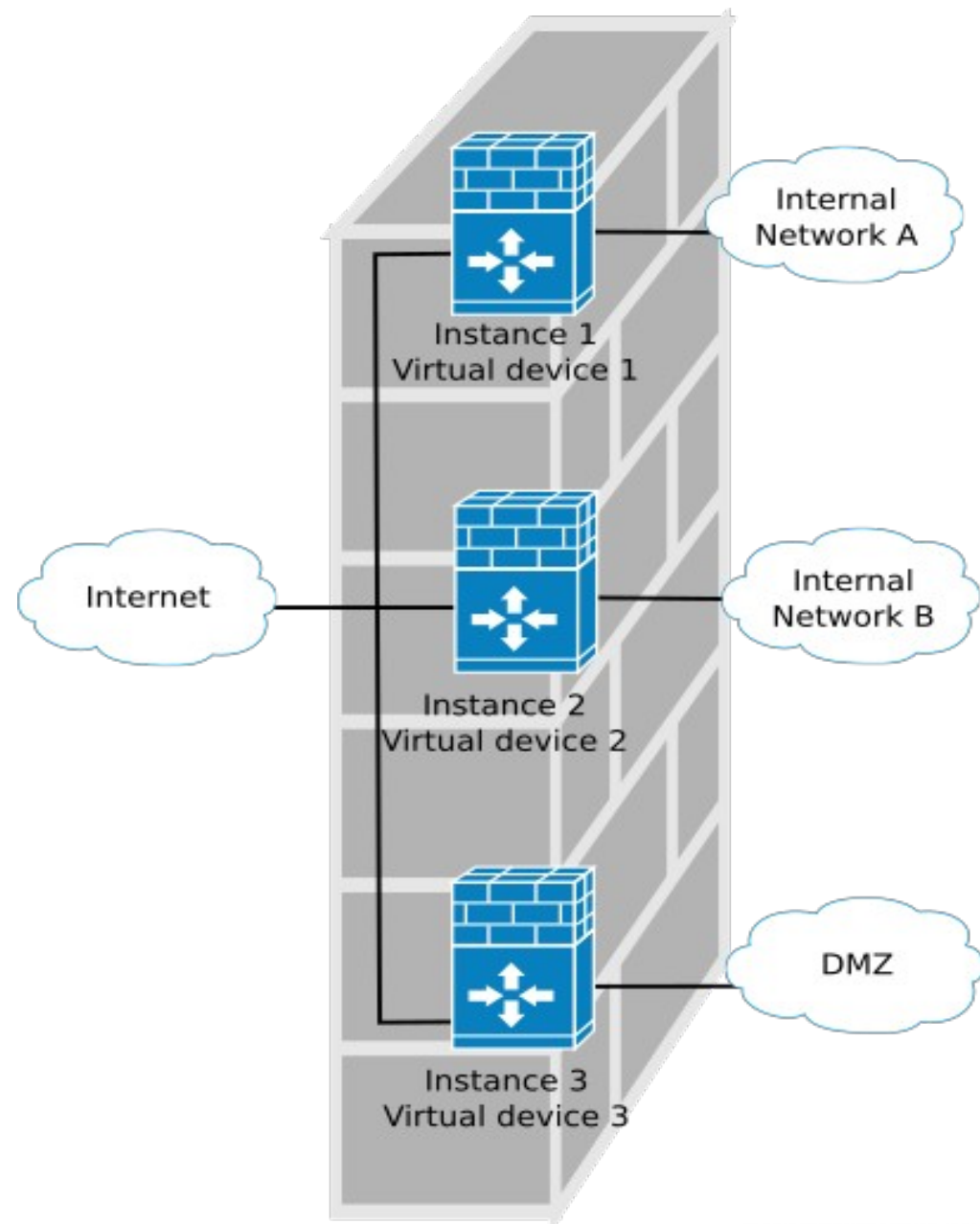
- A network can be divided in multiple zones/groups with different security levels.
 - Collections of IP addresses, networks, or ports.
- Once created, a group can be referenced by firewall rules as either a source or destination.
- Example: a Demilitarized Zone (DMZ) is a perimeter network outside the protected internal/private network
 - Used to place public servers/services.
 - The DMZ is a "semi-protected" Zone.
 - ➔ It must be assumed that any machine placed on the DMZ is at risk.





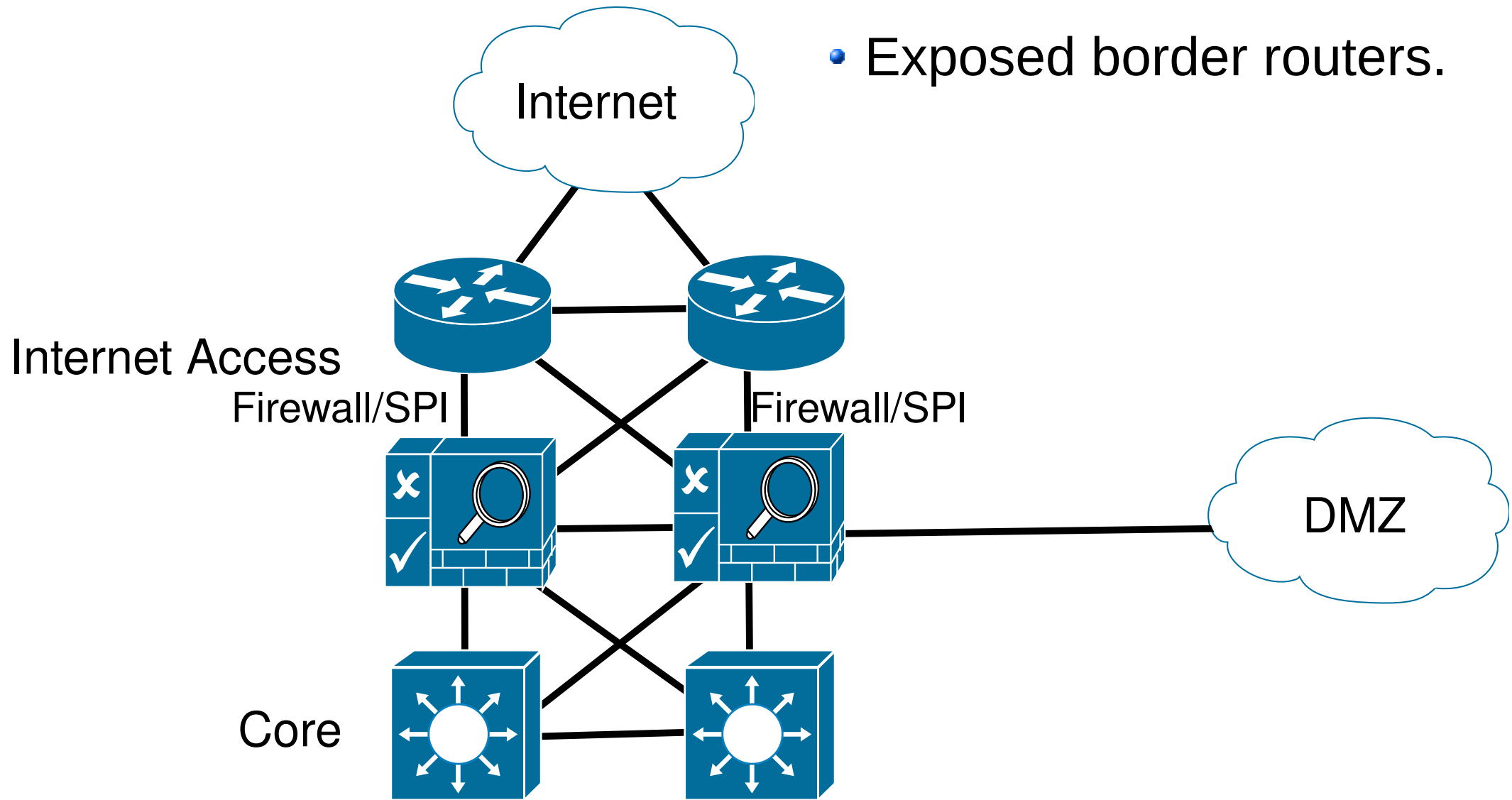
Firewall Virtual Instances

- Firewalls may have (theoretical) isolated instances to handle different zones/groups.
- Each instance is a virtual device that can perform flow control, switch, and/or routing.



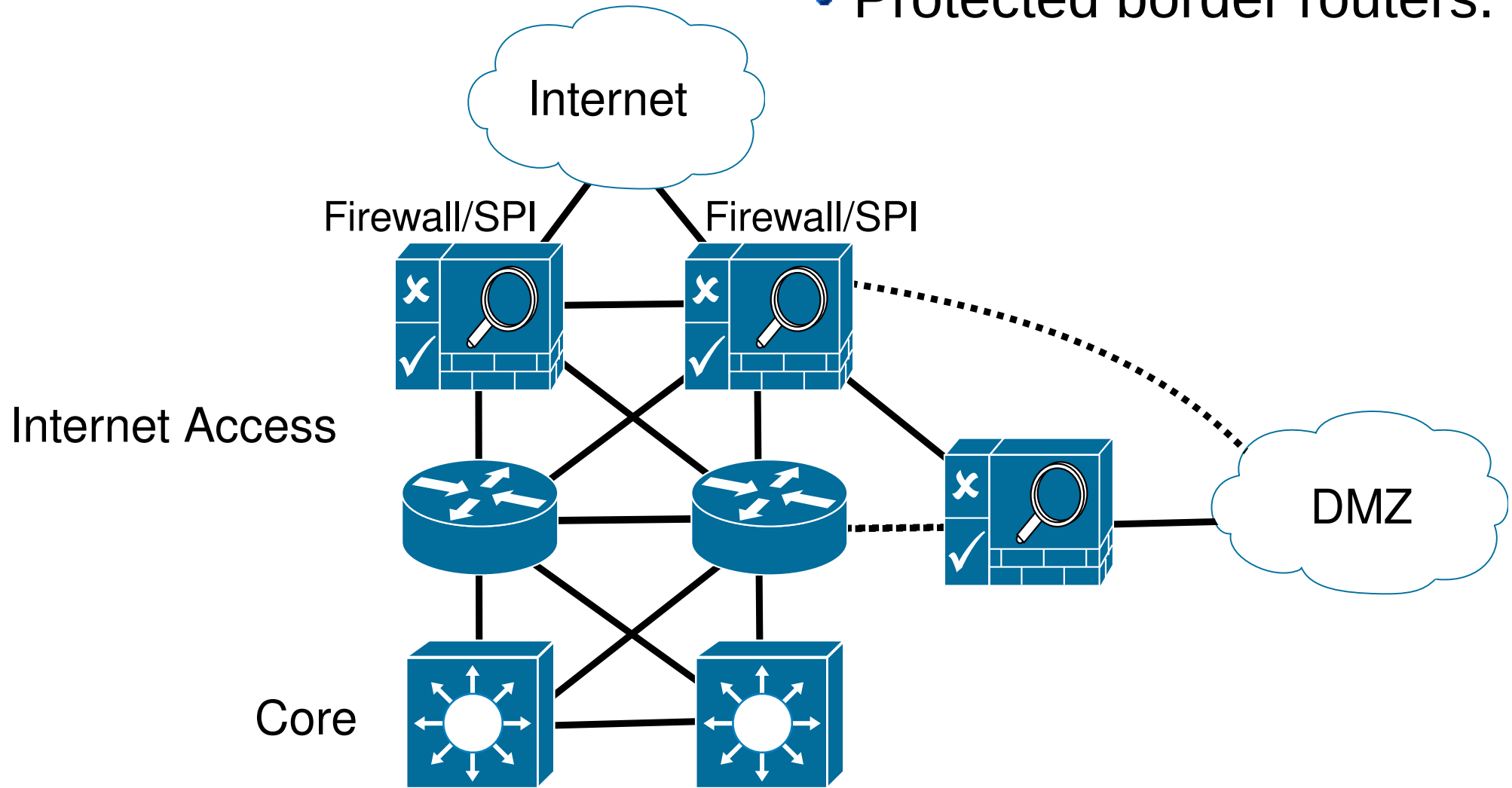
Firewall placement (with Redundancy)

- Exposed border routers.



Firewall placement (with Redundancy)

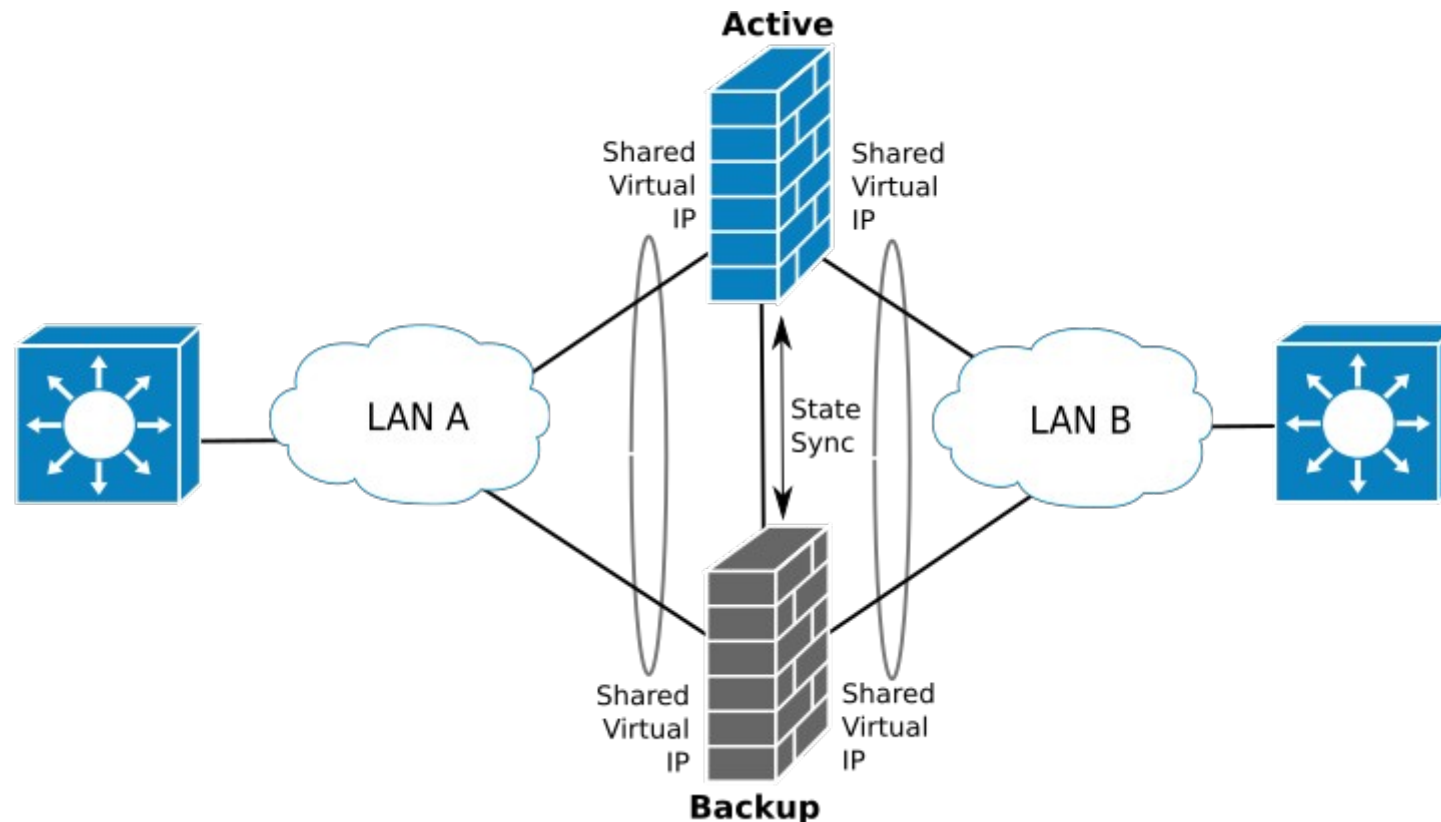
- Protected border routers.





High-Availability (1)

- Active-Backup Scenario
 - Firewalls share state via a dedicated connection
 - Firewalls share LAN (Virtual) IP addresses.
 - Backup firewall assumes IP and Services upon failure of Active firewall.

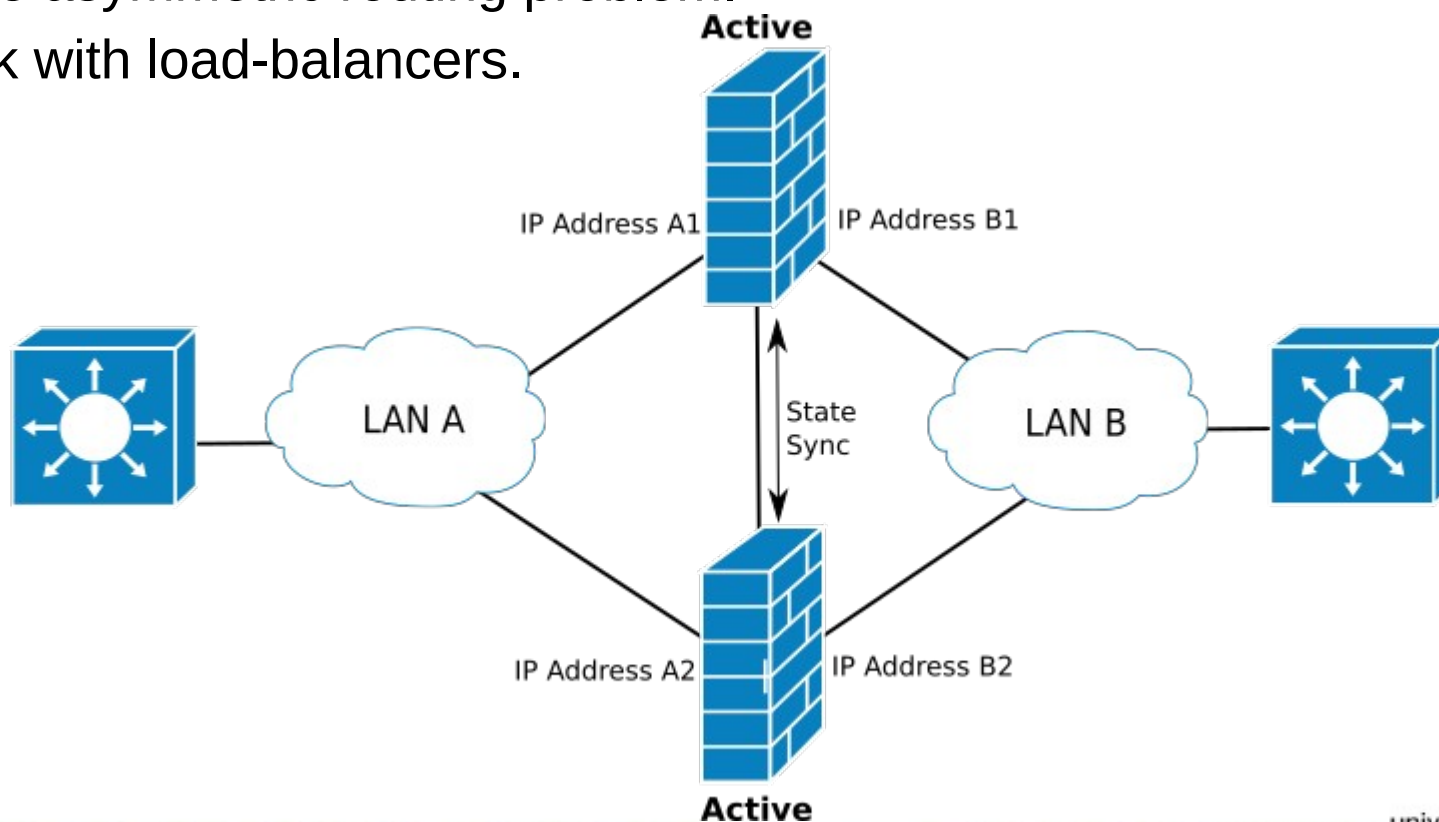




High-Availability (2)

- Active-Active Scenario

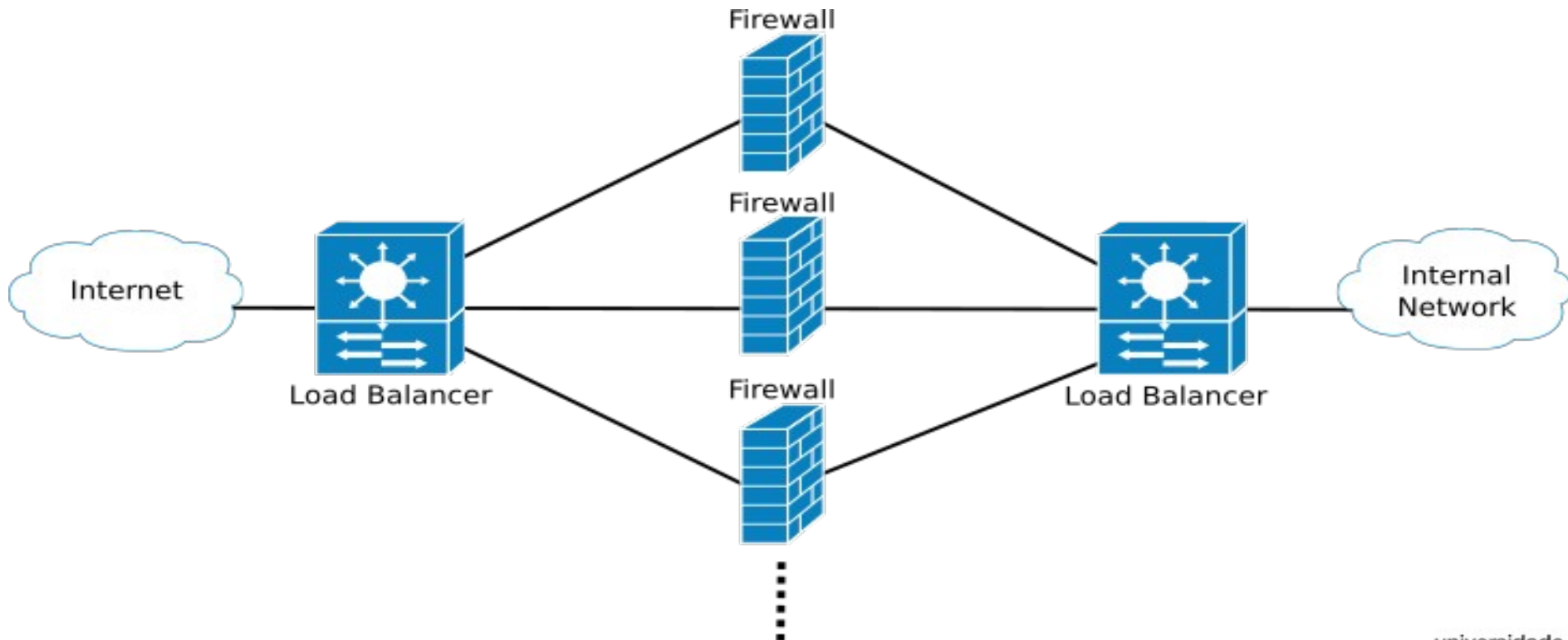
- Firewalls share state via a dedicated connection
- Firewalls have their own IP addresses.
- Both work simultaneously.
 - Share load.
 - Solve asymmetric routing problem.
 - Work with load-balancers.





Load Balancing Firewall Load

- Load-balancing equipment can distribute traffic by multiple firewalls.
- When the load balancer routes the traffic from the same flow ALWAYS to the same firewall (depends on the LB algorithm):
 - ◆ Firewalls do not have to share connections states!
 - ◆ Decrease processing and memory requirements of each firewall.
 - ◆ Allow for a scalable growth of traffic.
 - ◆ Makes the network less vulnerable to DoS attacks.
 - ◆ When its also responsible to distribute policies/rules is called an Orchestrator.





Load Balancing Algorithms

- IP Hash

- The IP address (or a set of flow identifiers) of the client is used to determine which server/firewall receives the flow or request.
- Does not require state synchronization (FW or LB). Hash function output determines target.

- Round Robin

- Requests are distributed across the group of devices sequentially.
- If firewalls do not share state, load-balancers must “memorize” the interface by which they received the traffic from firewalls, and use the same interface to route the response traffic.

- Least Connections

- A new request is sent to the server/firewall with the fewest current connections.
- The relative computing capacity of each server/firewall is factored into determining which one has the least connections.

- “Smart”

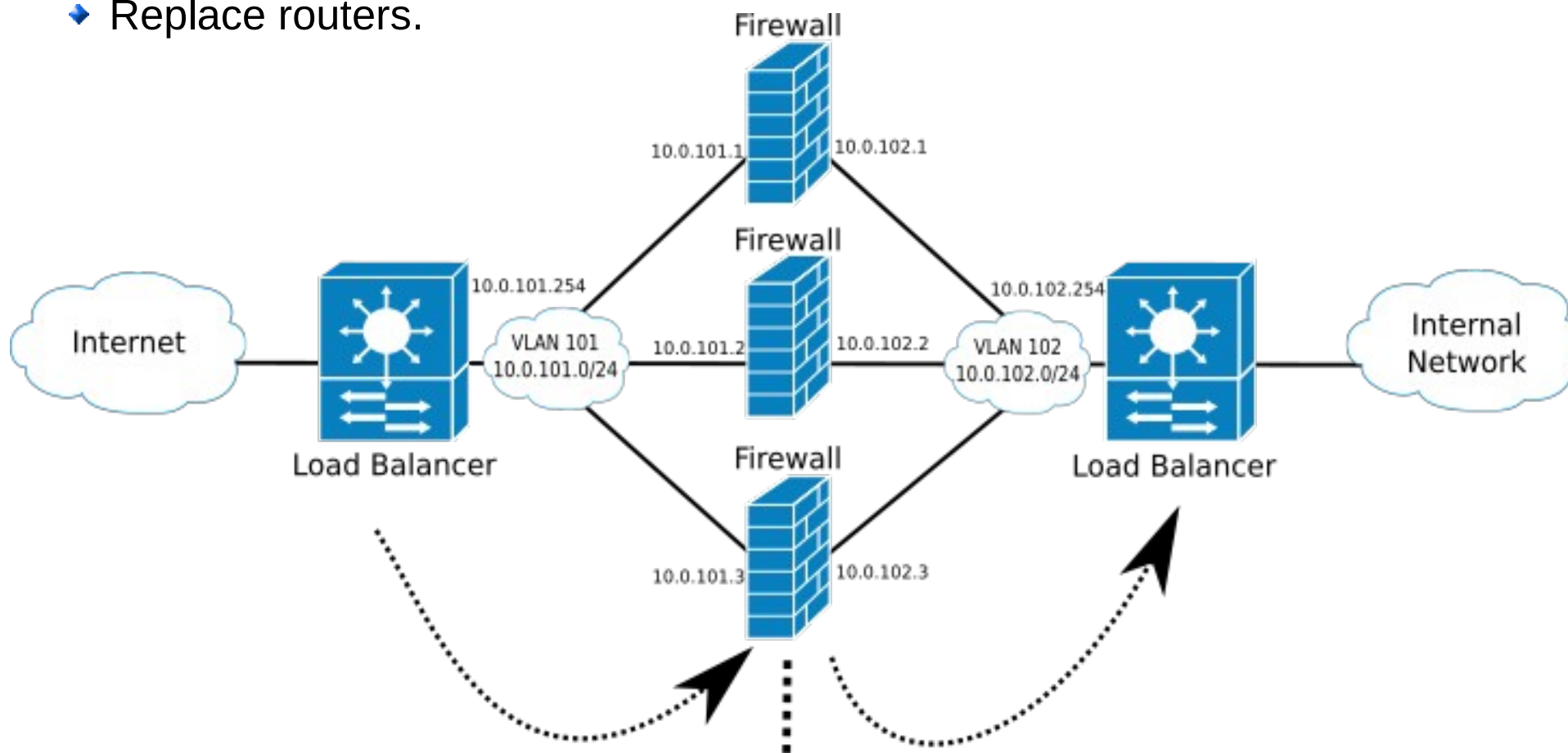
- Based on an external source of information.





Addressed Firewalls

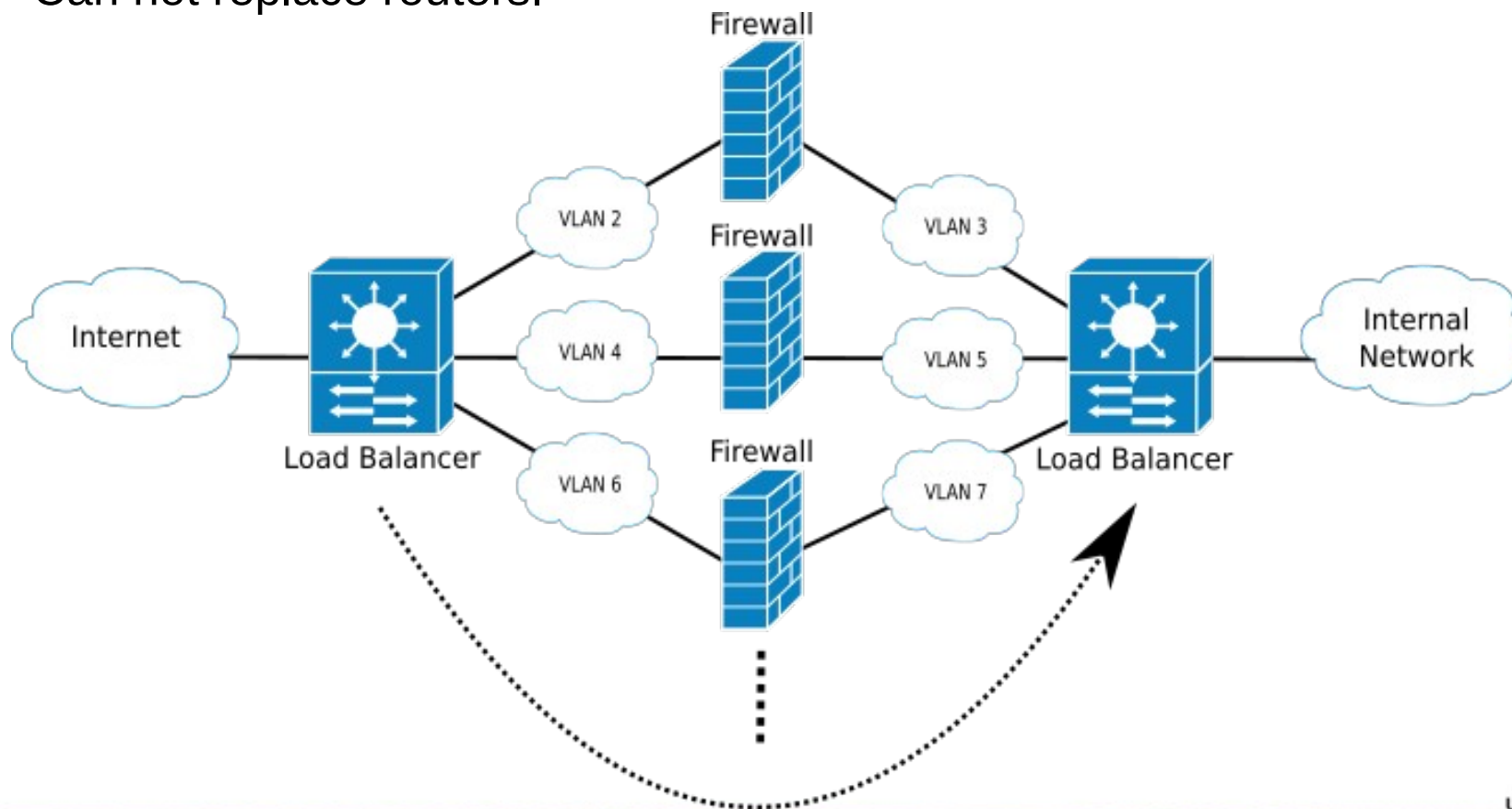
- Interfaces have IP addresses.
- Load balancers (or routers) route traffic as an IP next-hop.
- Can provide routing services.
 - ◆ Replace routers.





Stealth Firewalls

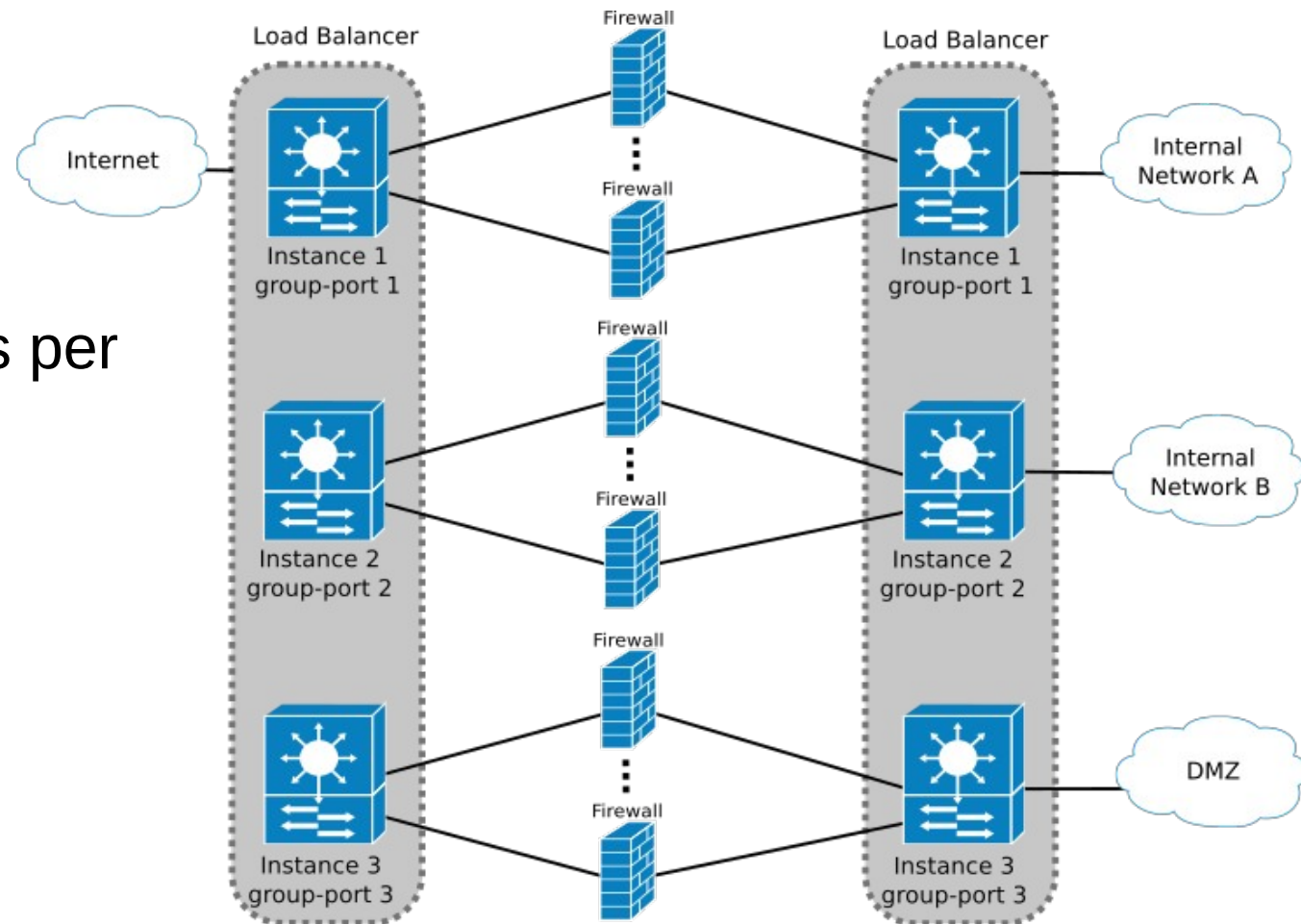
- Interfaces do not have IP addresses.
 - ◆ May have multiple layer rules.
- Load balancers (or switches) route traffic on a per interface/VLAN basis.
- Can not provide routing or NAT/PAT services.
 - ◆ Can not replace routers.





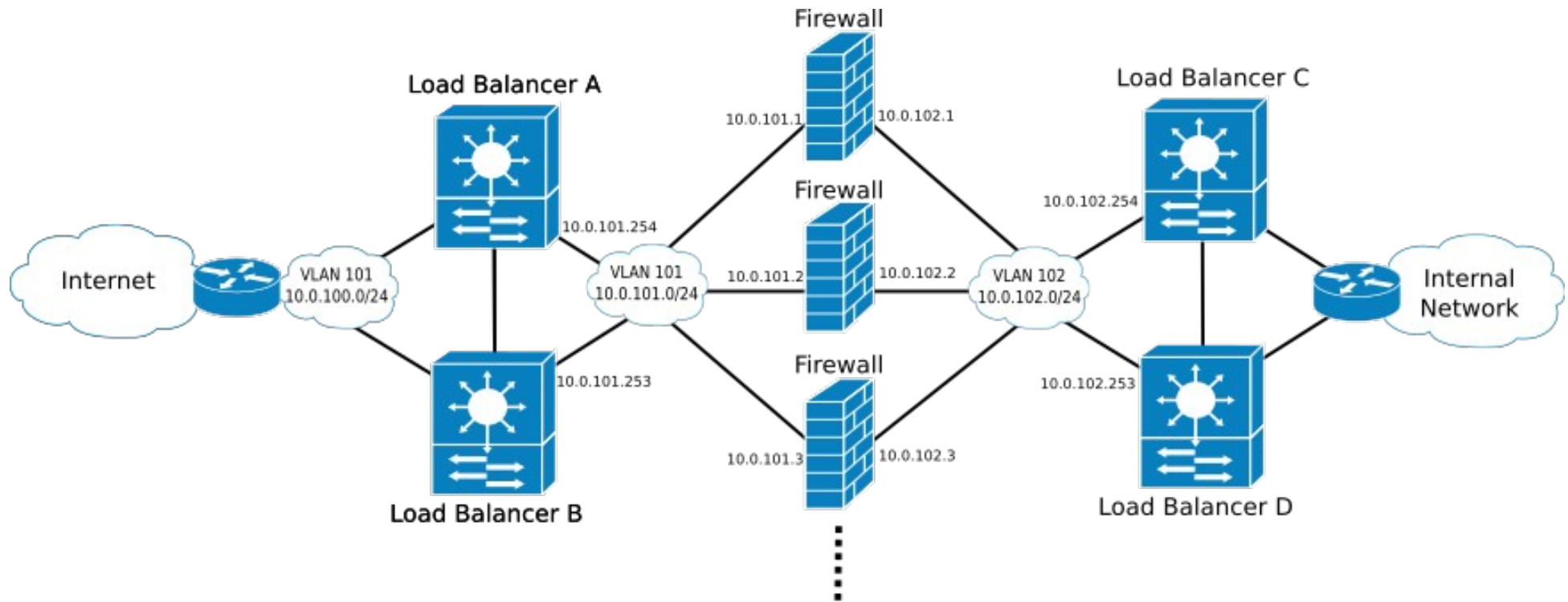
Load-Balancers Instances

- Load balancers may have (theoretical) isolated instances to handle different zones/groups.
 - With a set of firewalls per zone/group.
- Physical or virtual partitions.
- Some vendor call it group-ports.



Redundant Load Balancers

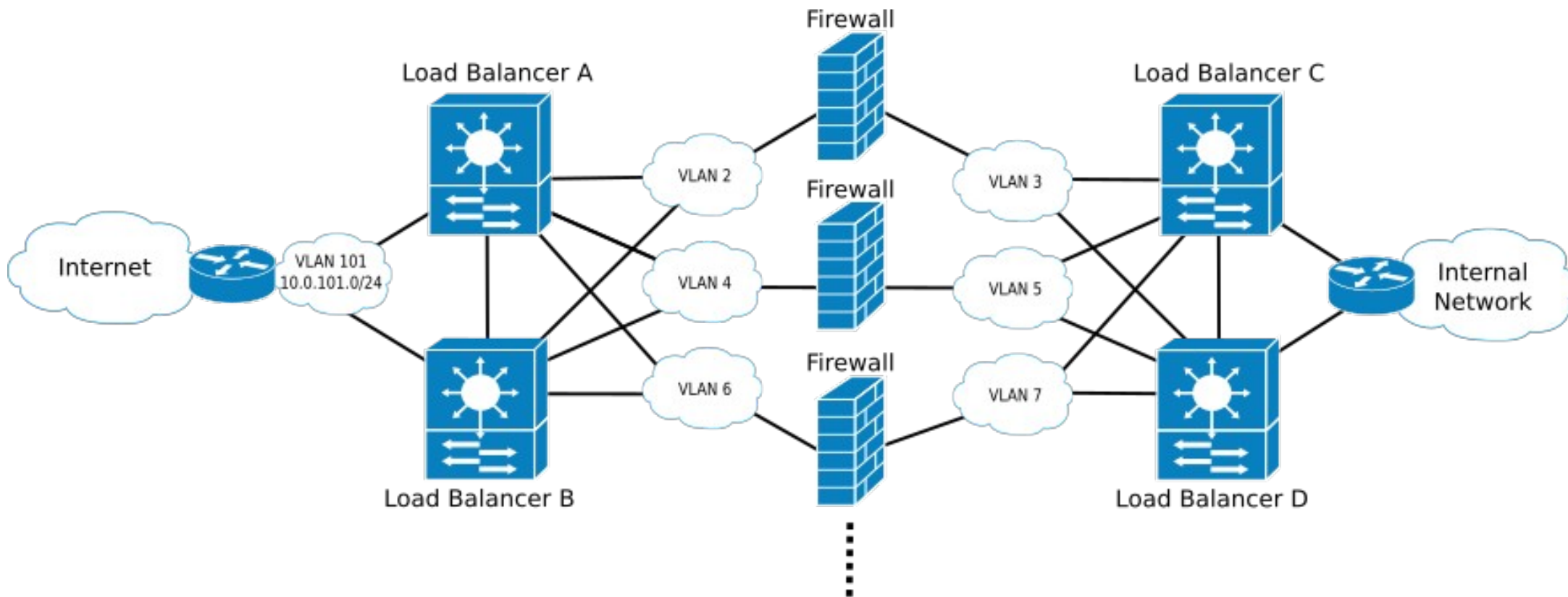
Addressed Firewalls



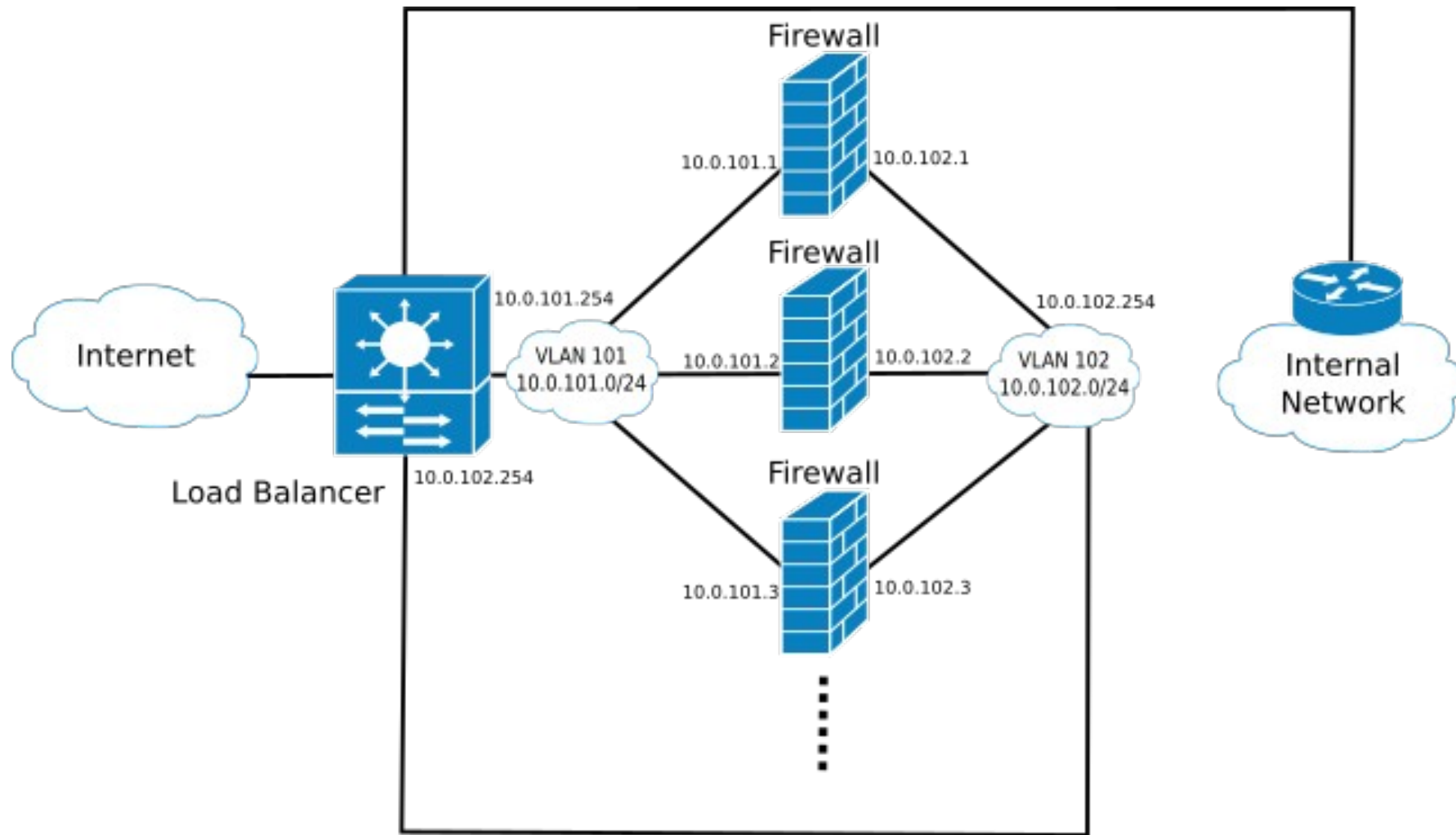
- To avoid FW state synchronizaion Load-Balancers should Sent packets of the same flow always to same firewall.
 - ◆ Must lower FW memory overload chance.
- Load-Balancers using IP Hash LB algorithms do nor require routing history synchronization (between LB).
 - ◆ Using other LB algorithms, they must share routing history.

Redundant Load Balancers

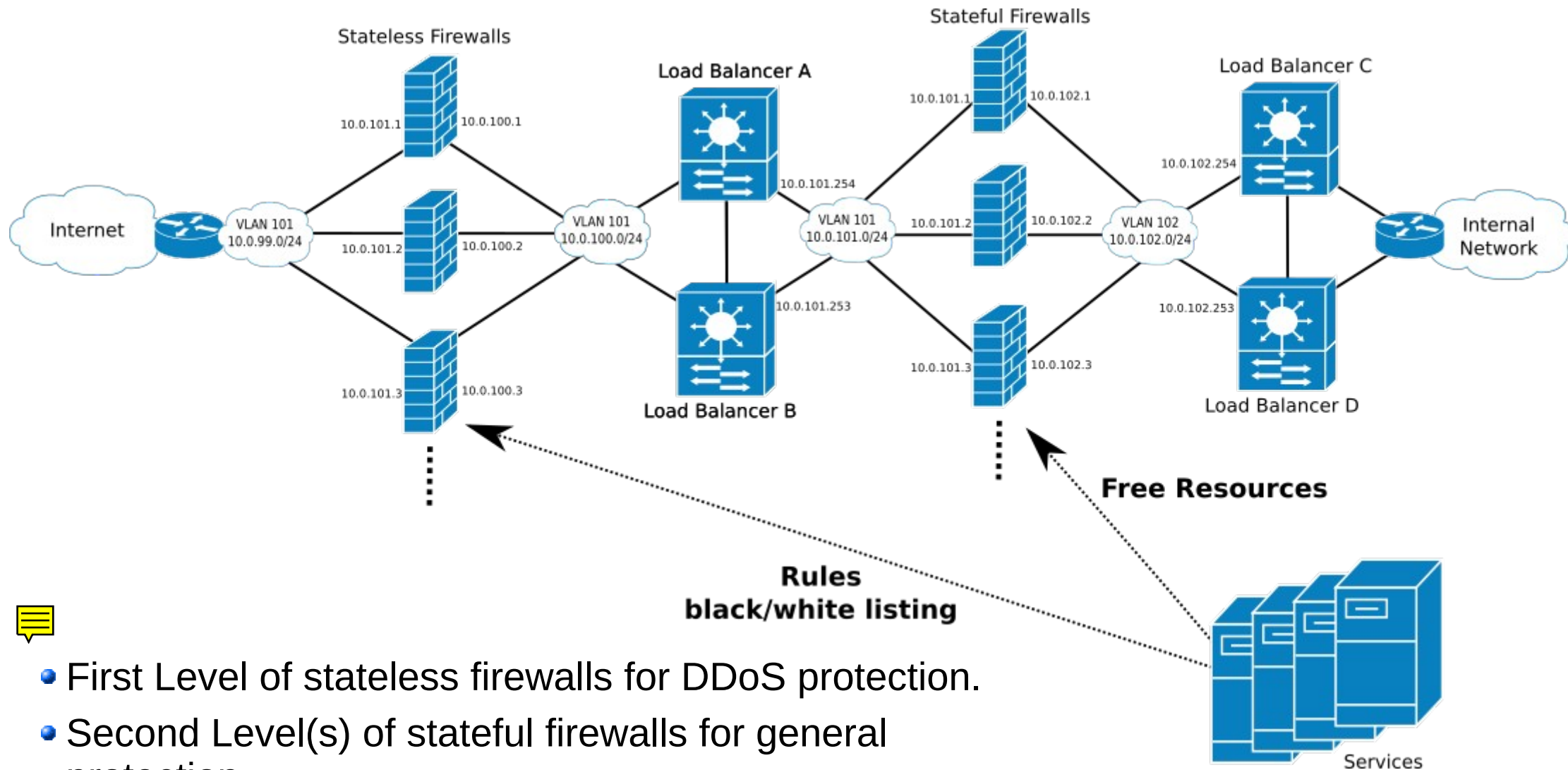
Stealth Firewalls



Single Load Balancer



Multi-Levels of Defense



- First Level of stateless firewalls for DDoS protection.
- Second Level(s) of stateful firewalls for general protection.
- Information from services may be used
 - ◆ To free resources in the stateful firewalls.
 - ◆ To configure black/white lists rules at the stateless firewalls.





Rules

- Firewall rules must be specified based on traffic source, destination and type.
 - Source and destination may be IP addresses, Ports, Zones, etc...
 - Type may be defined in terms of protocol or protocol specifics.
- Rules may be specified based on the state of a connection (requires a stateful firewall) upon the observation of a packet:
 - NEW
 - ➔ The observed packet is starting a new connection, or it is associated with a connection which has not generated packets in both directions.
 - ESTABLISHED
 - ➔ The observed packet is associated with a connection which has generated packets in both directions.
 - ➔ Usually a specific rule only allows traffic from one direction, an ESTABLISHED rule must be defined to dynamically allow the response from the other direction.
 - RELATED
 - ➔ The observed packet is starting a new connection, but is associated with an existing connection, such as an ICMP error (e.g., port unreachable related to an UDP connection)



Best Practices and Recommendations



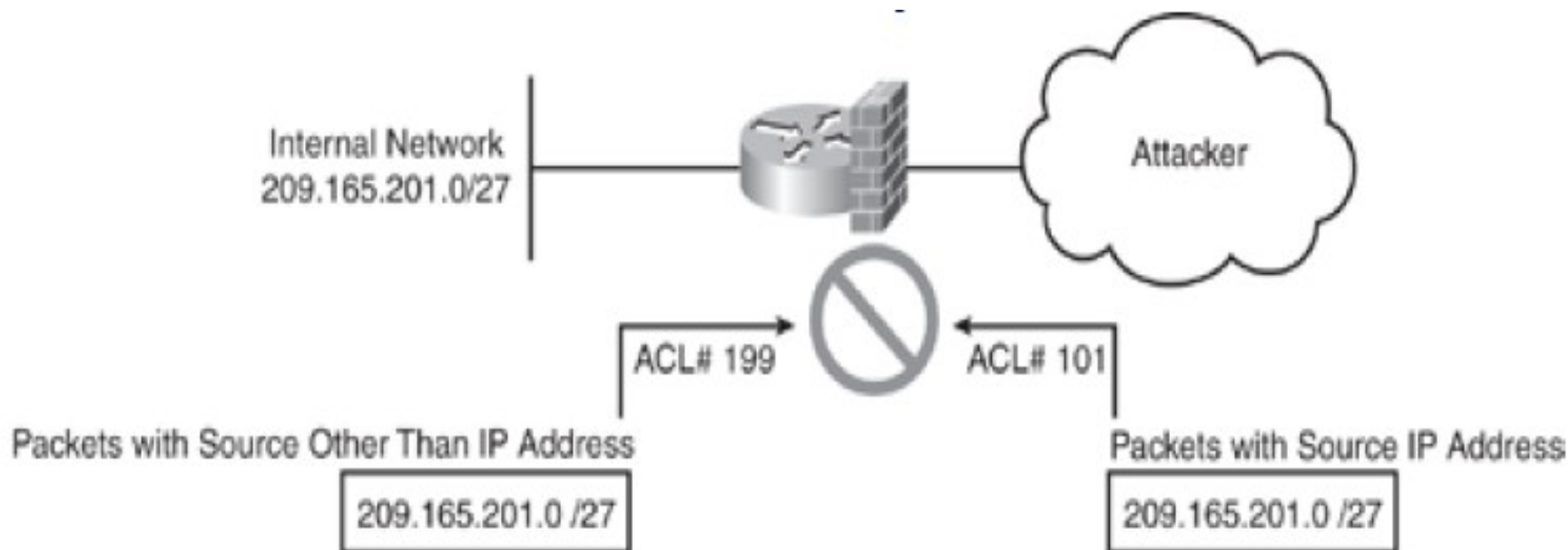
- Standardize your security policies.
 - Includes firewalls, network zones relations, devices and users profiles, active services, etc..
- Blocking all traffic by default.
 - Remove “Accept All” Rules.
- Add “Accept” exceptions.
 - Usually Clients to Service direction.
 - ➔ E.g., Internal to Internet, Internet to DMZ, etc...
 - ➔ Add reverse rule base on established /related connections.
- Maintain documentation of firewall rules:
 - Purpose, relation to security policies, affected devices and users, deployment and expiration dates, identification of the manager.
- Maintenance and monitoring of rules.
 - Periodically verify validity of rules within current security policies.
 - Analyze usage/match statistics of each rule.
- Integrate flow control with existing routing, switching and load balancing policies and services.



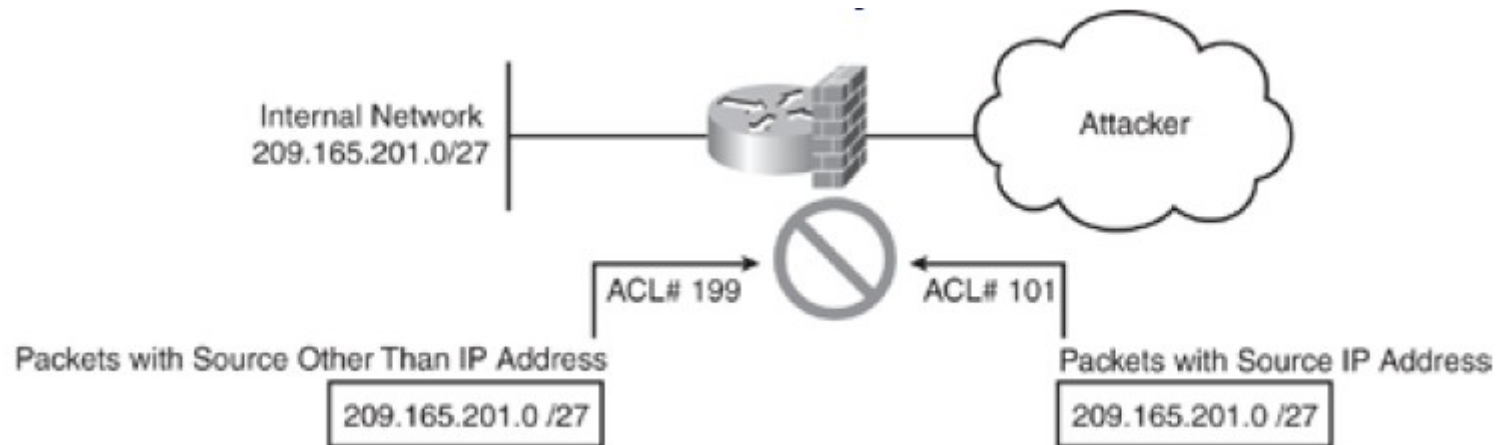


IP Spoofing

- IP spoofing refers to the creation of IP packets with a forged source IP address.
 - To hide the identity of the sender or impersonate another network system.
 - Spoofing IP datagrams is a well-known problem.
 - Most spoofing is done for illegitimate purposes.



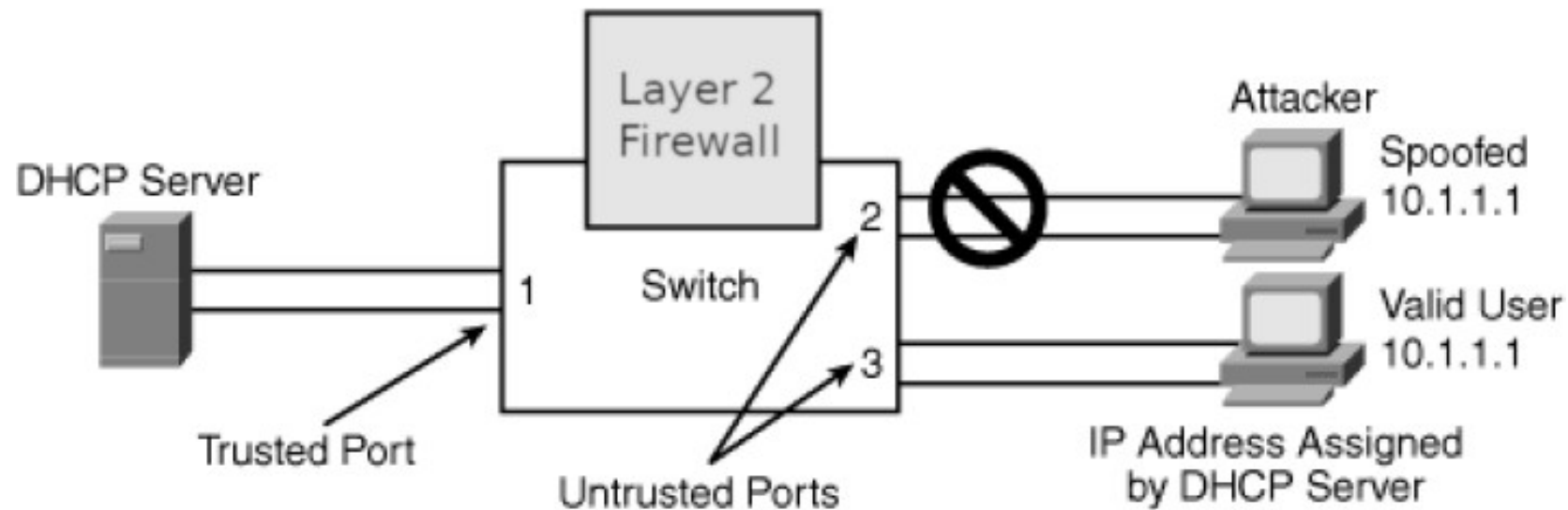
Preventing IP Spoofing at Layer 3



- Deny external traffic with
 - IP source equal to protected network IP ranges.
 - IP source equal to private addresses.
 - Multicast destinations.
- Reverse Path Verification
 - Deny traffic where the source IP network is not reachable using the interface where the packet arrived.

```
Interface interface-name
 ip access-group 101 in
 ip access-group 199 out
!
access-list 101 deny ip 209.165.201.0 0.0.0.31 any
access-list 101 deny icmp any any redirect
access-list 101 deny ip 224.0.0.0 31.255.255.255 any
access-list 101 deny ip 240.0.0.0 15.255.255.255 any
access-list 101 deny ip 127.0.0.0 0.255.255.255 any
access-list 101 deny ip host 0.0.0.0 any
access-list 101 deny ip 10.1.1.0 0.0.0.255 any
access-list 101 deny ip 172.16.0.0 0.15.255.255 any
access-list 101 deny ip 192.168.0.0 0.0.255.255 any
access-list 101 permit ip any any
!
access-list 199 permit ip 209.165.201.0 0.0.0.31 any
access-list 199 deny ip any any
```


Preventing IP Spoofing at Layer 2

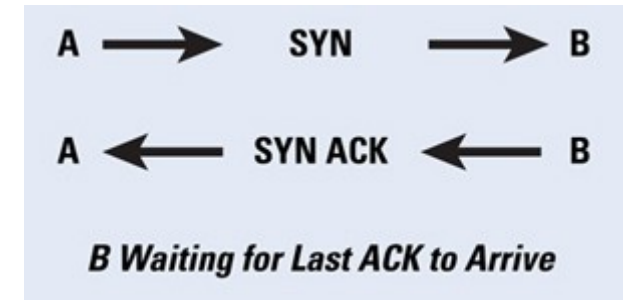


- To prevent IP spoofing attacks by restricting IP traffic on untrusted Layer 2 ports to clients with an assigned IP address.
- Works by filtering IP traffic with a source IP address other than that assigned via Dynamic Host Configuration Protocol (DHCP) or static configuration on the untrusted Layer 2 ports.
- Works in combination with the DHCP and is enabled on untrusted Layer 2 ports.

Half-Open TCP Connection Problem



- A DoS attack commonly uses half-open TCP connections.
 - Firewall keeps the state of the TCP session in memory.
 - Multiple half-open TCP connections can overrun firewalls.
 - Define timeout values for half-open TCP sessions:
 - Normal: small/medium values.
 - Under attack (based on traffic thresholds): very small values.
 - May be necessary to use external means to “clean” firewall.
 - Resetting (half-open) connections from the internal servers.



Firewall Performance Evaluation



- Basic Firewall

- IP Throughput

- ➔ Raw capability of the firewall to pass traffic from interface to interface

- Latency

- ➔ Time traffic delay in the firewall

- ➔ Should be measured and reported when the firewall is at its operating load

- Traditional Enterprise Firewall

- Connection Establishment Rate

- ➔ Speed at which firewalls can set up connections

- Concurrent Connection Capability

- ➔ Total number of open connections through the firewall at any given moment

- Connection Teardown Rate

- ➔ Speed at which firewalls can teardown connections and free resources

- Next Generation Firewall

- Application Transaction Rate

- ➔ Capability of the firewall to secure discrete application-layer transactions contained in an open connection

- ➔ May include application-layer gateways, intrusion prevention, or deep-inspection technology

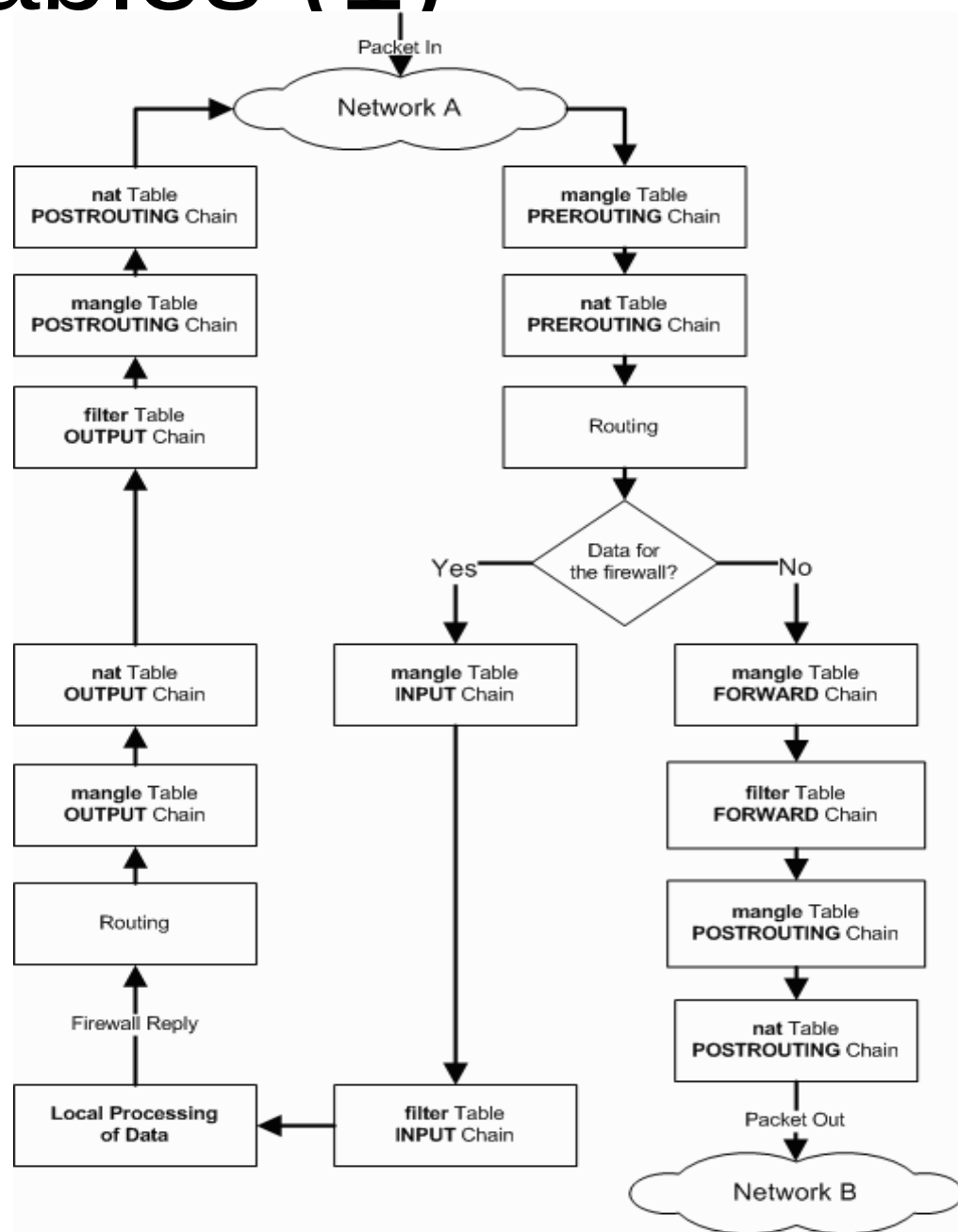
- ➔ Application transaction rate are highly data dependent



Linux iptables (1)



- Name of the user space tool by which administrators create rules for the packet filtering and NAT modules.
- Used to set up, maintain, and inspect the tables of IP packet filtering rules within the Linux kernel.
- Has 5 default chains:
 - ♦ INPUT, OUTPUT, FORWARD
 - ♦ PREROUTING
 - ♦ POSTROUTING
- Has 3 default tables,
 - ♦ Filter, nat and mangle
- Basic decisions
 - ♦ ACCEPT, DROP, QUEUE and RETURN
- Extended decisions
 - ♦ LOG, MARK, REJECT, TOS, SNAT, DNAT, MASQUERADE, REDIRECT, etc...
- Multiple state machines
 - ♦ Conntrack (connection tracker).



Linux IPTables (2)



- In addition to the built-in chains, the user can create any number of user-defined chains within each table, which allows them to group rules logically.
- Each chain contains a list of rules,
 - When a packet is sent to a chain, it is compared against each rule in the chain in order.
- The rule specifies what properties the packet must have for the rule to match (such as the port number or IP address).
- If the rule does not match, then processing continues with the next rule.
- If, however, the rule does match the packet, then the rule's target instructions are followed (and further processing of the chain is usually aborted).
- Some packet properties can only be examined in certain chains,
 - For example, the outgoing network interface is not valid in the INPUT chain.
- Some targets can only be used in certain chains, and/or certain tables,
 - For example, the SNAT target can only be used in the POSTROUTING chain of the NAT table.
- The target of a rule can be the name of a user-defined chain or one of the built-in targets (ACCEPT, DROP, RETURN, DNAT, SNAT and MASQUERADE).
- You can think of a target in the same way as a subroutine.






Linux nftables

- nftables replaces iptables.
- Provides a new in-kernel packet classification framework that is based on a network-specific Virtual Machine (VM).
- Uses a new nft userspace command line tool.
 - Userspace command line tool, with no need of kernel upgrades.
- High performance through maps and concatenations.
- Smaller kernel codebase. The intelligence is placed in userspace nft command line tool.
- Unified and consistent syntax for every support protocol family.



Control By Analysis of Higher Layers

- 
- Traffic flow control based on higher layer data/protocols only works with not ciphered traffic.
 - Some firewalls provide decryption and inspection of SSL/TLS traffic.
 - Traffic deciphering may be achieved using a root certificate on client machines, acting as Certificate Authority for SSL requests.
 - ◆ Firewalls must issue certificates to clients on behalf of the web servers they are connecting to.
 - ◆ Firewalls intercept SSL/TLS handshake.
 - ◆ Requires client device level changes.
 - Implementing this technique is processor-intensive.
 - ◆ Results in performance degradation.
 - ◆ Can be avoided by off-loading SSL/TLS decryption to a dedicated devices.
 - May break privacy/confidentiality laws and rights in some countries.

Cisco's Access Control Lists (ACL)

- An access list is a sequential collection of **permit** and **deny** conditions.
- Software tests packets against the conditions in an access list one by one.
- The first match determines whether the software accepts or rejects the packet.
 - Because the software stops testing conditions after the first match, the order of the conditions is critical.
- If no conditions match, the software rejects the packet.
- Can be applied to inbound or outbound traffic.



ACL Types

- Standard

- ♦ Control traffic by the analysis of the source address of the IP packets.
- ♦ Numbered from 1 to 99
 - Example: access-list 1 permit 10.1.1.0 0.0.0.255

- Extended

- ♦ Control traffic by the analysis of the source and destination addresses and protocol of the IP packets.
- ♦ Numbered from 100 to 199
 - Example: access-list 101 permit ip any 10.1.1.0 0.0.0.255

- Named

- ♦ Allow standard and extended ACLs to be given names Intuitively identify an ACL using an alphanumeric name.
- ♦ Eliminate the number limits that exist on standard and extended ACLs.
- ♦ Named ACLs provide the ability to modify ACLs without deleting and then reconfiguring them.
 - Example: ip access-list {extended | standard} name

- Reflexive

- ♦ Allow IP packets to be filtered based on upper-layer session information.
- ♦ Communication in one direction opens doors in the opposite direction.
- ♦ Generally used to allow outbound traffic and to limit inbound traffic in response to sessions that originate inside the network.

- Context-Based Access Control (CBAC)

- ♦ Inspects traffic to discover and manage state information for TCP and UDP sessions
- ♦ This state information is used to create temporary openings in the firewall access lists

