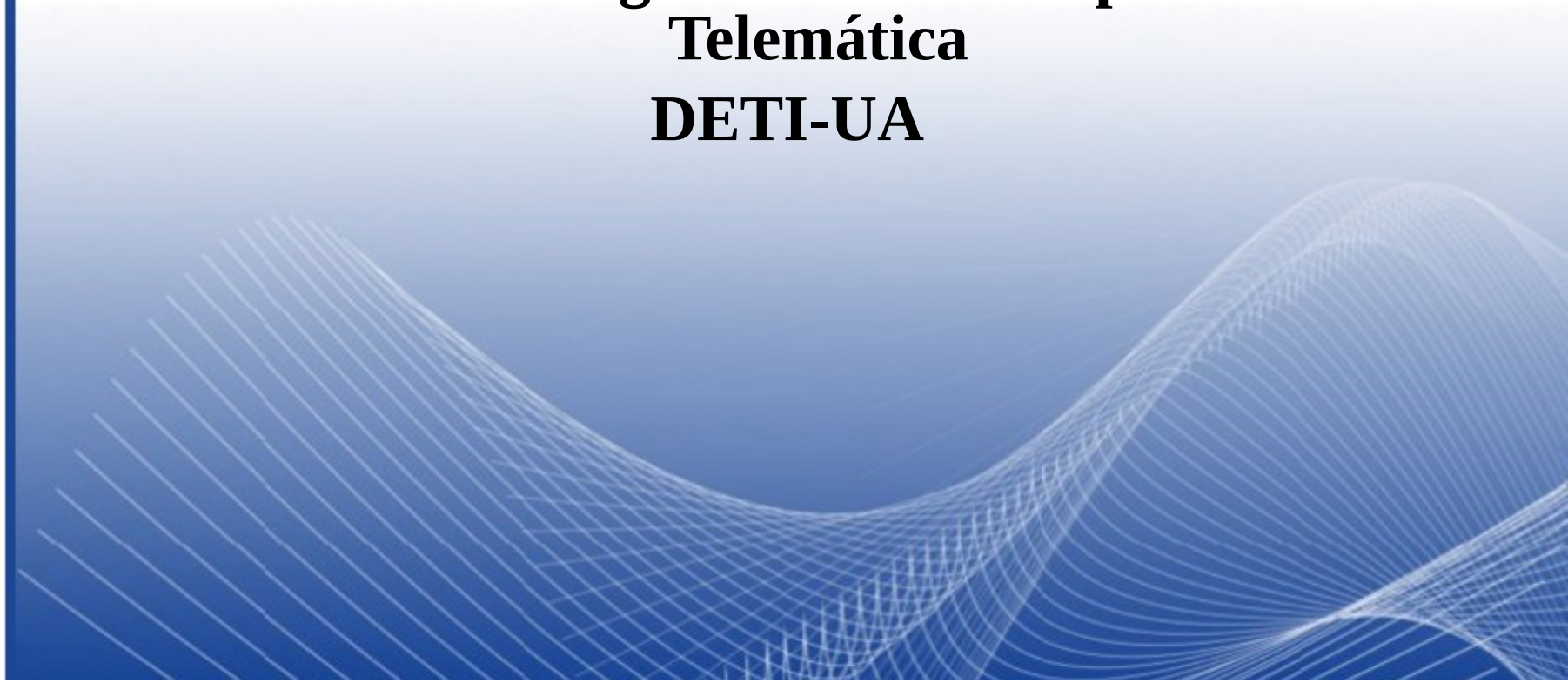
Corporate Network Topics

Segurança em Redes de Comunicações

Mestrado em Cibersegurança

Mestrado em Engenharia de Computadores e Telemática

DETI-UA



universidade de aveiro

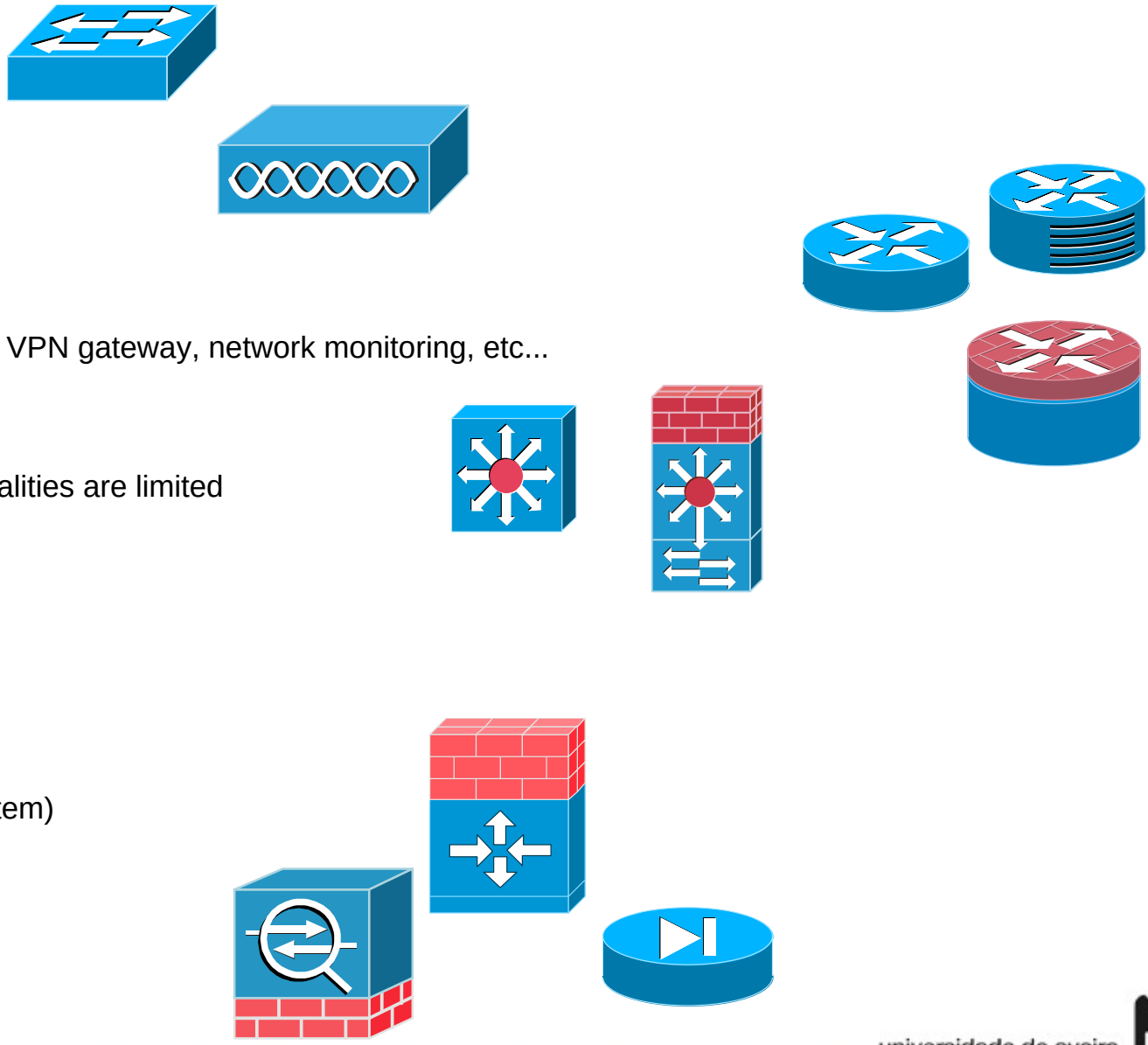
deti.ua.pt

Objectives of Network Design

- Network should be **Modular**
  - Support growth and change.
  - Scaling the network is eased by adding new modules instead of complete redesigns.
- Network should be **Resilient**
  - Up-time close to 100 percent.
    - If network fails in some companies (e.g. financial), even for a second, may represent millions of lost revenue.
    - If network fails in a modern hospital, this may represent lost of lives.
  - Resilience has costs.
    - Resilience level should be a trade-off between available budget and acceptable risk.
- Network should have **Flexibility**
  - Businesses change and evolve.
  - Network should adapt quickly.

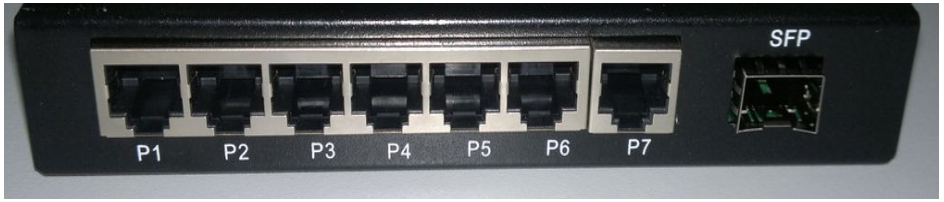
Equipments

- Switch
  - OSI Layer 2 inter-connection
  - Implements VLAN
  - Spanning-tree based routing
    - STP, RSTP, MSTP
  - Wireless Access Points
- Router
  - OSI Layer 3 inter-connection
  - Have extra functionalities like QoS, Security, VPN gateway, network monitoring, etc...
- L3 Switch
  - Switch+Router
  - Low-end and mid-end range routing functionalities are limited
  - High-end have full routing functionalities
  - Many have dedicated L2 routing hardware
- Router with switching modules
  - L3 Switch with full routing capabilities
- Security Appliance
  - Firewall
  - IDS/IPS (Intrusion Detection/Prevention System)
  - NAT/PAT
  - VPN Gateway
  - Services proxy

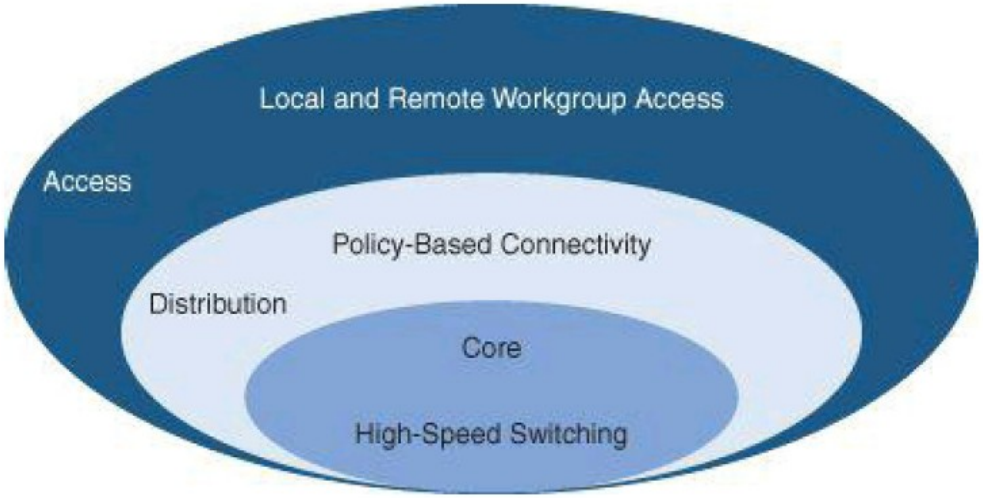


How to Choose the Equipments

- Type
  - L2 Switch, L3 Switch, Router + Switching module, Router, …
- Manufacturer
  - Reliability
    - (Expected) Maximum MTBF (mean time between failures) as possible.
    - Depends on multiple factors:
      - Hardware/Electronics redundant architectures, inherent quality, environmental constrains, etc...
  - Price
    - Usually (not always), a lower price means lower reliability.
  - Assistance
- Range/Model
  - Processing/Commutation speed
    - Number of bytes/packets processed/commuted per second.
      - Lower than the sum of all ports speed.
  - Software version
    - Supported protocols and functionalities.
    - Determines also memory requirements.
  - Number of ports (and speed of ports)
    - Ethernet (10 Mbps, 100 Mbps, 1Gbps, 10Gbps, …)
    - Connectors
      - To copper or to fiber.
      - RJ-45, Small form-factor pluggable (SFP), Enhanced small form-factor pluggable (SFP+) …
    - With or without PoE (Power over Ethernet)
      - For VoIP phones, Access Points, etc...
  - Number of slots
    - For additional port/processing modules.

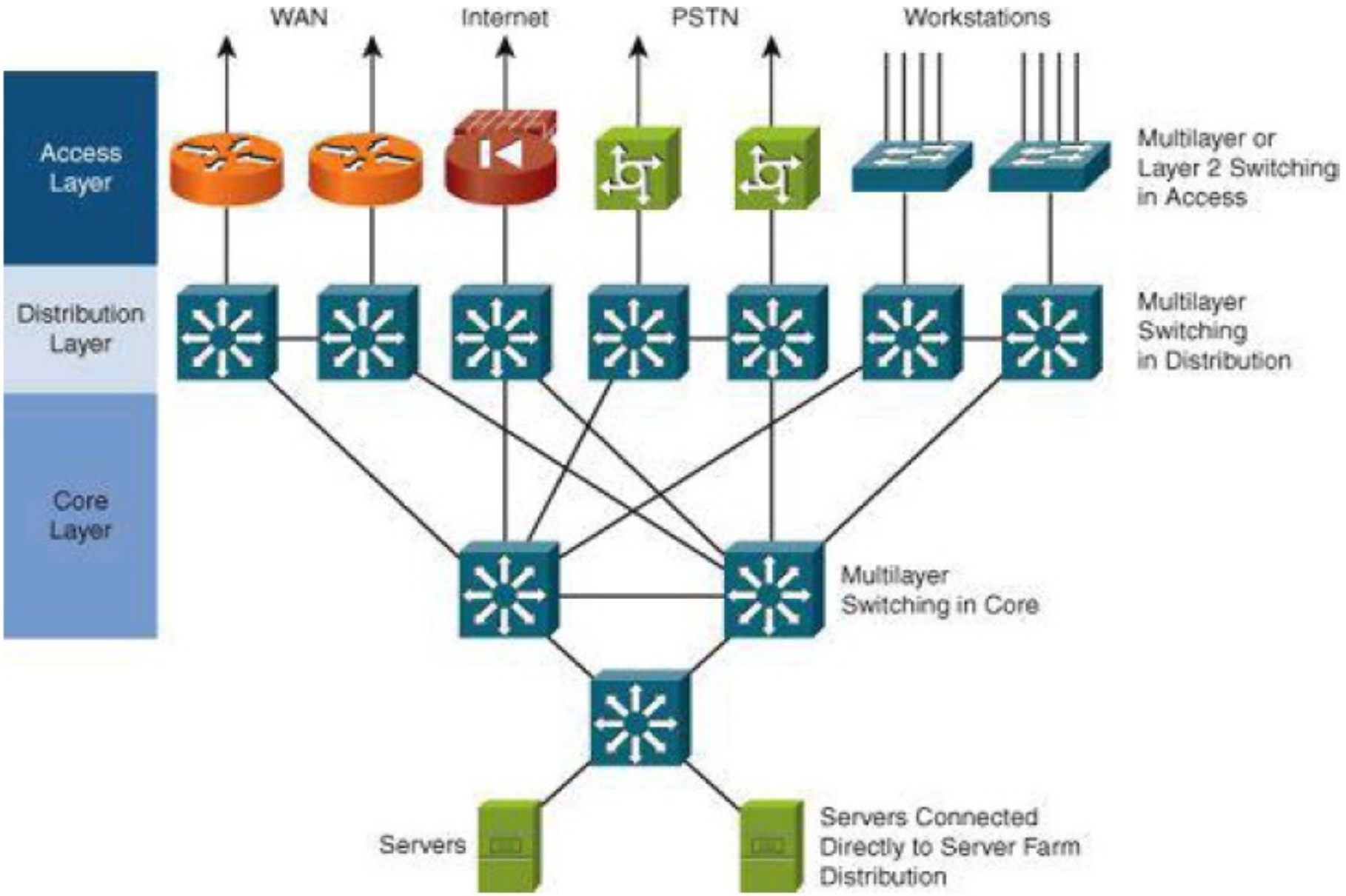


Hierarchical Network Model

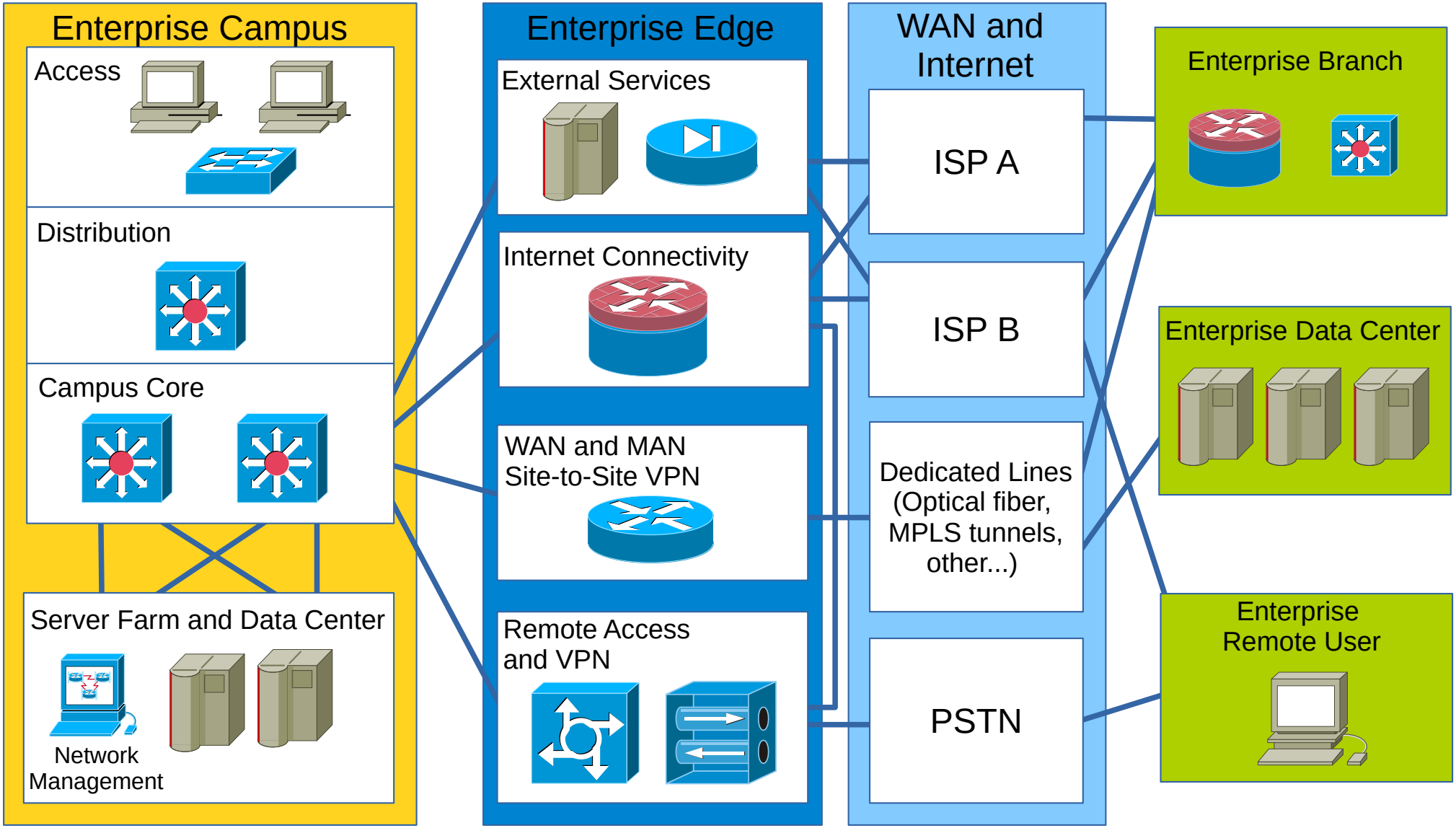


- Access layer
  - Provides user access to network.
  - Generally incorporates switched LAN devices that provide connectivity to workstations, IP phones, servers, and wireless access points.
  - For remote users or remote sites provide an entry to the network across WAN technology.
- Distribution layer
  - Aggregates LAN devices.
  - Segments work groups and isolate network problems.
  - Aggregates WAN connections at the edge of the campus and provides policy-based connectivity.
  - Implements QoS policies.
- Core layer
  - A high-speed backbone.
  - Core is critical for connectivity, must provide a high level of availability and adapt quickly to changes.
  - Should provide scalability and fast convergence.
  - Should provide an integration point for data center.

A Hierarchical Network



Modular Network Design



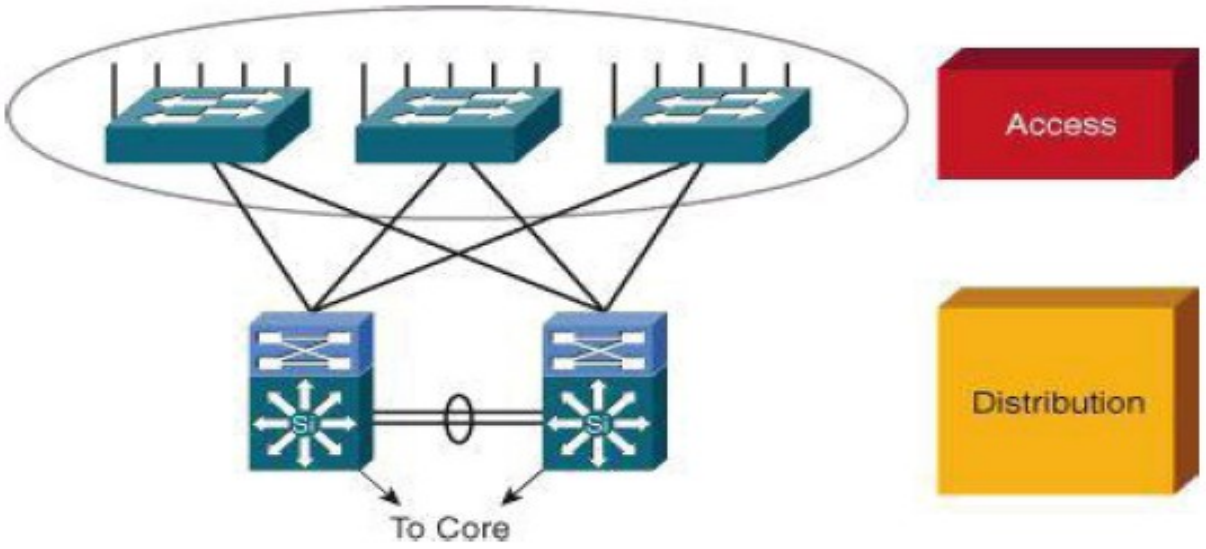
Network Modules (1)

- Campus
  - Operating center of an enterprise.
  - This module is where most users access the network.
  - Combines a core infrastructure of intelligent switching and routing with mobility, and advanced security.
- Data Center
  - Redundant data centers provide backup and application replication.
  - Network and devices offer server and application load balancing to maximize performance.
  - Allows the enterprise to scale without major changes to the infrastructure.
  - Can be located either at the campus as a server farm and/or at a remote facility.
- Branch
  - Allows enterprises to extend head-office applications and services to remote locations and users or to a small group of branches.
  - Provides secure access to voice, mission-critical data, and video applications.
  - Should provide a robust architecture with high levels of resilience for all the branch offices.

Network Modules (2)

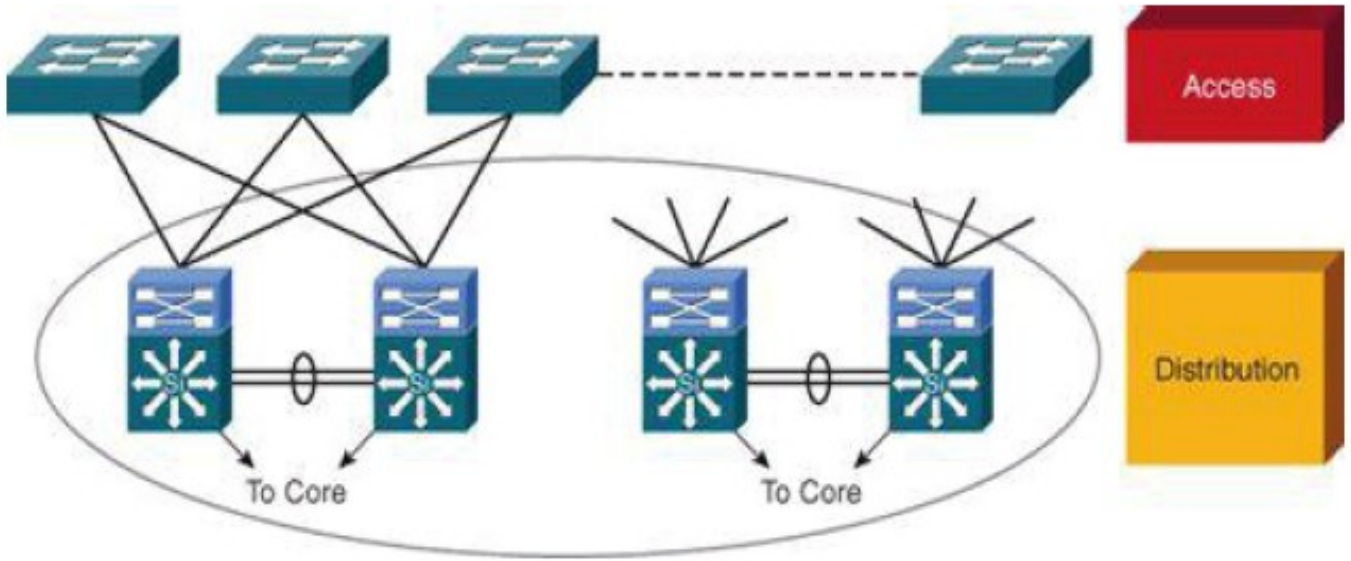
- WAN and MAN
  - Offers the convergence of voice, video, and data services.
  - Enables the enterprise a cost-effectively presence in large geographic areas.
  - QoS, granular service levels, and comprehensive encryption options help ensure the secure delivery to all sites.
  - Security is provided with multiservice VPNs (IPsec and MPLS) over Layer 2 or Layer 3 communications.
- Remote User
  - Allows enterprises to securely deliver voice and data services to a remote small office/home office (SOHO) over a standard broadband access service.
  - Allows a secure log in to the network over a VPN and access to authorized applications and services.

Designing the Access Layer



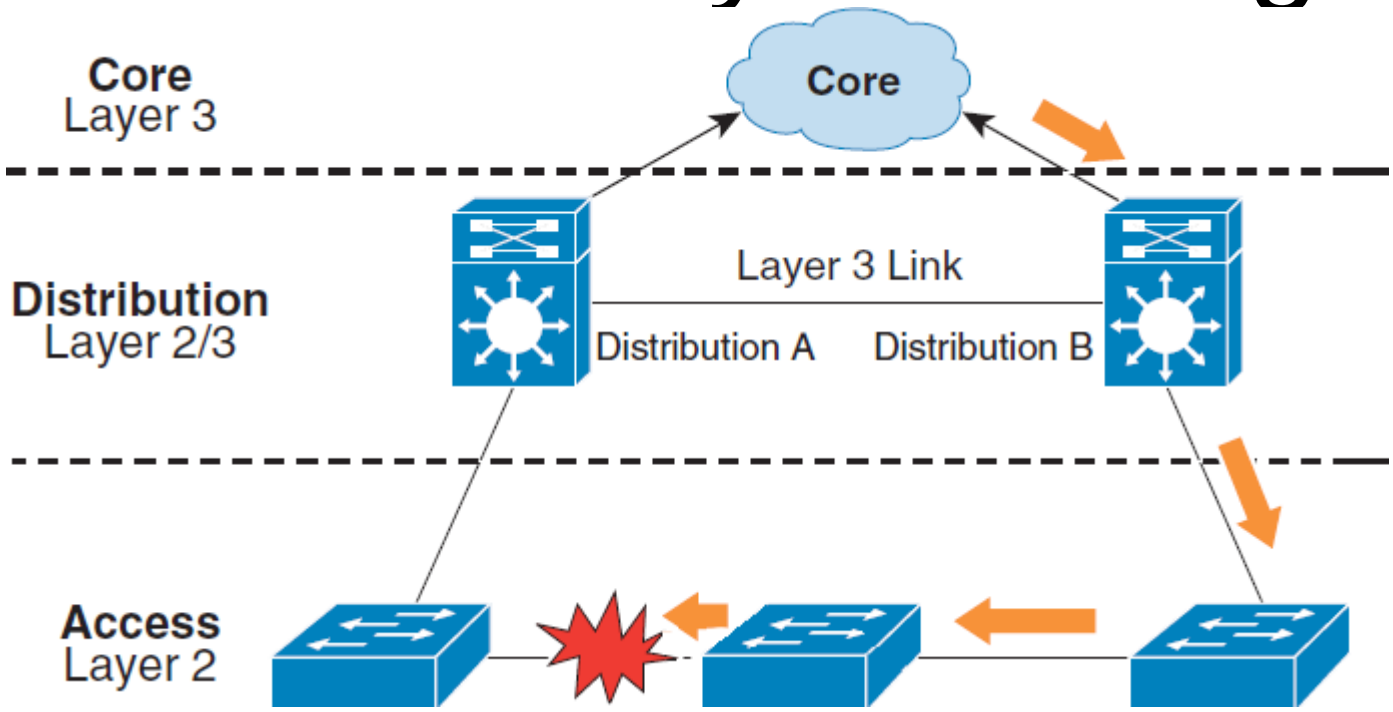
- High availability
  - Default gateway redundancy using multiple connections from access switches to redundant distribution layer switches.
  - Redundant power supplies.
- Other considerations
  - Convergence: the access layer should provide seamless convergence of voice into data network and providing roaming wireless LAN (WLAN).
  - Security: for additional security against unauthorized access to the network, the access layer should provide tools such as IEEE 802.1X, port security, DHCP snooping and dynamic ARP inspection (DAI).
  - Quality of service (QoS): The access layer should allow prioritization of critical network traffic using traffic classification and queuing as close to the ingress of the network as possible.
  - IP multicast: the access layer should support efficient network and bandwidth management using features such as Internet Group Management Protocol (IGMP) snooping.

Designing the Distribution Layer



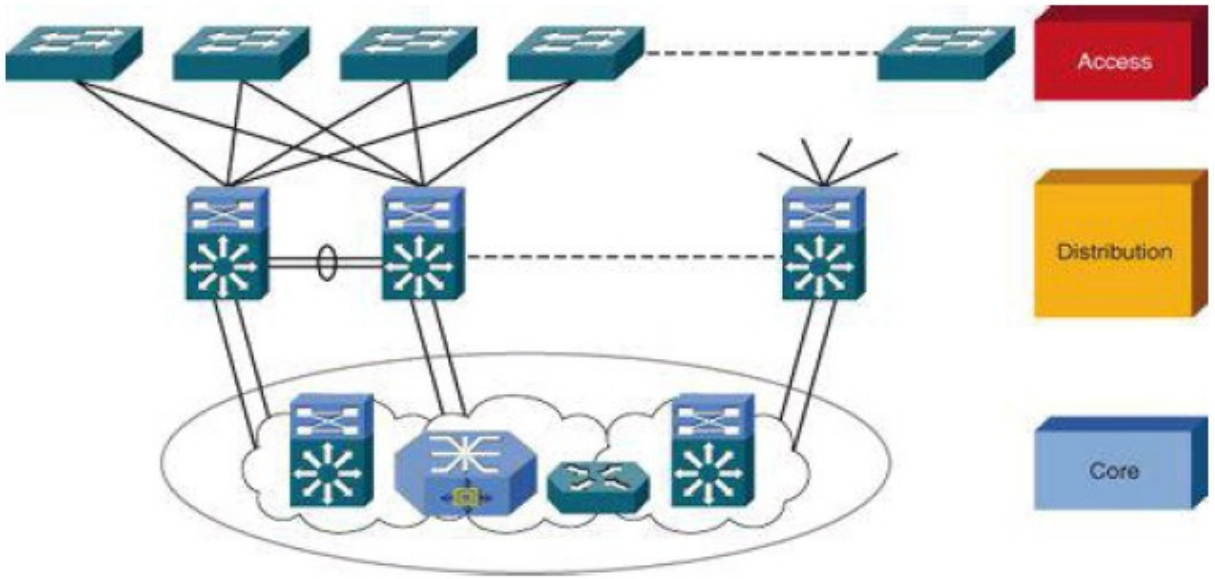
- Uses a combination of Layer 2 and multilayer switching to segment workgroups and isolate network problems, preventing them from impacting the core layer.
- Connects network services to the access layer and implements QoS, security, traffic loading balancing, and implements routing policies.
- Major design concerns: high availability, load balancing, QoS, and provisioning.
- In some networks, offers a default route to access layer routers and runs dynamic routing protocols when communicating with core routers.
- The distribution layer it is usually used to terminate VLANs from access layer switches.
- To further improve routing protocol performance, summarizes routes from the access layer.
- To implement policy-based connectivity, performs tasks such as controlled routing and filtering and QoS.

Avoid Daisy Chaining



- When using a L3 link between Distribution layer switches
  - In Access layer, any path from a switch should not require another switch from the Access layer.
  - In Distribution layer, any path between Distribution layer switches should not require a switch from the Access layer.
- When using a L2 link between Distribution layer switches
  - Daisy chain is acceptable, however
    - Could overload some Access layer switches.
    - Could increase STP convergence in case of failure.

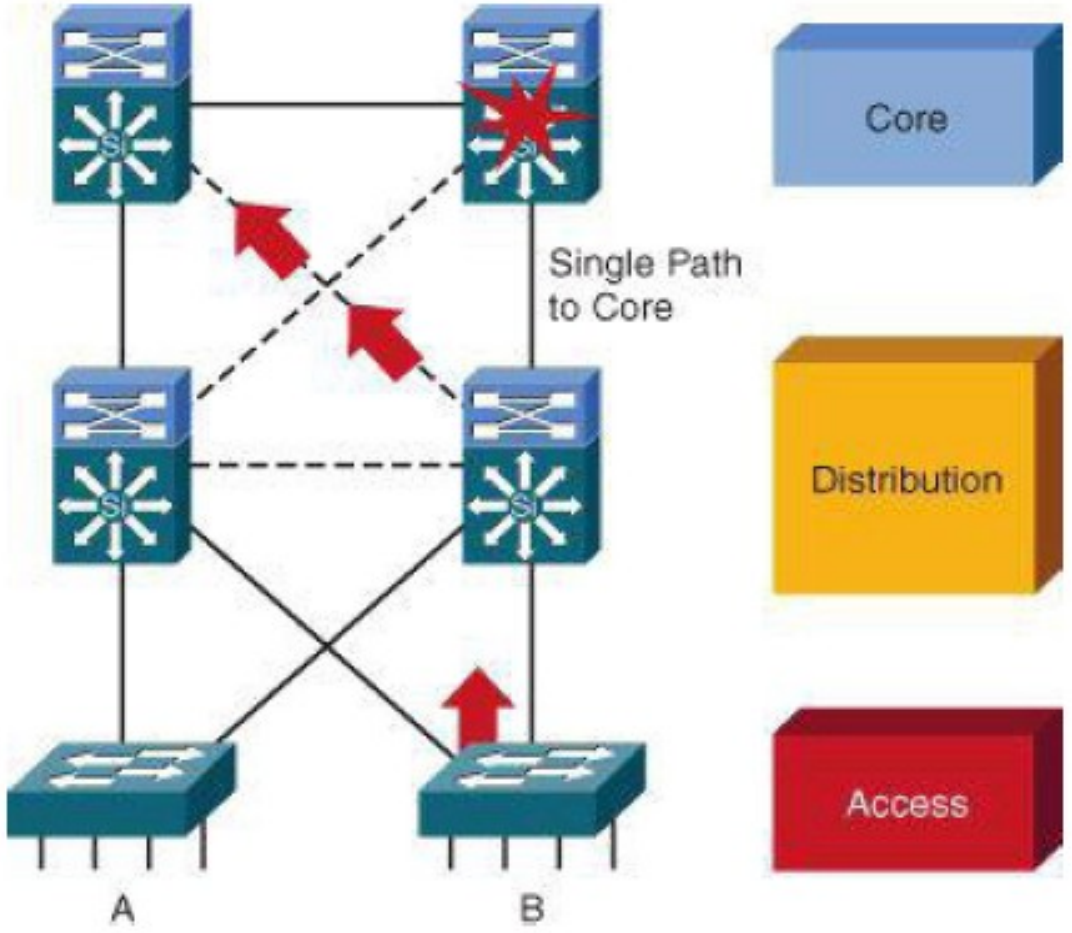
Designing the Core Layer



- Backbone for campus connectivity and is the aggregation point for the other layers.
- Should provide scalability, high availability, and fast convergence to the network.
  - The core layer should scale easily.
  - High-speed environment that should use hardware-acceleration, if possible.
  - The core should provide a high level of redundancy and adapt to changes quickly.
    - Core devices should be more reliable
    - Accommodate failures by rerouting traffic and respond quickly to changes in the network topology.
  - Implements scalable protocols and technologies.
  - Provides alternate paths and load balancing.
  - Packet manipulation should be avoided, such as checking access lists and filtering, which could slow down the switching of packets.
- Not all campus implementations require a campus core.
- The core and distribution layer functions can be combined at the distribution layer for a smaller campus.

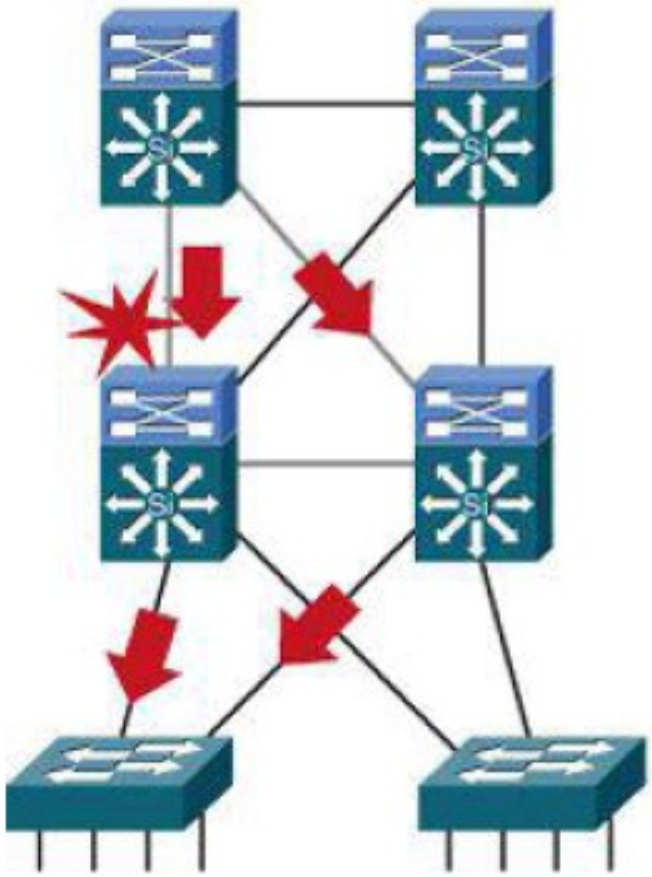
Provide Alternate Paths

- An additional link providing an alternate path to a second core switch from each distribution switch offers redundancy to support a single link or node failure.



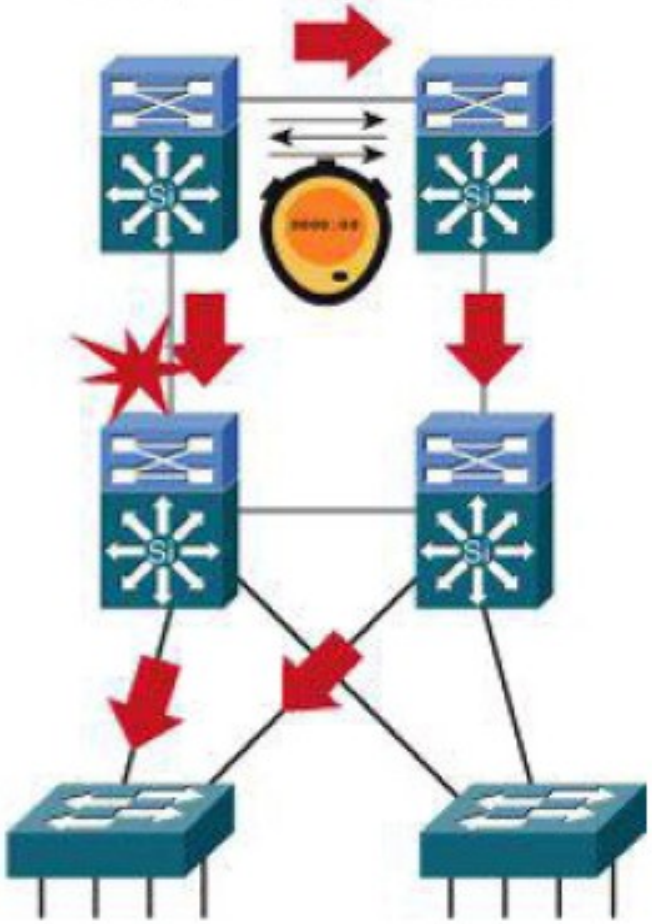
Core Redundant Triangles

Triangles: Link or box failure does *not* require routing protocol convergence.



Model A

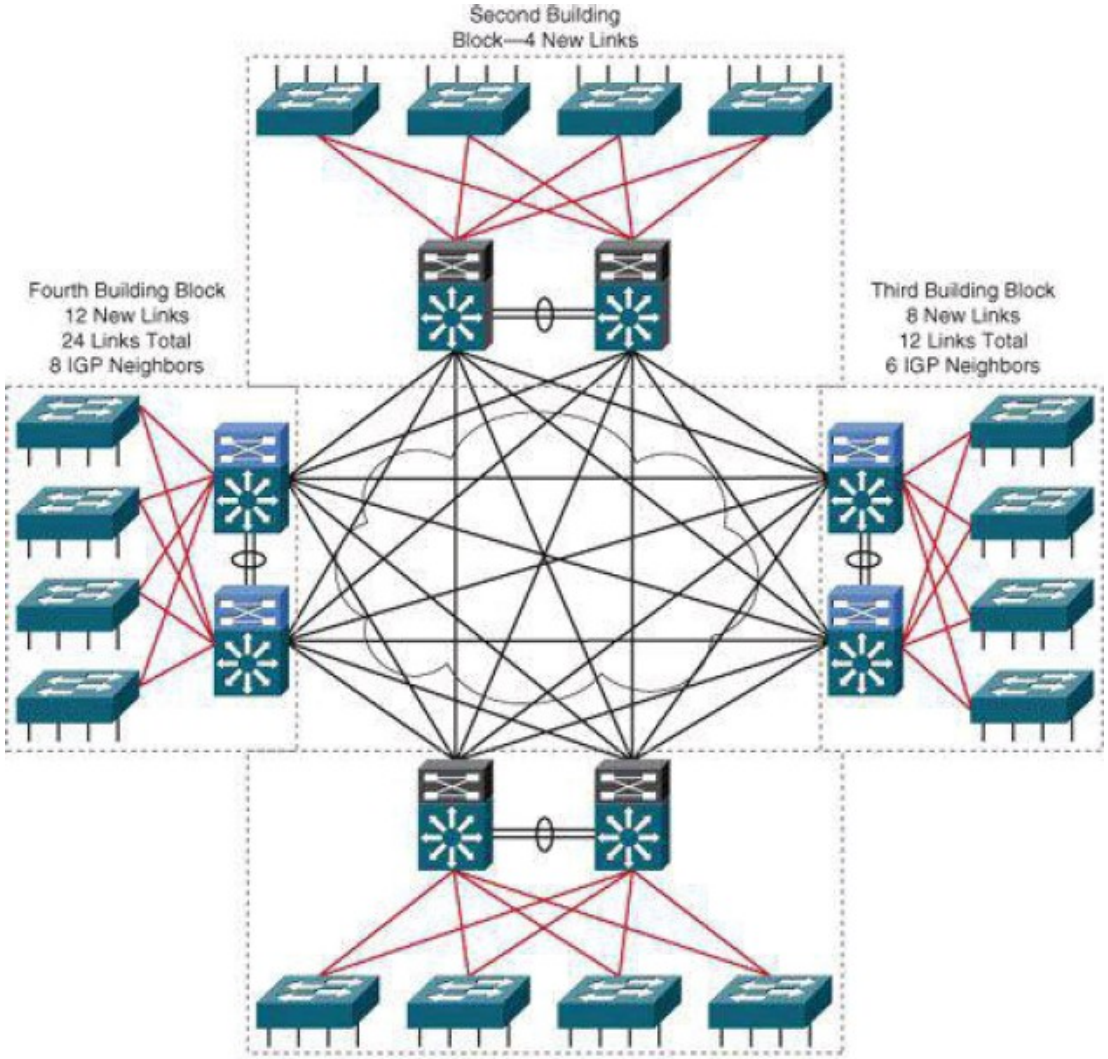
Squares: Link or box failure requires routing protocol convergence.



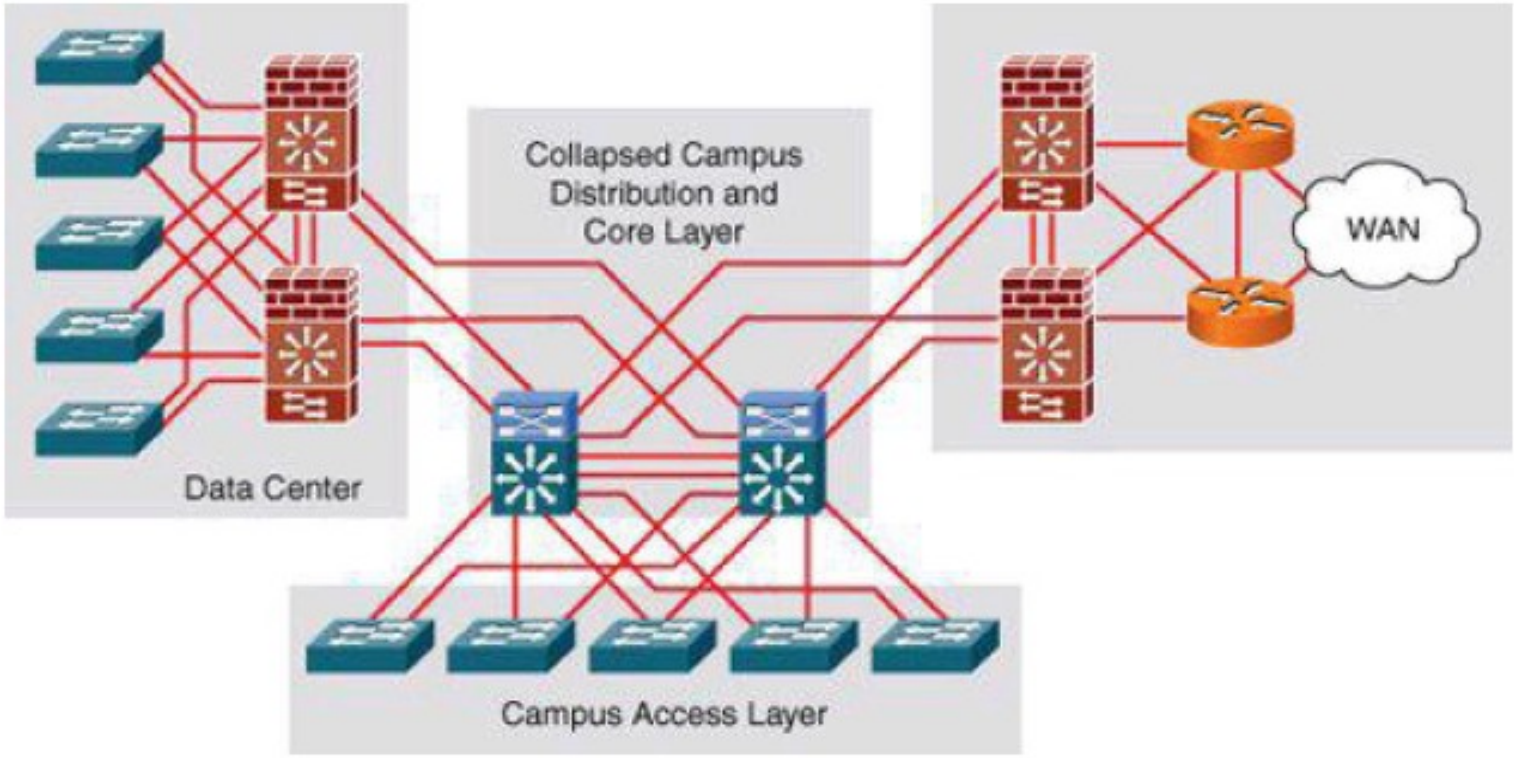
Model B

Without a Core Layer

- The distribution layer switches need to be fully meshed.
- Can be difficult to scale.
- Increases the cabling requirements.
- Routing complexity of a full-mesh design increases as new neighbors are added.
- Can be used in small campus with no perspective of growing.

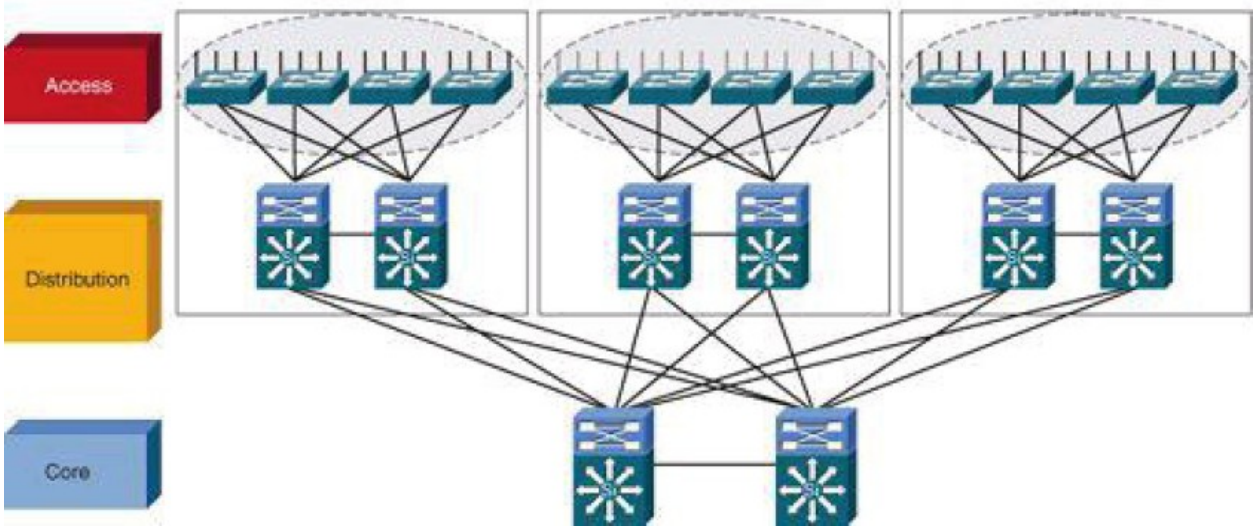


Collapsed Core Layer Architecture



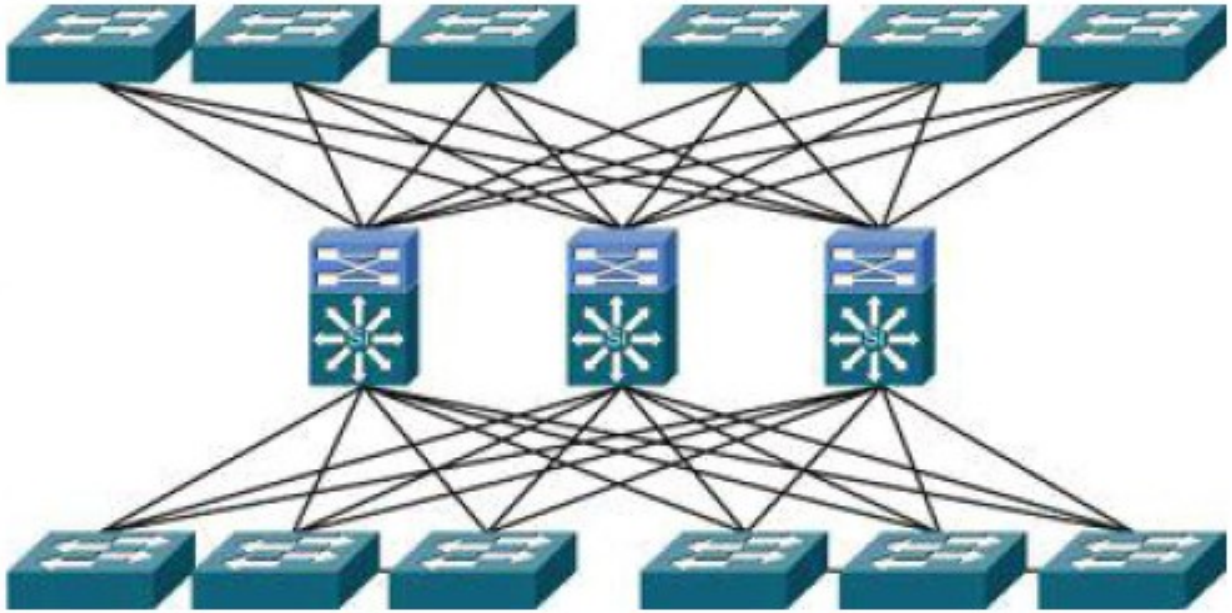
- In smaller networks, the core and the distribution layer can be only one,
  - Eliminates the need for extra switching hardware and simplifies the network implementation.
- However, eliminates the advantages of the multilayer architecture, specifically fault isolation.

Avoid Single Points of Failure



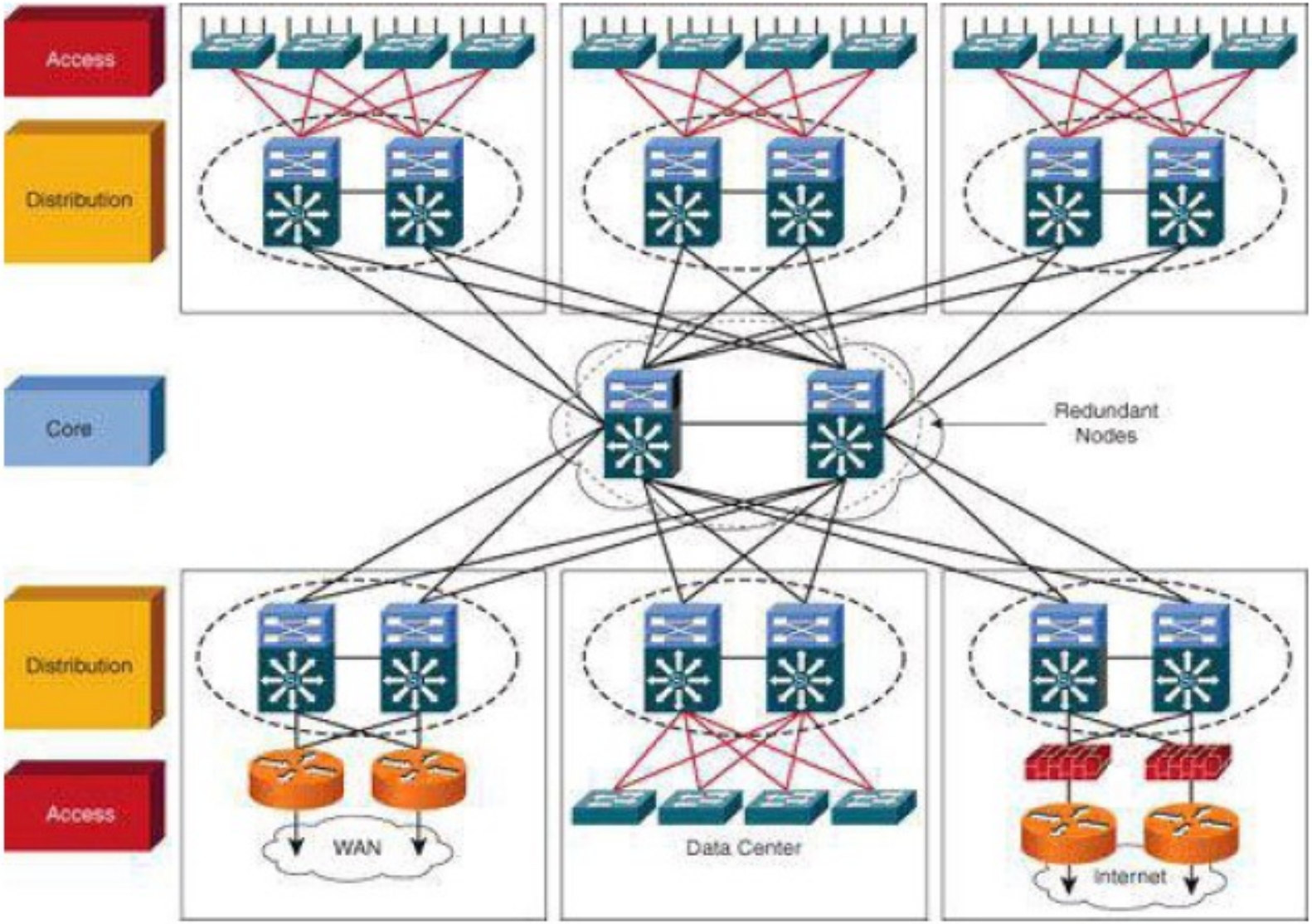
- With an hierarchical design,
  - In Distribution and Core Layers the single points of failure are easy to avoid with redundant links.
    - Don't forget redundant power and cooling!
  - In Access Layer, all L2 switches are single points of failure (only) to the user connected to them,
    - Solution 1, redundant backup hardware activated by a (proprietary) supervision mechanism to “replace” faulty equipment.
      - Copies full configuration and state to backup hardware.
    - Solution 2, have multiple connections between each user terminal and different access switches
      - Requires multiple network cards in user terminals and more plugs/wiring.
      - Cheaper?

Avoid Too Much Redundancy



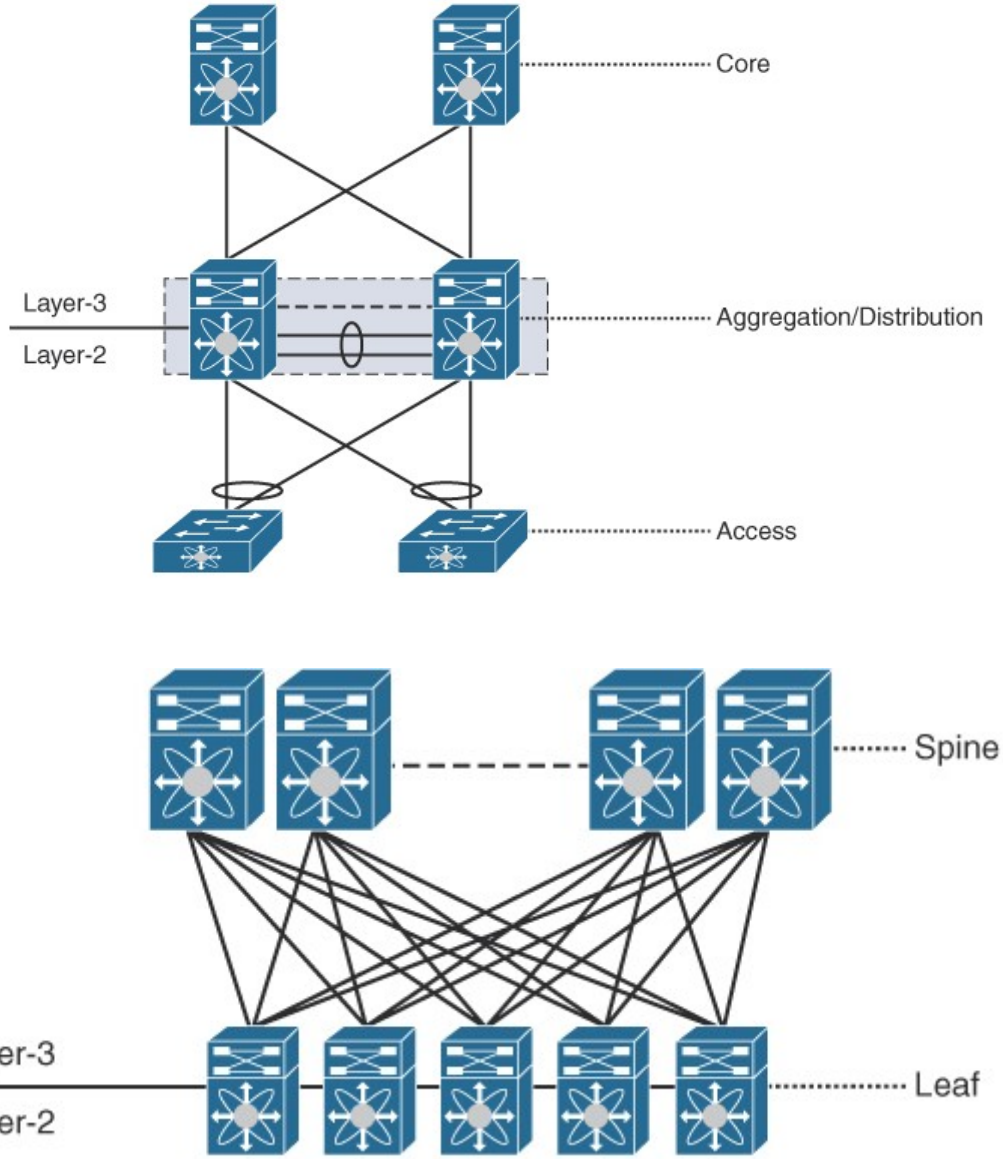
- Increases,
  - Routing complexity
  - Number of ports used
  - Wiring

Optimal Redundancy



Datacenter CLOS Topology

- With large-scale data center deployments, three-tier topologies have become scale bottlenecks.
- The classic three-tier topology evolved to a CLOS topology.
  - Original designed by Charles Clos in 1950 to find a more efficient way to handle telephonic call transfers.
- Eliminating the need for STP the network evolved to greater stability and scalability.
- Layer 3 moves to the Access Layer.
- Usually called Spine-and-Leaf Architecture.

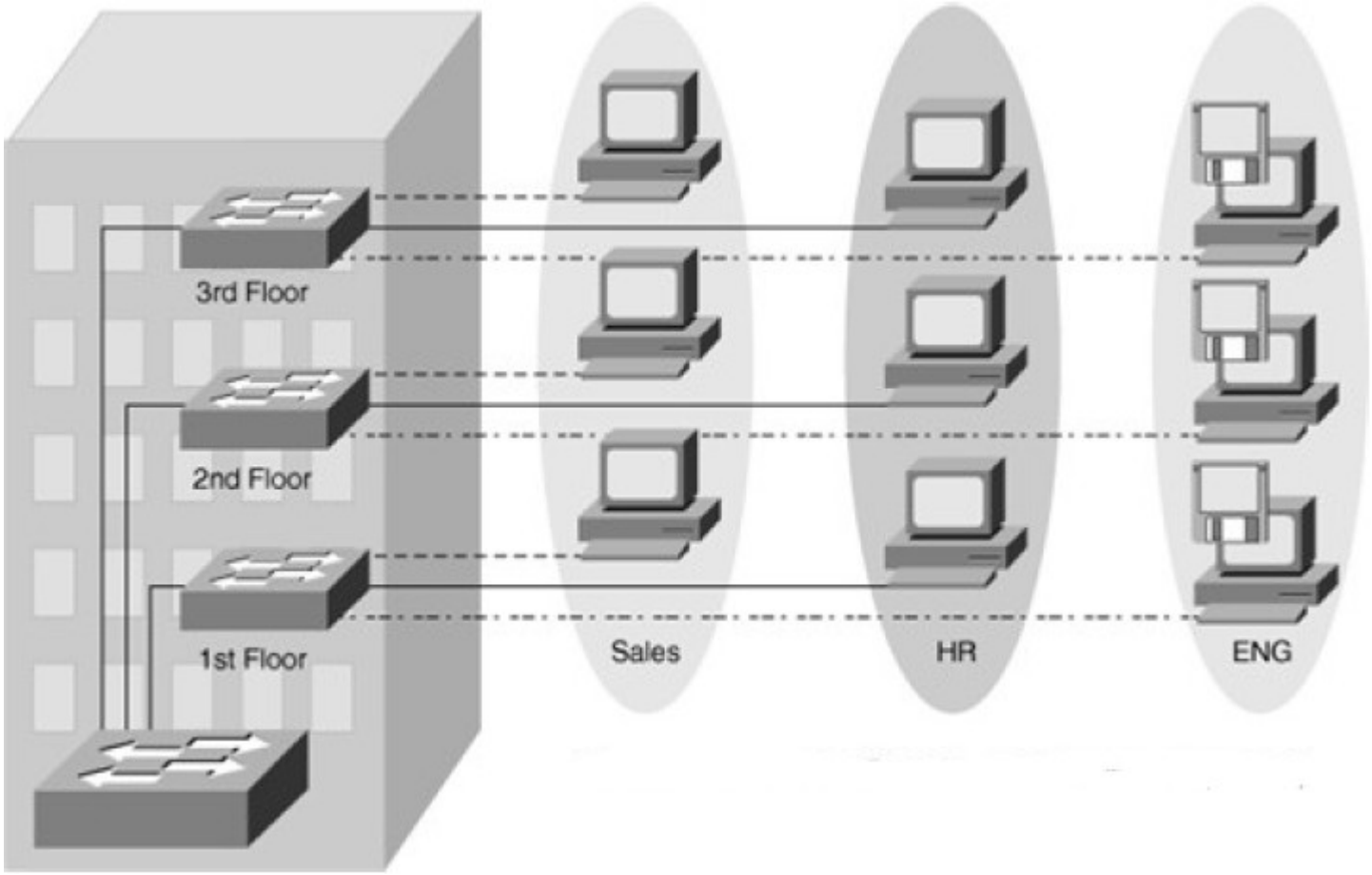


Virtual LANs

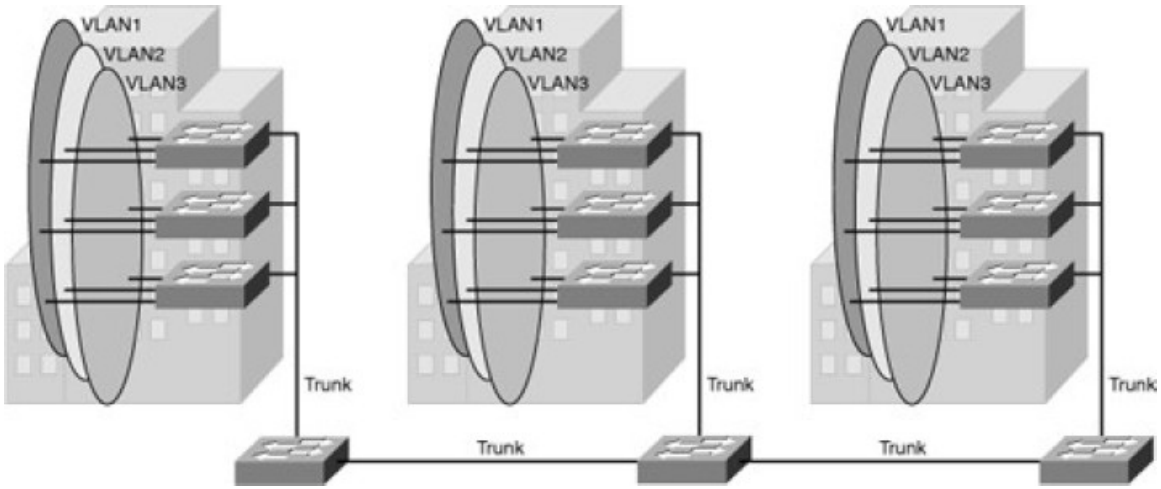
- Group of individual switch ports into switched logical *workgroup*
  - Restrict the broadcast domain to designated VLAN member ports
  - Communication between VLANs requires a router.
- Solves the scalability problems of large flat networks
  - By breaking a single broadcast domain into several smaller broadcast domains.

Implementing VLANs

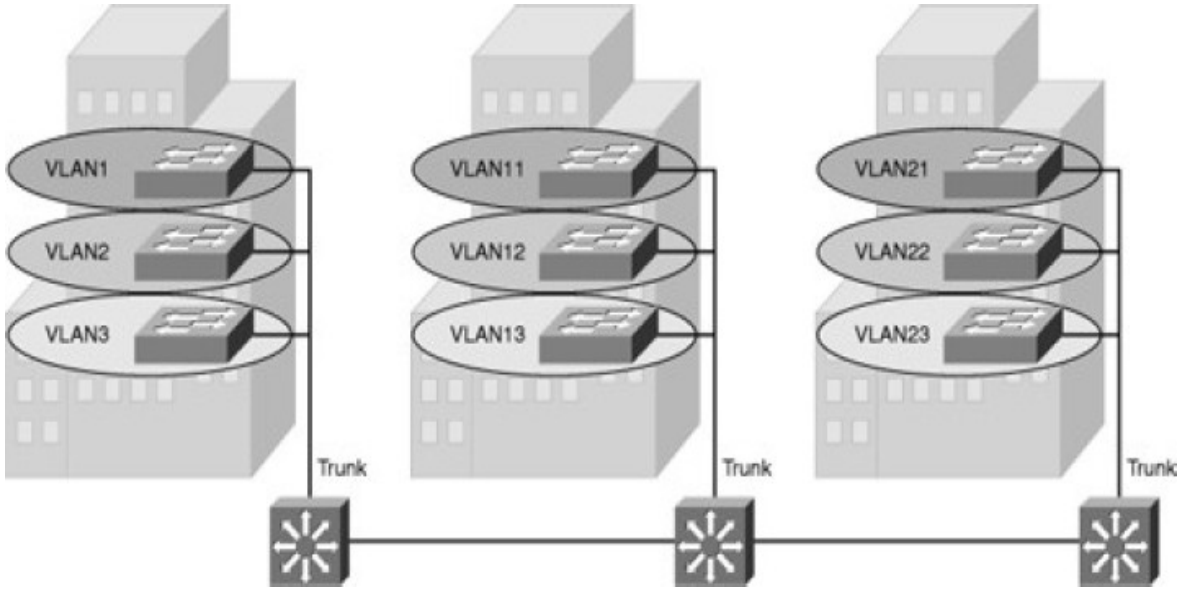
- VLAN is a logical group of end devices with a common set of requirements independent of their physical location.



VLAN Segmentation Models



- End-to-End VLAN
  - VLAN are associated with switch ports widely dispersed over the network



- Local VLAN
  - Local VLANs are generally confined to a wiring closet.

VLAN Segmentation (examples)

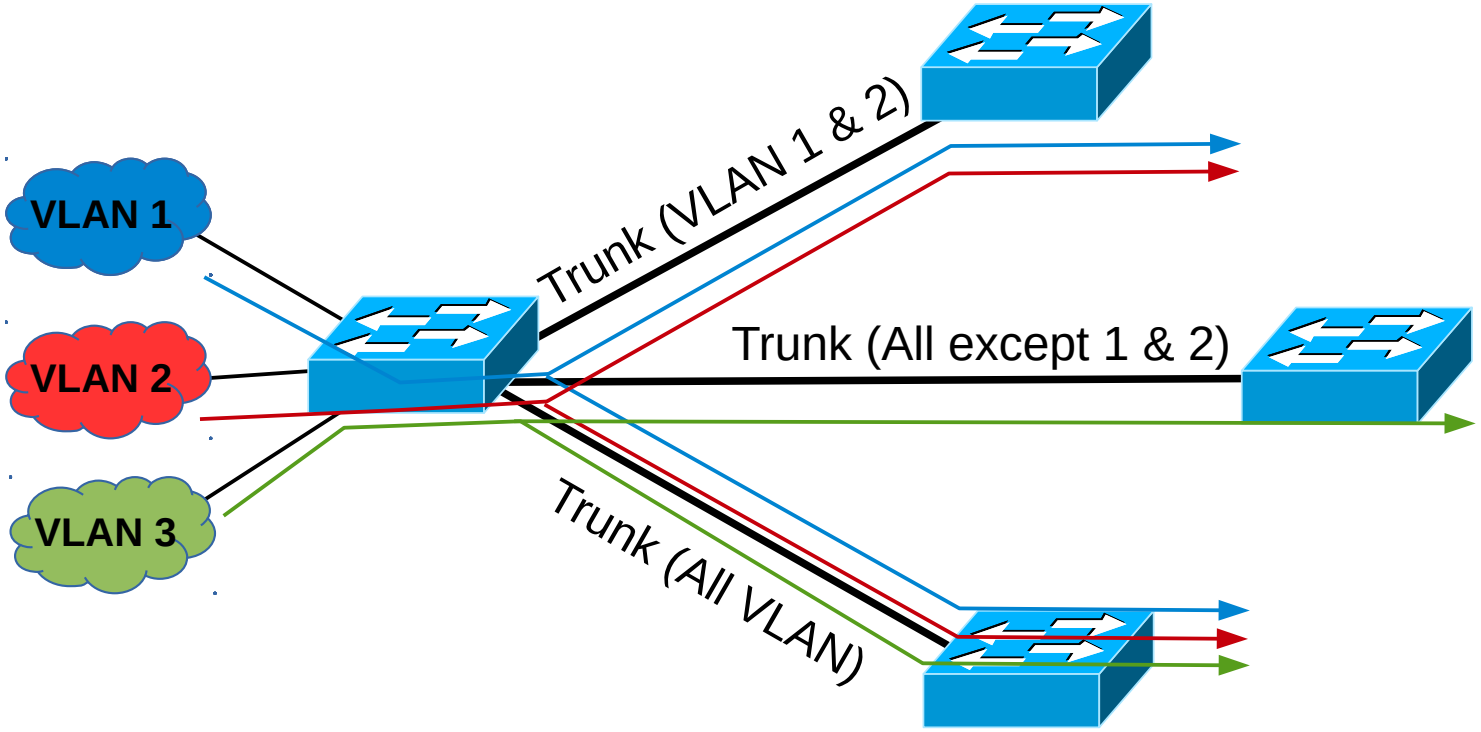
- Local VLANs
  - Per service/function
    - VoIP phones, Video conference, printers, cameras, PCs, servers, …
  - Per user role
    - Engineers I, engineers II, technicians, administrators, …
  - Per location
    - Building I, floor 4, right wing, etc...
  - Mixture of service/function, role, location
    - e.g.: VLAN of VoIP phones, of the Engineers in Building I.
- End-to-end VLANs
  - Services/roles that have a global scope within the network.
  - Wireless network
    - Same IP network (same IP address) independently of location.
    - To avoid IP changes when moving from location to location.
  - Administration VLAN (optional)
    - VLAN used by the network administrator to remotely access network equipments.
    - Same administrator of (all) equipments independent of location.

VLAN Segmentation Purpose

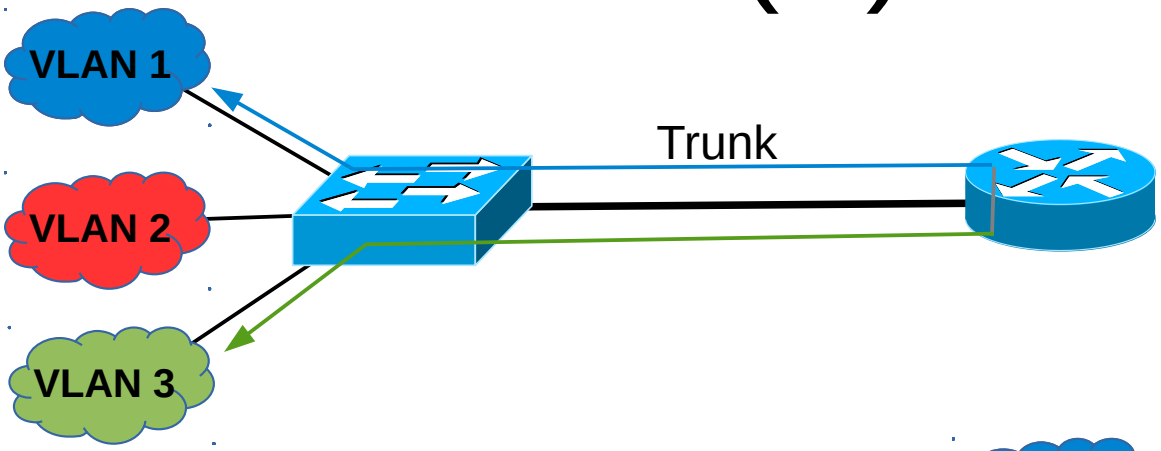
- Joint in the same logical network services/terminals/users with same traffic/security/QoS policies.
  - Each VLAN must have an unique IP (sub-)network.
  - May have more than one IP (sub-)network.
    - Including IPv4 public and IPv4 private networks.
    - And, IPv6 networks.
- Neighbor (local) VLANs with similar traffic/security/QoS policies should have IP (sub-)networks that can be summarized/aggregated.
  - E.g.: VLAN of VoIP phones in Building 1 (VLAN 21: 200.0.0.0/24)
  - VLAN of VoIP phones in Building 2 (VLAN 22: 200.0.1.0/24)
  - Summarized/aggregated address of VLAN21+VLAN22: 200.0.0.0/23.

Trunk Links

- A VLAN trunk carries traffic for multiple VLANs by using IEEE 802.1Q.
  - Inter-Switch Link (ISL) encapsulation is an alternative but it getting obsolete.
- Trunks may transport all VLAN or only some!

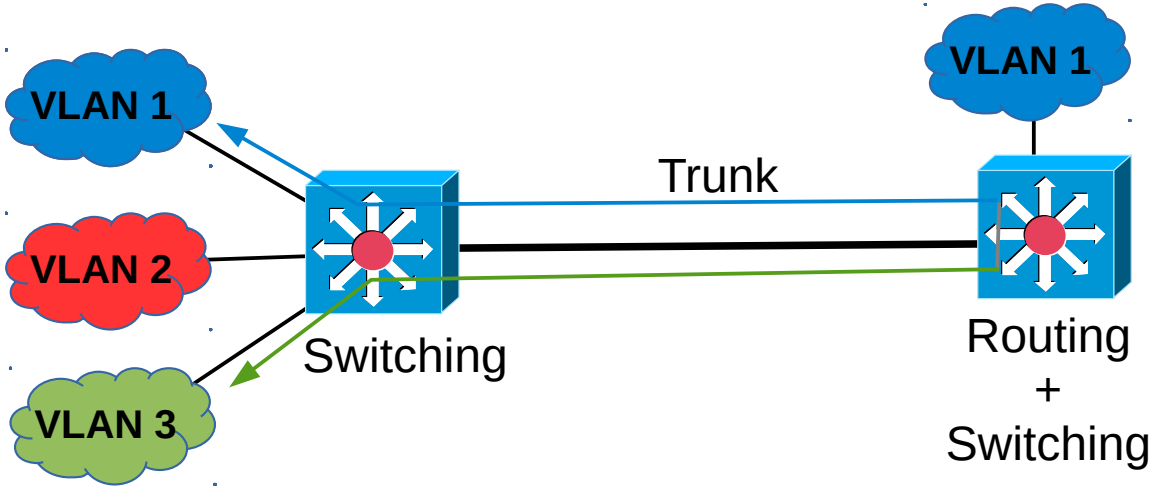


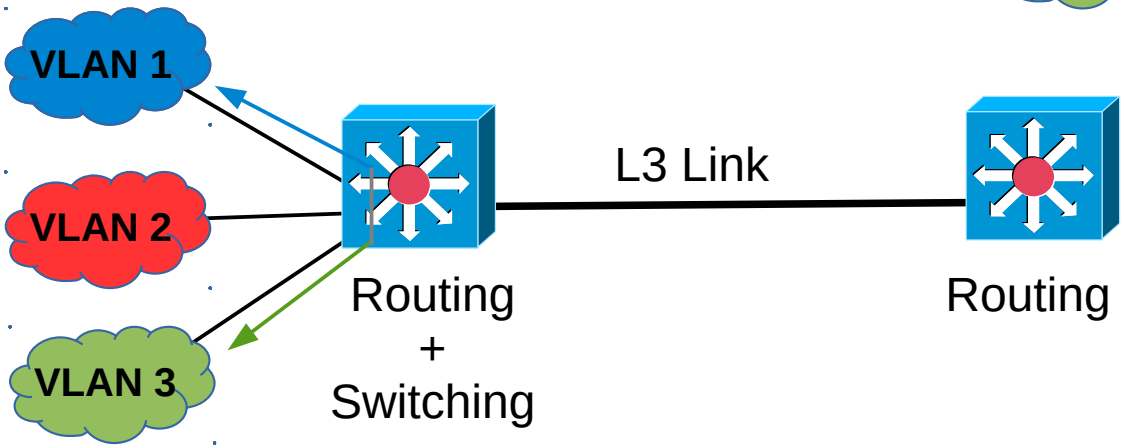
Inter-(V)LAN Routing



- L2 Switch + Router
  - Does not allow end-to-end VLANs.

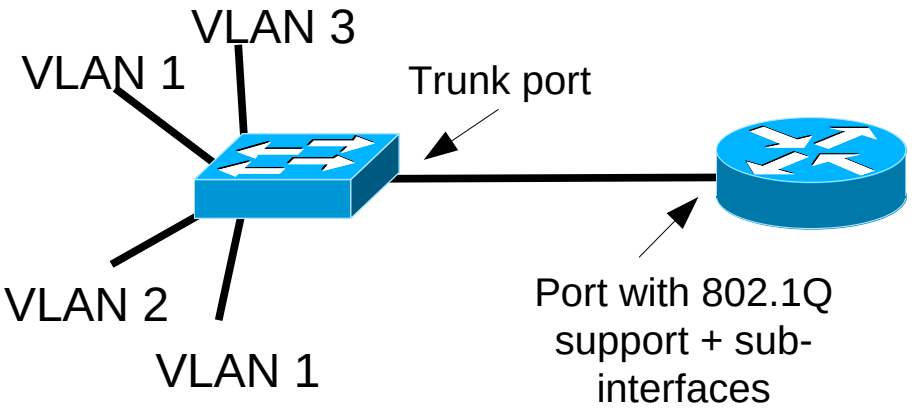
- L3 Switch + L3 Switch
  - Traffic between VLANs must “travel” until the first L3 Switch performing Routing.

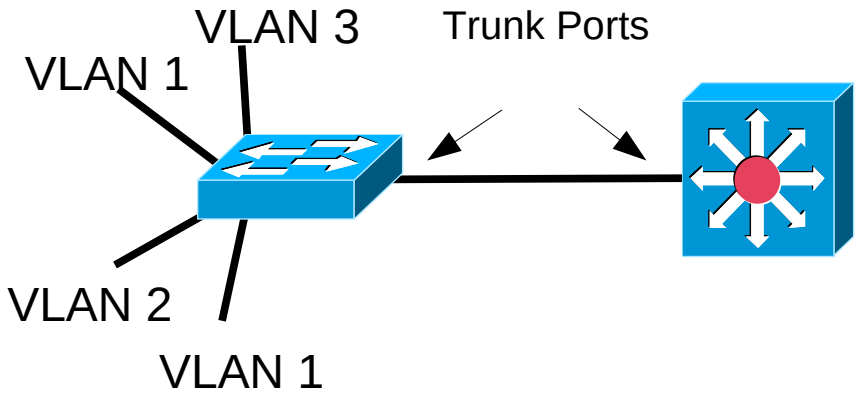




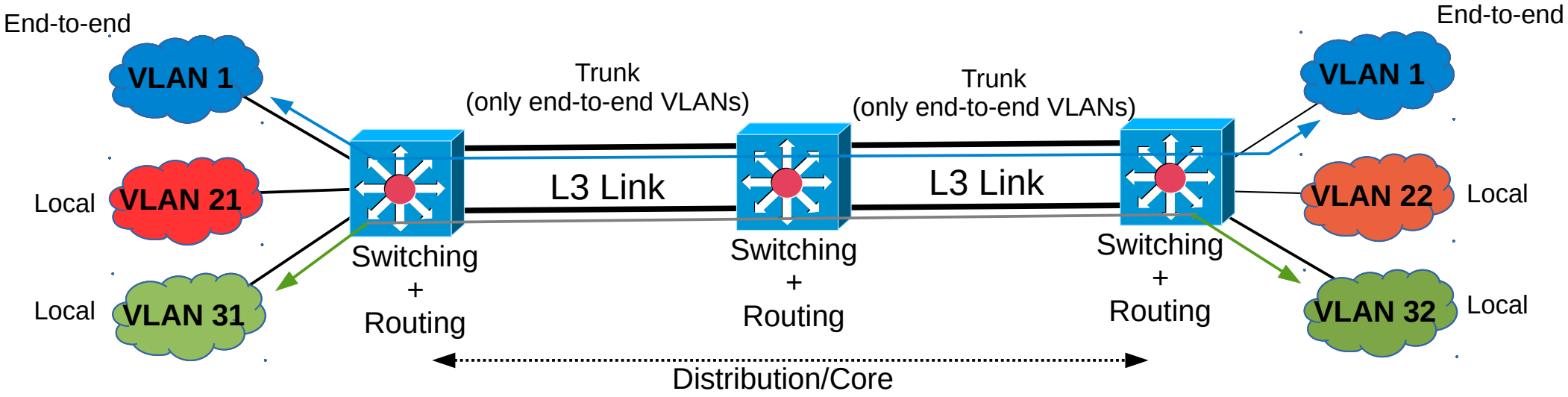
IP Connection between VLANs

- To communicate between different VLAN it is required to use Layer 3 (IP Routing).
- Common solutions:
  - A router with support to 802.1Q,
    - Connecting the physical router interface to a Trunk port.
    - The router's physical interface is sub-divided in sub-interfaces (one for each VLAN).
    - The IP gateway for a VLAN host is the IP address of the respective sub-interface in the Router.
  - A Layer 3 switch,
    - Connecting both switches (L3 and L2) using Trunk ports.
    - Each VLAN is mapped to a virtual Layer 3 interface.
    - The IP gateway for a VLAN host is the IP address of the respective virtual interface in the L3 switch.





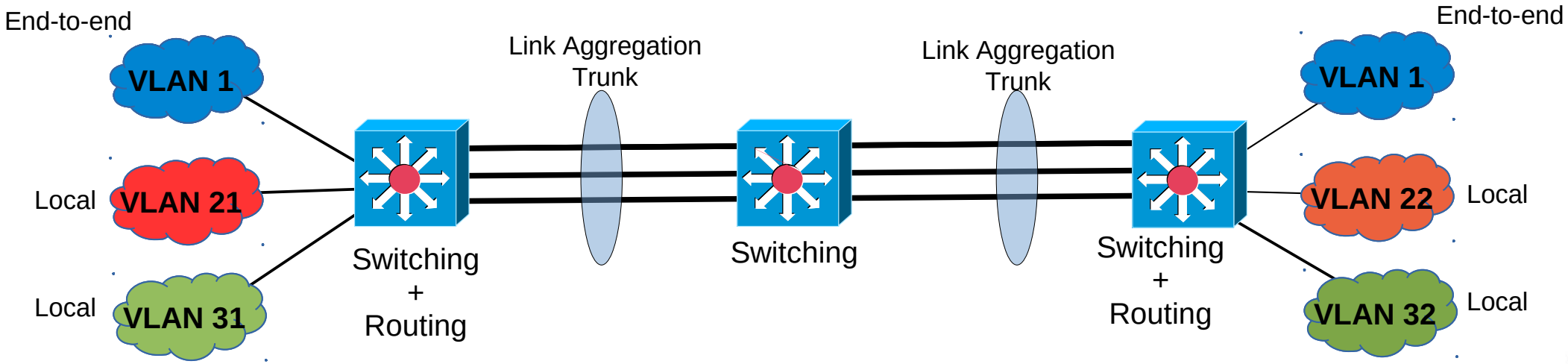
Inter-(V)LAN Traffic (1)



- End-to-end VLANs traffic **should be switched** over the Distribution/Core layers
  - Using a trunk (for end-to-end VLANs only).
- Local VLANs traffic **should be routed** over the Distribution/Core layers
  - Using standard layer 3 Links.
  - Using static routing (not the best solution!).
  - Exchange the routing information only through the L3 links
    - End-to-end VLAN should be passive interfaces for the routing processes.
      - Routes are not exchanged → Traffic is not routed!

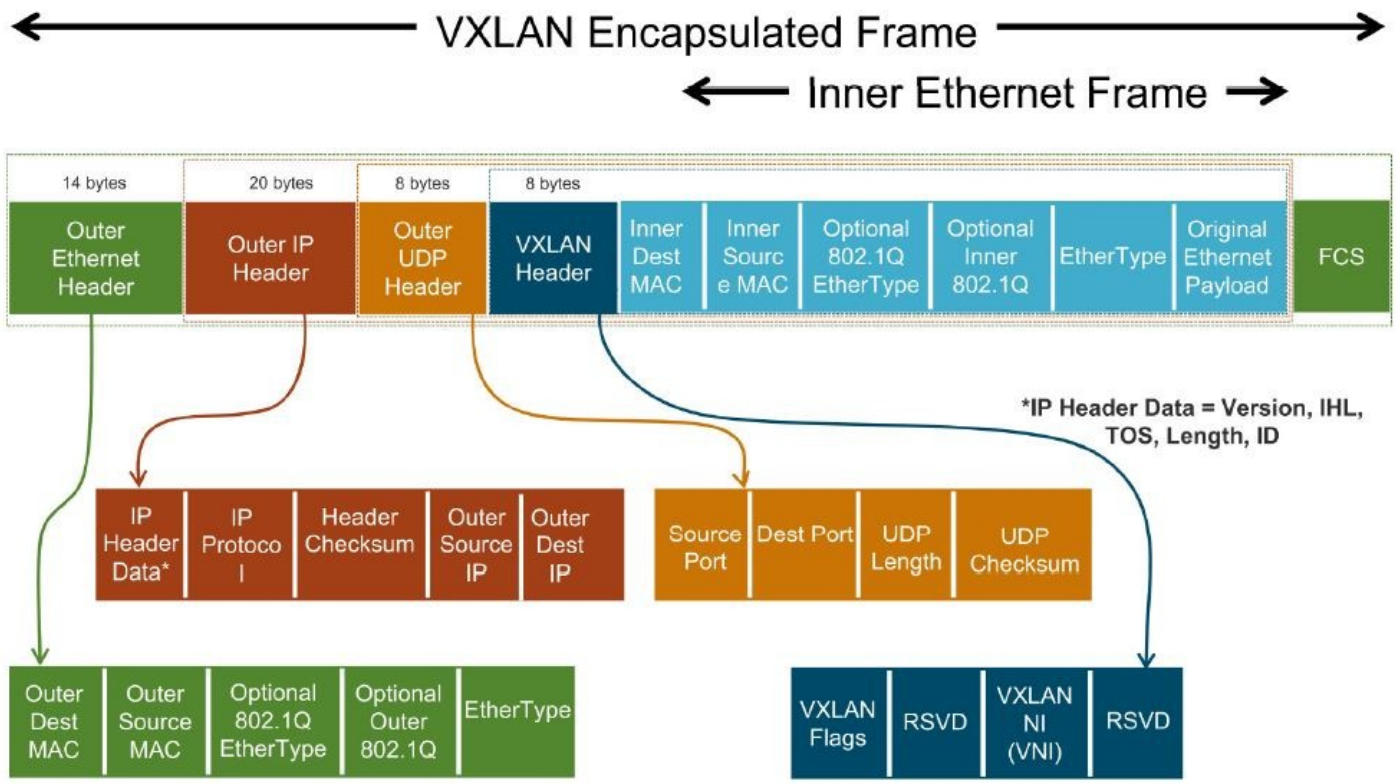
Ethernet Link Aggregation

- The throughput/speed of one connection link may not be enough to fulfill the requirements.
- Multiple Ethernet links may aggregated, provide a seamless trunk connection with N times the single throughput/speed of one link.
- Ethernet frames are “load-balanced” between all available physical links.



Virtual Extensible LAN (VXLAN)

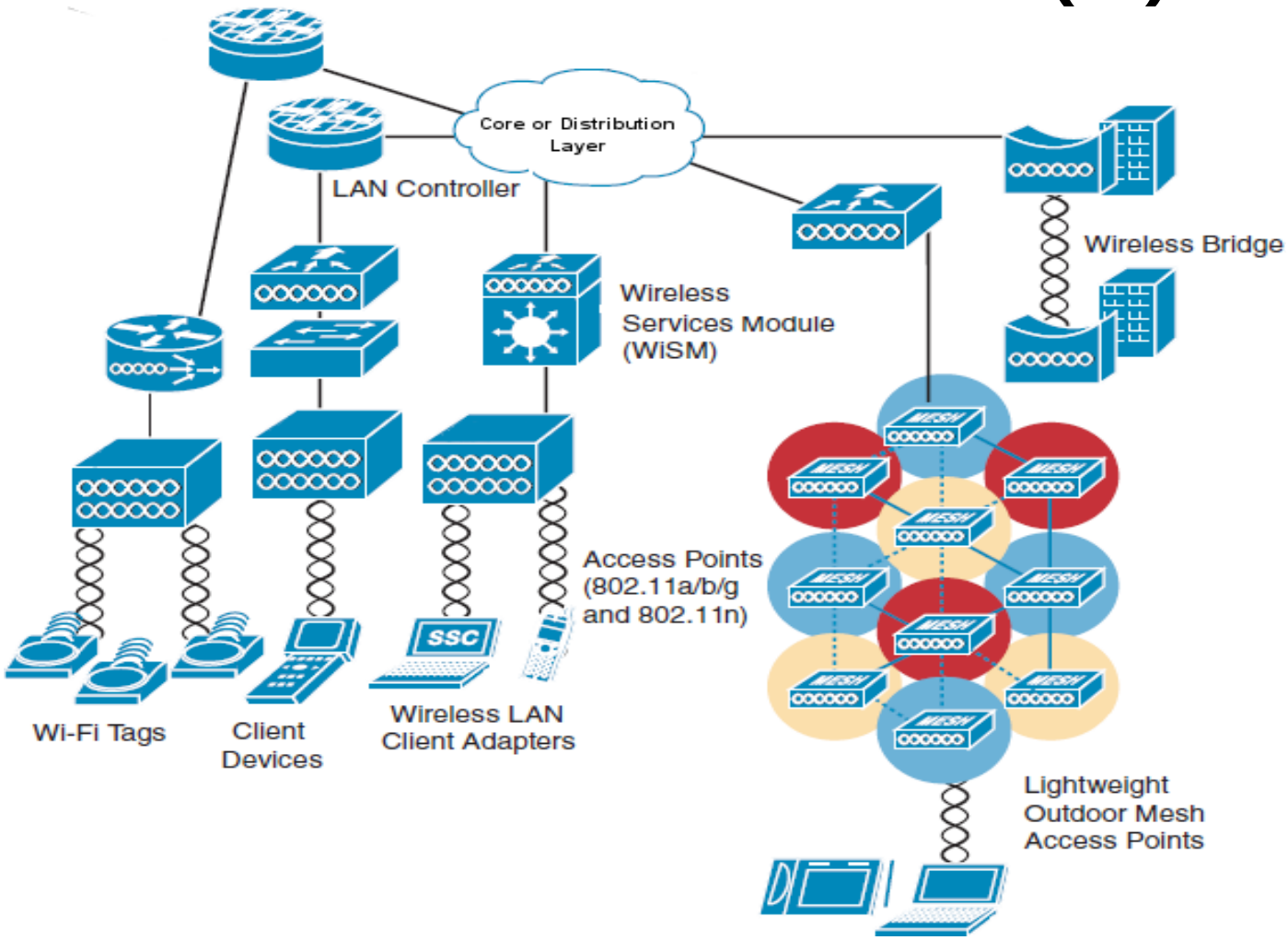
- Encapsulates OSI Layer 2 Ethernet frames within Layer 4 UDP datagrams.
  - Default port 4789.
- Alternative to 802.1Q.



Spanning Tree Protocol

- STP enables the network to deterministically block interfaces and provide a loop-free topology in a network with redundant links.
- There are several STP Standards and Features:
  - STP is the original IEEE 802.1D version (802.1D-1998) that provides a loop-free topology in a network with redundant links.
  - RSTP, or IEEE 802.1W, is an evolution of STP that provides faster convergence of STP.
  - Multiple Spanning Tree (MST) is an IEEE standard. MST maps multiple VLANs into the same spanning-tree instance.
  - Per VLAN Spanning Tree Plus (PVST+) is a Cisco enhancement of STP that provides a separate 802.1D spanning-tree instance for each VLAN configured in the network.
  - RPVST+ is a Cisco enhancement of RSTP that uses PVST+. It provides a separate instance of 802.1W per VLAN.
- Recommended Practices for STP
  - Define by configuration (using STP priority) the root bridge/switch.
  - Use the same cost in all interfaces (if possible).

Wireless Network(s)

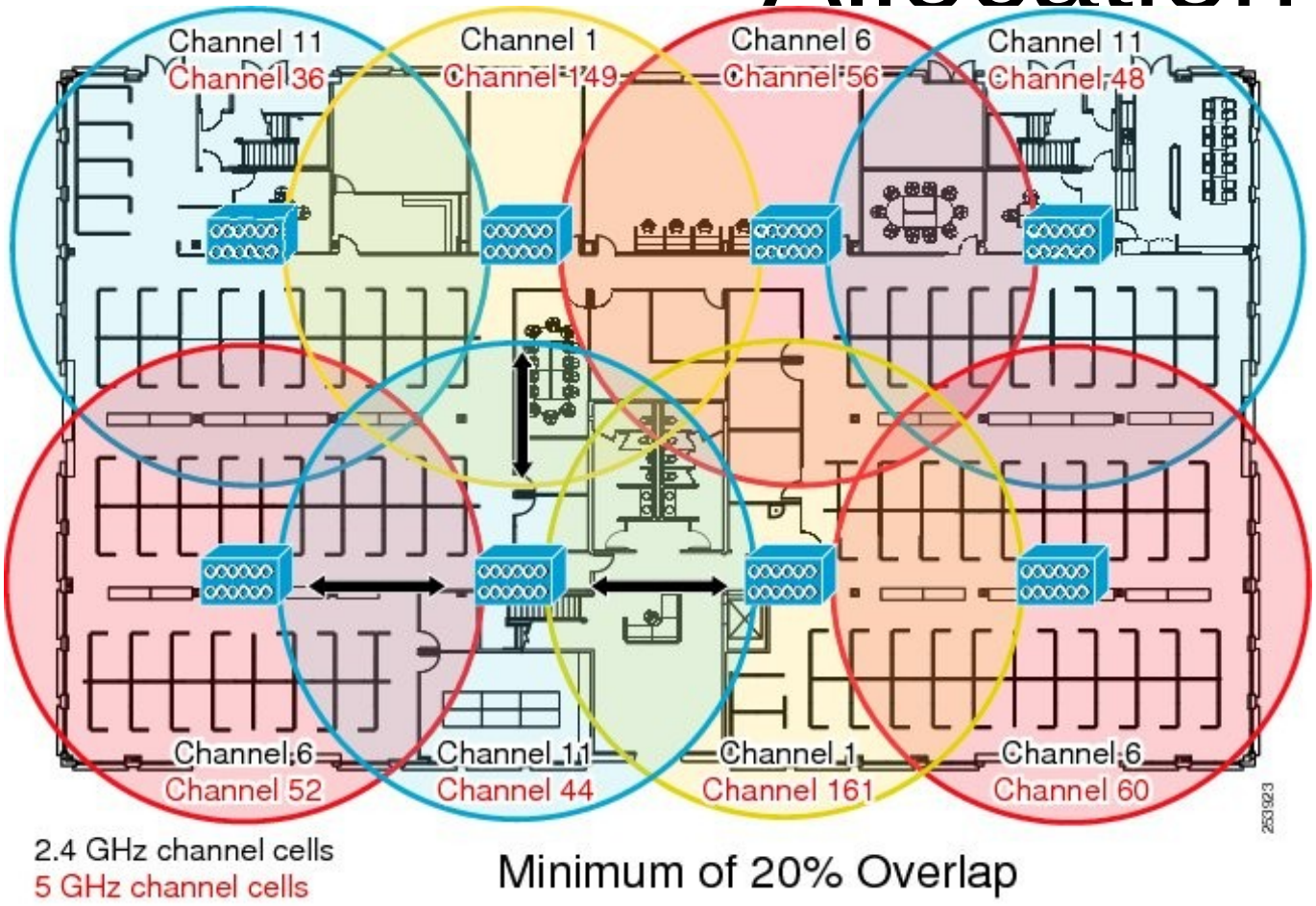


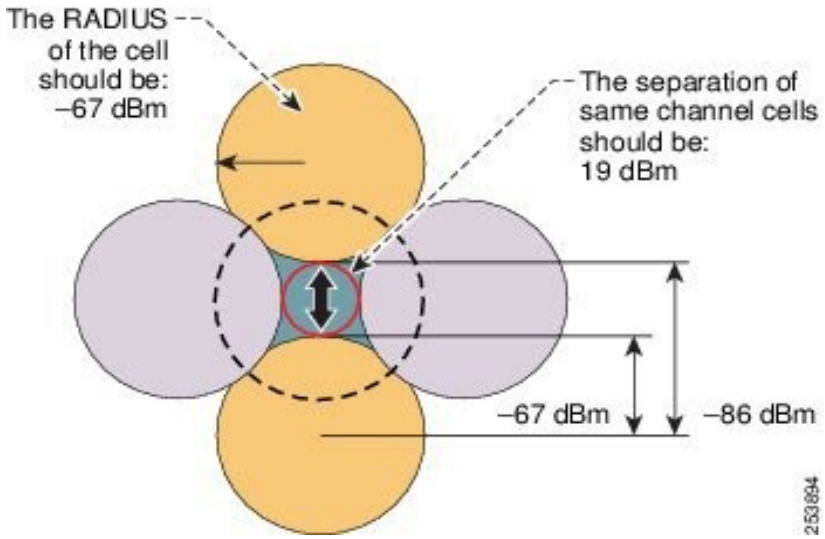
- Wireless networking technologies should have an integration point at core or distribution layers.
- In terms of network architecture a WLAN can be seem as any LAN.
  - Except that we have mobility and must have seamless roaming while moving.
- A large number of AP can be managed by a (Wireless) LAN Controller.

VLANs on Access Points

- AP have trunk ports to distribution/core switches.
- “Wired” VLANs must/can be extended to the wireless domain.
  - e.g., VLAN 30 “Green” and VLAN 10 “Red”.
- Each SSID can be mapped to a VLAN.
  - Different SSID/VLAN can have different security policies.
- Wireless VLANs should be configured as end-to-end.
  - Mobility and AP roaming should not break Layer 3 connectivity.
  - IP address should be the same → same VLAN with campus.
- A Native VLAN is required to provide management capability and client authentications.
  - Never extended to the wireless domain!!
    - e.g., VLAN 1.

AP Placement and Channel Allocation





- 802.11n or 802.11ac 5GHz deployment does not have the overlap or collision domain issues of 2.4GHz.

IP Routing Overview

- Routers forward packets toward destination networks.
- Routers must be aware of destination networks to be able to forward packets to them.
- A router knows about the networks directly attached to its interfaces
- For networks not directly connected to one of its interfaces, however, the router must rely on outside information.
- A router can be made aware of remote networks by:
  - **Static routing**: An administrator manually configure the information.
  - **Dynamic routing**: Learns from other routers.

  Policy based routing: Manually routing rules that outweigh static/dynamic routing and may depend on parameters other than the destination address.

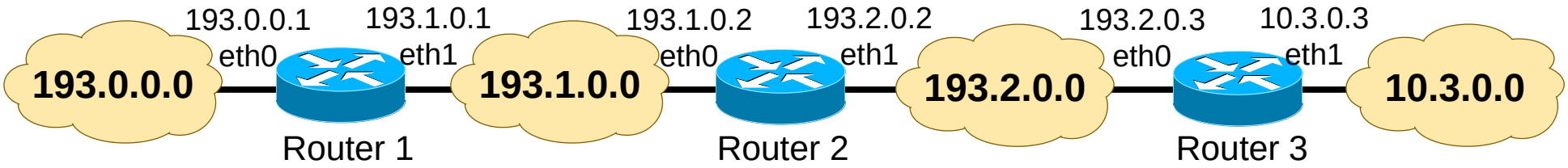
Default Routes

- In some circumstances, a router does not need to recognize the details of remote networks.
- The router can be configured to send all traffic (or all traffic for which there is not a more specific entry in the routing table) to a specific neighbor router.
- This is known as a default route.
- Default routes are either dynamically advertised using routing protocols or statically configured.
- IPv4 default route - 0.0.0.0/0
- IPv6 default route - ::/0

Static Routing

- Stating routing do not react to network topology changes.
  - If a link fails, the static route is no longer valid if it is configured to use that failed link, so a new static route must be configured.
  - Connectivity may be lost until intervention of an administrator.
- Static routing does not scale well when network grows.
  - Administrative burden to maintain routes may can become excessive.
- Static routes can be used in the following circumstances:
  - When the administrator needs total control over the routes used by the router.
  - When a backup to a dynamically recognized route is necessary.
  - When it is used to reach a network accessible by only one path (a stub network).
    - There is no backup link, so dynamic routing has no advantage.
  - When a router connects to its ISP and needs to have only a default route pointing toward the ISP router, rather than learning many routes from the ISP.
    - Again, a single path of access without backup.
  - When a router is underpowered and does not have the CPU or memory resources necessary to handle a dynamic routing protocol.
  - When it is undesirable to have dynamic routing updates forwarded across low bandwidth links.

Static Routing Examples



- Example 1
  - Router2 do not know networks 193.0.0.0/24 and 10.3.0.0/24
  - Necessary static routes:
    - 193.0.0.0/24 accessible through 193.1.0.1 (eth1, Router1)
    - 10.3.0.0/24 accessible through 193.2.0.3 (eth0,Router3)
- Example 2
  - Router1 do not know networks 193.2.0.0/24 and 10.3.0.0/24
  - Necessary static routes:
    - 193.2.0.0/24 accessible through 193.1.0.2 (eth0, Router2)
    - 10.3.0.0/24 accessible through 193.1.0.2 (eth0, Router2)

      OR
    - Using default route: 0.0.0.0/0 accessible through 193.1.0.2 (eth0, Router2)

Dynamic Routing

- Dynamic routing allows the network to adjust to changes in the topology automatically, without administrator involvement.
- Routers exchange information about the reachable networks and the state of each network/link.
  - Routers exchange information only with other routers running the same routing protocol.
  - When the network topology changes, the new information is dynamically propagated throughout the network, and each router updates its routing table to reflect the changes.

(Complex) Routing Tables

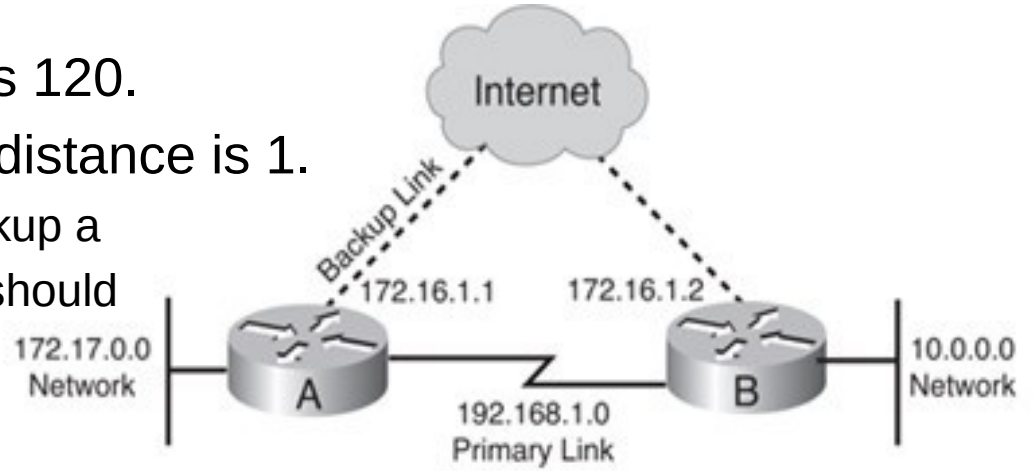
- An IP address may have multiple matches on a Routing Table:
  - Example: 192.168.1.12
  - Will match:
    - 192.168.1.0/25 via ...
    - 192.168.1.0/24 via ...
    - 192.168.0.0/23 via ...
    - 192.168.0.0/16 via ...
    - …
  - Router will choose entry with the largest network prefix (most specific network).
    - i.e., 192.168.1.0/25 via ...
- Load balancing
  - Routing tables may have more than one path for each network
    - Traffic will be divided by all entries.
    - By packet, flow (TCP session, UDP IPs/port), etc...
      - E.g, packet 1 path 1, packet 2 path 2, packet 3 path 1, …
      - Flow 1 path 1, flow 2 path 2, flow 3 path 3, flow 4 path 1, flow 5 path 2, ...

Administrative Distance

- Most routing protocols have metric structures and algorithms that are incompatible with other protocols.
- It is critical that a network using multiple routing protocols be able to seamlessly exchange route information and be able to select the best path across multiple protocols.
- Routers use a value called administrative distance to select the best path when they learn from different routing protocols the same destination (same network prefix and mask length).
- The Protocol/Method with the lowest Administrative Distance is preferred
  - The Administrative Distance value is configurable.
- Example:
  - Static [**1**/1] 192.168.1.0/24 via … ← Chosen!
  - RIP [**120**/1] 192.168.1.0/24 via …
  - OSPF [**110**/1] 192.168.1.0/24 via ...

Floating Static Routes

- Based on the default administrative distances, routers use static routes over any dynamically learned route.
  - However, this default behavior might not be the desired behavior.
  - For example, when you configure a static route as a backup to a dynamically learned route, you do not want the static route to be used as long as the dynamic route is available.
- A static route that appears in the routing table only when the primary route goes away is called a floating static route.
  - The administrative distance of the static route is configured to be higher than the administrative distance of the primary route and it “floats” above the primary route, until the primary route is no longer available.
- RIP default administrative distance is 120.
- Static Routes default administrative distance is 1.
  - To create a floating static route (to backup a RIP route) the administrative distance should be greater than 120.
    - In example: 200.

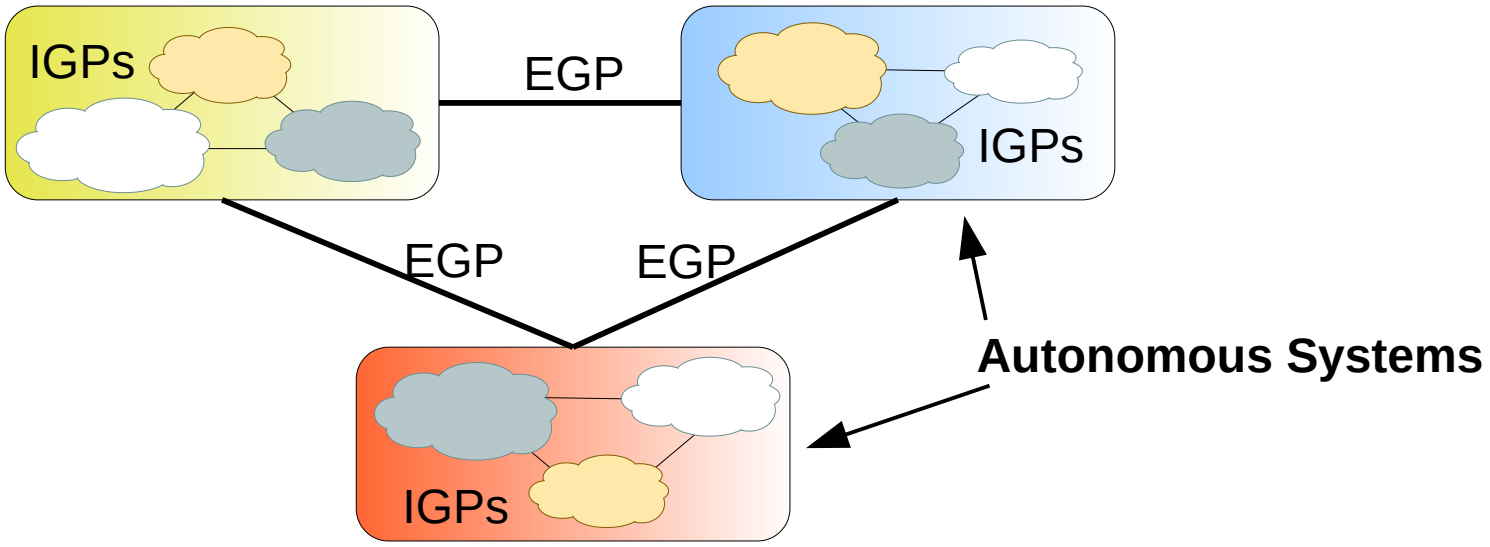



```
ip route 10.0.0.0 255.0.0.0 172.16.1.2 200

router rip
  network 192.168.1.0
  network 172.17.0.0
```

```
ip route 172.17.0.0 255.255.0.0 172.16.1.1 200

router rip
  network 192.168.1.0
  network 10.0.0.0
```

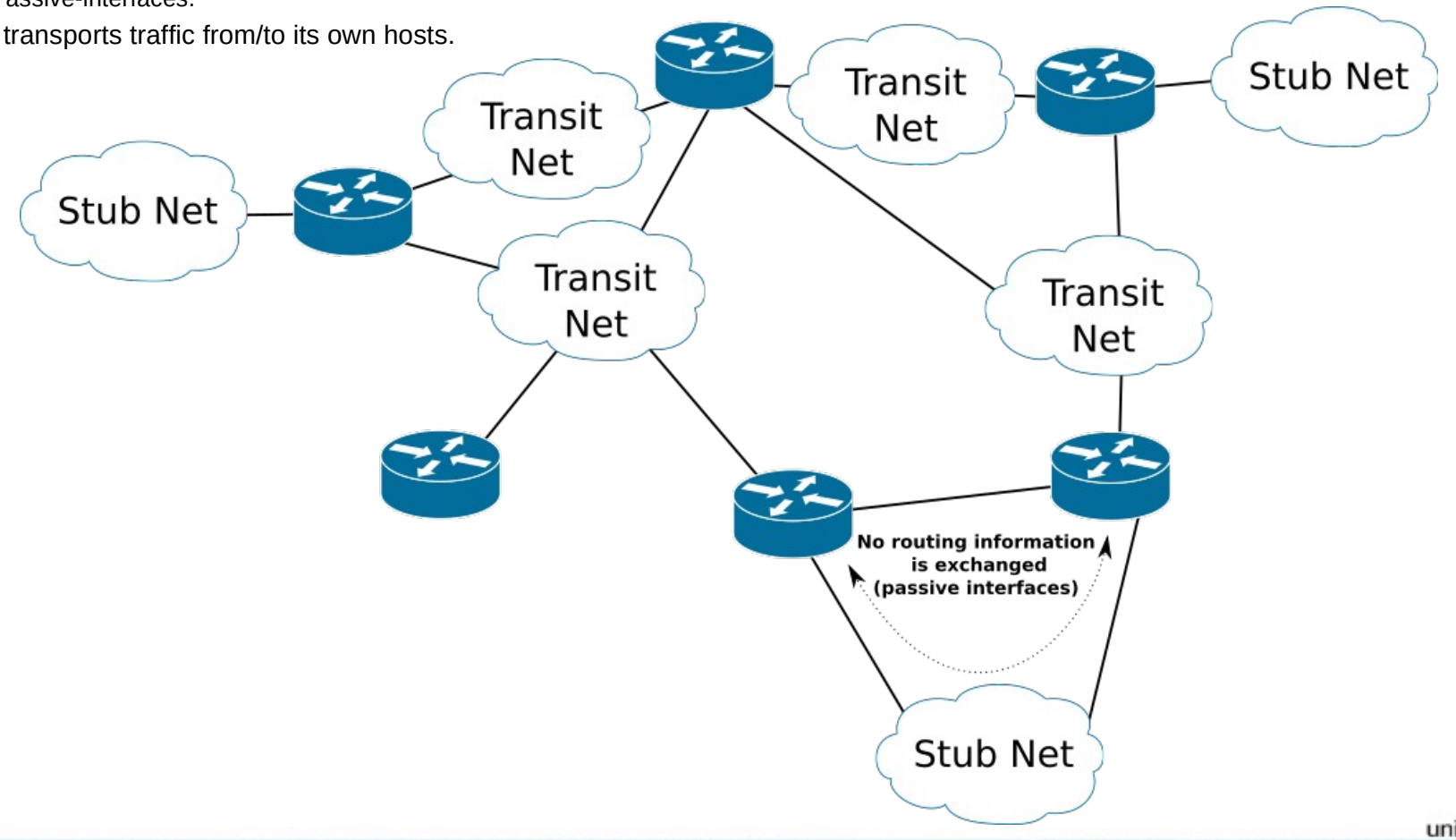
Autonomous Systems

- AS (Autonomous System) – set of routers/networks with a common routing policy and under the same administration.
- Routing inside an AS is performed by IGPs (Interior Gateway Protocols) such as RIPv1, RIPv2, OSPF, IS-IS and EIGRP.
  - Called Internal Routing
- Routing between AS is performed by EGPs (Exterior Gateway Protocols) such as BGP.
- IGPs and EGPs have different objectives:
  - IGPs: optimize routing performance
  - EGPs: optimize routing performance obeying political, economic and security policies.



Type of Networks

- Transit/Transport
  - Used to interconnect networks.
    - Routers exchange routing information using it.
  - Transports traffic from/to other network hosts and from/to its own hosts.
- Stub
  - Single router network.
  - or multiple routers network, if routers do not exchange routing information.
    - Passive-interfaces.
  - Only transports traffic from/to its own hosts.



Distance Vector versus Link State Protocols

- Distance vector
  - Each routers learns networks and best path based on the information sent periodically by its neighbors.
    - Network and cost (distance) to that network.
  - Each router determines the shortest paths to all know networks based on a distributed and asynchronous version of the Bellman-Ford algorithm.
  - Examples: RIPv1, RIPv2, IGRP, EIGRP.
- Link state
  - Routers learn the complete network topology and use a centralized algorithm to determine the shortest paths to all known networks.
  - The information necessary to construct and maintain in each router a data base with the network topology is obtain by a flooding process.
  - Network information is only exchanged on bootstrap and after any topology change.
  - Examples: OSPF, IS-IS.

Open Shortest Path First (OSPF) Protocol

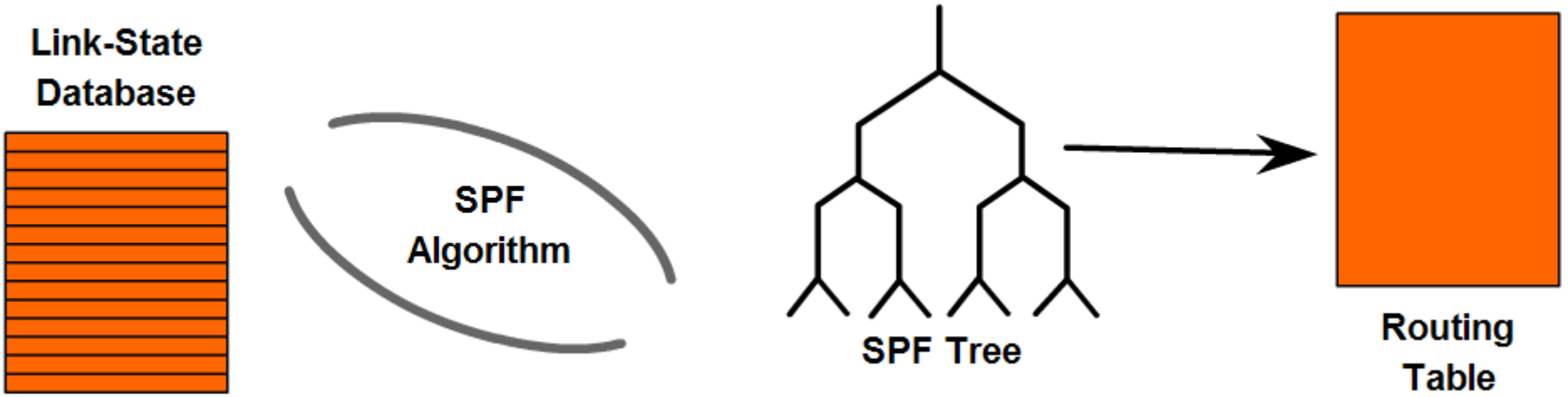
- OSPF is an open-standard protocol based primarily on RFC 2328.
- OSPF is a link-state routing protocol
  - Respond quickly to network changes,
  - Send triggered updates when a network change occurs,
  - Send periodic updates, known as link-state refresh, at long time intervals, such as every 30 minutes.
- Routers running OSPF collect routing information from all other routers in the network (or from within a defined area of the network)
- And then each router independently calculates its best paths to all destinations in the network, using Dijkstra's (SPF) algorithm.

OSPF Necessary Routing Information

- For all the routers in the network to make consistent routing decisions, each link-state router must keep a record of the following information:
  - Its immediate neighbor routers
    - If the router loses contact with a neighbor router, within a few seconds it invalidates all paths through that router and recalculates its paths through the network.
    - For OSPF, adjacency information about neighbors is stored in the OSPF neighbor table, also known as an adjacency database.
  - All the other routers in the network, or in its area of the network, and their attached networks
    - The router recognizes other routers and networks through LSAs, which are flooded through the network.
    - LSAs are stored in a topology table or database (which is also called an LSDB).
  - The best paths to each destination
    - Each router independently calculates the best paths to each destination in the network using Dijkstra's (SPF) algorithm.
    - All paths are kept in the LSDB.
    - The best paths are then offered to the routing table (also called the forwarding database).
    - Packets arriving at the router are forwarded based on the information held in the routing table.

Link-State Protocol Operation

- Link-state routing protocols generate routing updates only when a change occurs in the network topology.
- When a link changes state, the device that detected the change creates a Link-State Advertisement (LSA) concerning that link.
  - LSA propagates to neighbor devices using a special multicast address.
- Each router stores the LSA, forwards the LSA to neighboring devices and updates its Link-State DataBase (LSDB).
- Link-state routers find the best paths to a destination by applying Dijkstra's algorithm, also known as SPF, against the LSDB to build the SPF tree.
- Each router selects the best paths from their SPF tree and places them in their routing table.



Link-State Advertisement (LSA)

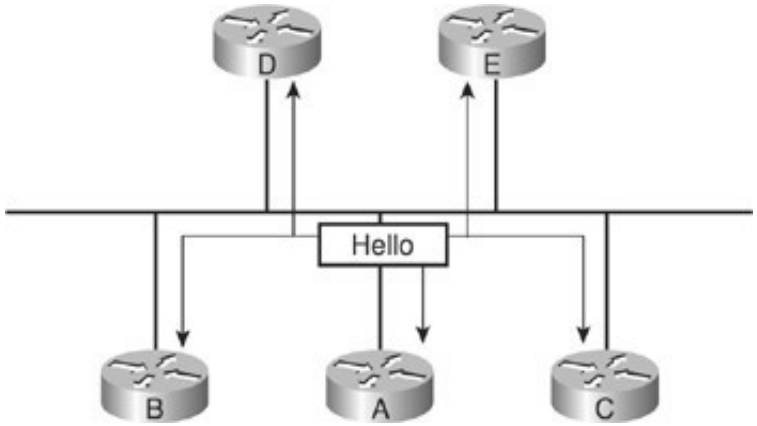
- LSAs report the state of routers and the links between routers.
- Link-state information must be synchronized between routers.
- LSAs have the following characteristics:
  - LSAs are reliable. There is a method for acknowledging their delivery.
  - LSAs are flooded throughout the area (or throughout the domain if there is only one area).
  - LSAs have a sequence number and a set lifetime, so each router recognizes that it has the most current version of the LSA.
  - LSAs are periodically refreshed to confirm topology information before they age out of the LSDB.

OSPF Router ID (RID)

- The Router ID identifies the router and is:
  - The highest IPv4 address of all router interfaces at the moment of the OSPF process activation.
  - A value administratively defined.
- If a physical interface address is being used as the router ID, and that physical interface fails, and the router (or OSPF process) is restarted, the router ID will change.
  - This change in router ID makes it more difficult for network administrators to troubleshoot and manage OSPF.
- Administratively defining the RID or using loopback interfaces for the router ID forces the router ID to stay the same, regardless of the state of the physical interfaces.

OSPF Adjacencies

- A router running a link-state routing protocol must first establish neighbor adjacencies, by exchanging hello packets with the neighboring routers
- The router sends and receives Hello packets to and from its neighboring routers.
  - The destination address is typically a multicast address.
  - It is possible to define unicast OSPF relations.



- The routers exchange hello packets subject to protocol-specific parameters, such as checking whether the neighbor is in the same area, using the same hello interval, and so on.
  - Routers declare the neighbor up when the exchange is complete.
- Two OSPF routers on a point-to-point serial link, usually encapsulated in High-Level Data Link Control (HDLC) or Point-to-Point Protocol (PPP), form a full adjacency with each other.
- However, OSPF routers on broadcast networks, such as LAN links, elect one router as the designated router (DR) and another as the backup designated router (BDR).
  - All other routers on the LAN form full adjacencies with these two routers and pass LSAs only to them.

DR and BDR Election

- The first OSPF router to boot becomes the Designated Router (DR).
- The second router to boot becomes the Backup Designated Router (BDR).
- If multiple routers boot simultaneously,
  - The DR it will be the router with the highest priority. The BDR the second.
    - The OSPF priority is a administratively defined parameter.
  - In case of tie, it will be chosen the router with the highest Router ID (RID).
- When the DR fails, the BDR assumes the role of DR.
  - The BDR does not perform any DR functions when the DR is operating.
  - The choice of the new BDR is done according to some criteria of the initial election.
- After the election, the DR and BDR maintain that role, independently of which routers join the OSPF process.
- The ID of an OSPF Network is the IP address of the network's Designated Router (DR) interface.

OSPF LS Database

- The OSPF database (LSDB) is organized in two tables.
  - Router Link States – Routers related information table.
    - The routers are identified by theirs RID.
  - Net Link States – Networks/Links related information table.
    - Networks are identified by their ID.

```
          OSPF Router with ID (20.20.20.1) (Process ID 1)

         Router Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum Link count
20.20.20.1      20.20.20.1      40          0x8000000A 0x00E7FB 2
30.30.30.2      30.30.30.2      69          0x80000006 0x002906 2
30.30.30.3      30.30.30.3      41          0x80000007 0x00283D 2

         Net Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum
10.10.10.3      30.30.30.3      41          0x80000001 0x00051C
20.20.20.2      30.30.30.2      70          0x80000001 0x00A164
30.30.30.3      30.30.30.3      154         0x80000001 0x00A91C
```

OSPF LS Database Tables (1)

- Router Link States
  - For each router, it contains the information about the networks directly connected to that router.

```
LS age: 321
Options: (No TOS-capability, DC)
LS Type: Router Links
Link State ID: 20.20.20.1
Advertising Router: 20.20.20.1
LS Seq Number: 8000000A
Checksum: 0xE7FB
Length: 48
Number of Links: 2

  Link connected to: a Transit Network
   (Link ID) Designated Router address: 20.20.20.2
   (Link Data) Router Interface address: 20.20.20.1
    Number of TOS metrics: 0
     TOS 0 Metrics: 1

  Link connected to: a Transit Network
   (Link ID) Designated Router address: 10.10.10.3
   (Link Data) Router Interface address: 10.10.10.1
    Number of TOS metrics: 0
     TOS 0 Metrics: 1
```

Router ID

Number of Links

Network Type

Network ID

Interface IP Address

Interface Cost

OSPF LS Database Tables (2)

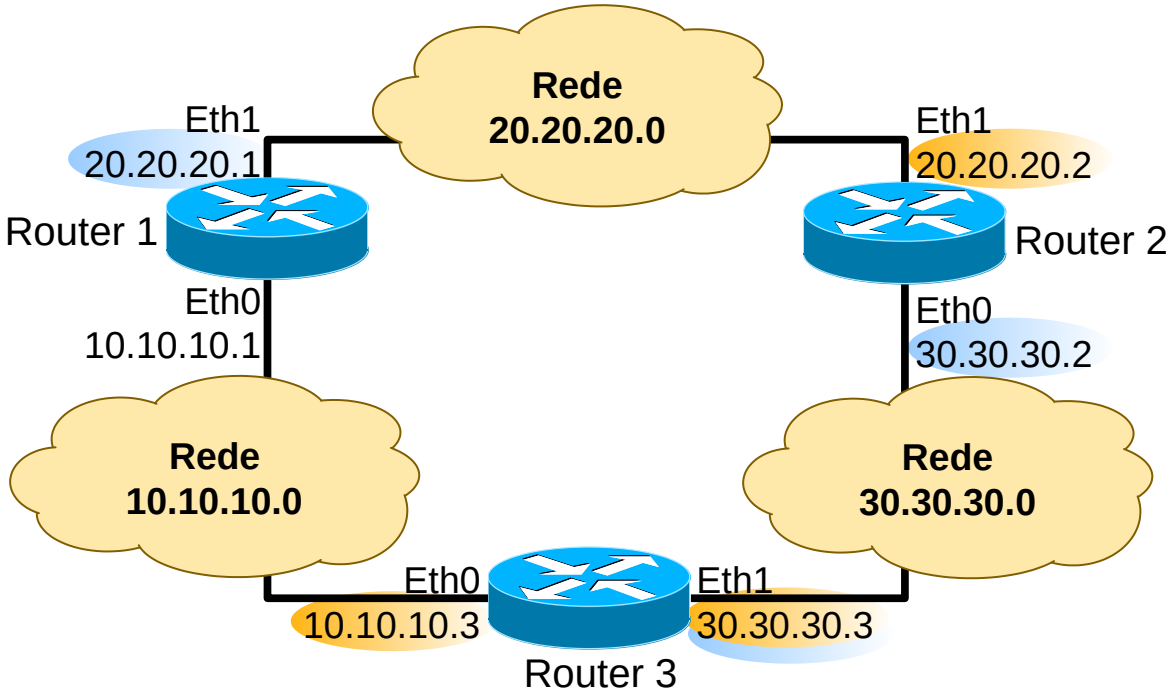
- Network Link States
  - For each network, it contains the information about the routers directly attached to that network.

```
Routing Bit Set on this LSA
LS age: 483
Options: (No TOS-capability, DC)
LS Type: Network Links
Link State ID: 10.10.10.3 (address of Designated Router)
Advertising Router: 30.30.30.3
LS Seq Number: 80000001
Checksum: 0x51C
Length: 32
Network Mask: /24
  Attached Router: 30.30.30.3
  Attached Router: 20.20.20.1
```

Network ID

Attached routers (RID)

OSPF LSDatabase Example




```
 Routing Bit Set on this LSA
  LS age: 208
  Options: (No TOS-capability, DC)
  LS Type: Network Links
  Link State ID: 20.20.20.2 (address of Designated
Router)
  Advertising Router: 30.30.30.2
  LS Seq Number: 80000001
  Checksum: 0xA164
  Length: 32
  Network Mask: /24
Attached Router: 30.30.30.2
Attached Router: 20.20.20.1
```

Network 20.20.20.0's Network Link State

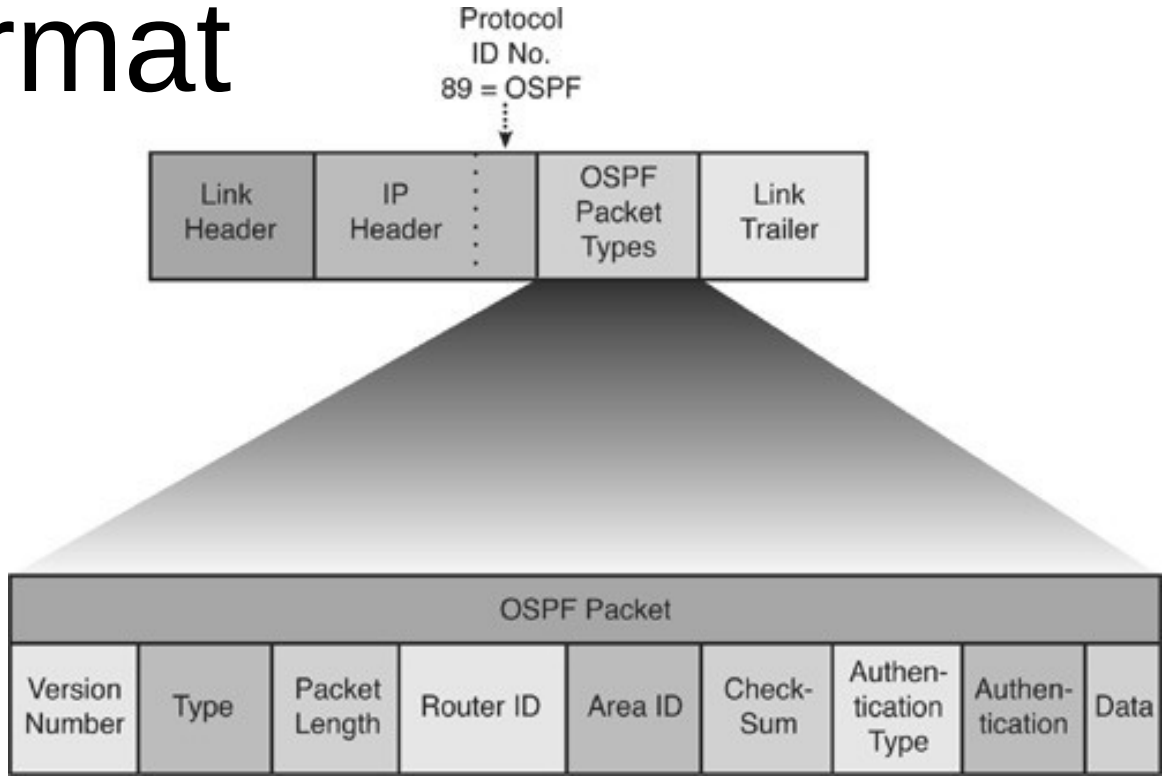
```
LS age: 321
 Options: (No TOS-capability, DC)
 LS Type: Router Links
 Link State ID: 20.20.20.1
 Advertising Router: 20.20.20.1
 LS Seq Number: 8000000A
 Checksum: 0xE7FB
 Length: 48
 Number of Links: 2

   Link connected to: a Transit Network
    (Link ID) Designated Router address: 20.20.20.2
    (Link Data) Router Interface address: 20.20.20.1
     Number of TOS metrics: 0
      TOS 0 Metrics: 1

   Link connected to: a Transit Network
    (Link ID) Designated Router address: 10.10.10.3
    (Link Data) Router Interface address: 10.10.10.1
     Number of TOS metrics: 0
      TOS 0 Metrics: 1
```

Router 1's Router Link State

OSPF Packets

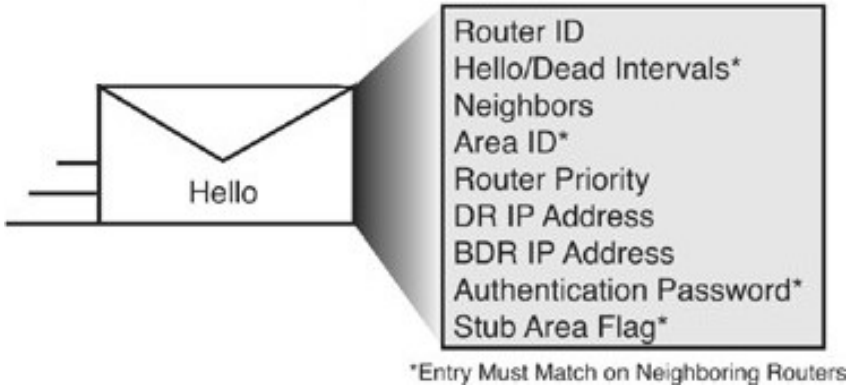
- Hello - Discovers neighbors and builds adjacencies between them.
- Database Description (DBD) - Checks for database synchronization between routers.
- Link-State Request (LSR) - Requests specific link-state records from another router.
- Link-State Update (LSU) - Sends specifically requested link-state records.
- LSAck - Acknowledges the other packet types.

OSPF Packet Format



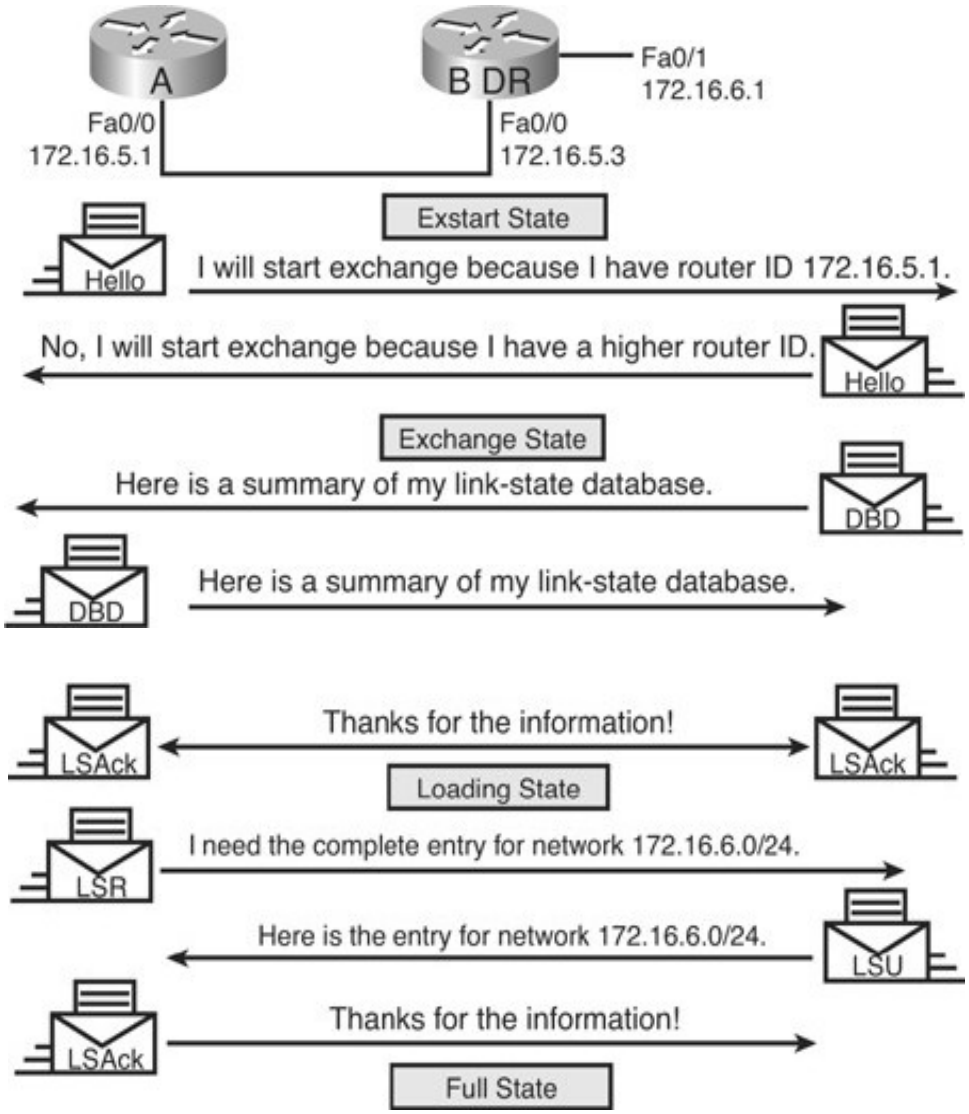
- Version Number
  - Set to 2 for OSPF Version 2, the IPv4 version of OSPF.
  - Set to 3 for OSPF Version 3, the IPv6 version of OSPF.
- Type
  - Differentiates the five OSPF packet types.
- Packet Length
  - The length of the OSPF packet in bytes.
- Router ID
  - Defines which router is the packet's source.
- Area ID
  - Defines the area in which the packet originated.
- Checksum
  - Used for packet header error detection to ensure that the OSPF packet was not corrupted during transmission.
- Authentication Type
  - An option in OSPF that describes either no authentication, clear-text passwords, or encrypted message digest 5 (MD5) for router authentication.
- Authentication
  - Used with authentication type.
- Data, contains different information, depending on the OSPF packet type:
  - For the Hello packet - Contains a list of known neighbors.
  - For the DBD packet - Contains a summary of the LSDB, which includes all known router Ids and their last sequence number, among several other fields.
  - For the LSR packet - Contains the type of LSU needed and the router ID of the router that has the needed LSU.
  - For the LSU packet - Contains the full LSA entries. Multiple LSA entries can fit in one OSPF update packet.
  - For the LSAck packet - This data field is empty.

OSPF Hello Packets



- An hello packet contains the following information:
  - Router ID
    - A 32-bit number that uniquely identifies the router.
  - Hello and dead intervals
    - The hello interval specifies how often, in seconds, a router sends hello packets (10 seconds is the default on multiaccess networks).
    - The dead interval is the amount of time in seconds that a router waits to hear from a neighbor before declaring the neighbor router out of service (the dead interval is four times the hello interval by default).
    - These timers must be the same on neighboring routers; otherwise an adjacency will not be established.
  - Neighbors
    - The Neighbors field lists the adjacent routers with which this router has established bidirectional communication.
    - Bidirectional communication is indicated when the router sees itself listed in the Neighbors field of the hello packet from the neighbor.
  - Area ID
    - To communicate, two routers must share a common segment, and their interfaces must belong to the same OSPF area on that segment.
    - These routers will all have the same link-state information for that area.
  - Router priority
    - An 8-bit number that indicates a router's priority. Priority is used when electing a DR and BDR.
  - DR and BDR IP addresses
    - If known, the IP addresses of the DR and BDR for the specific multiaccess network.
  - Authentication password
    - If router authentication is enabled, two routers must exchange the same password.
    - Authentication is not required, but if it is enabled, all peer routers must have the same password.
  - Stub area flag
    - A stub area is a special area.
    - The stub area technique reduces routing updates by replacing them with a default route.
    - Two neighboring routers must agree on the stub area flag in the hello packets.
- Hello Interval, Dead Interval, Area ID, Authentication Password and Stub Area Flag fields must match on neighboring routers for them to establish an adjacency.

Discovering the Network Routes



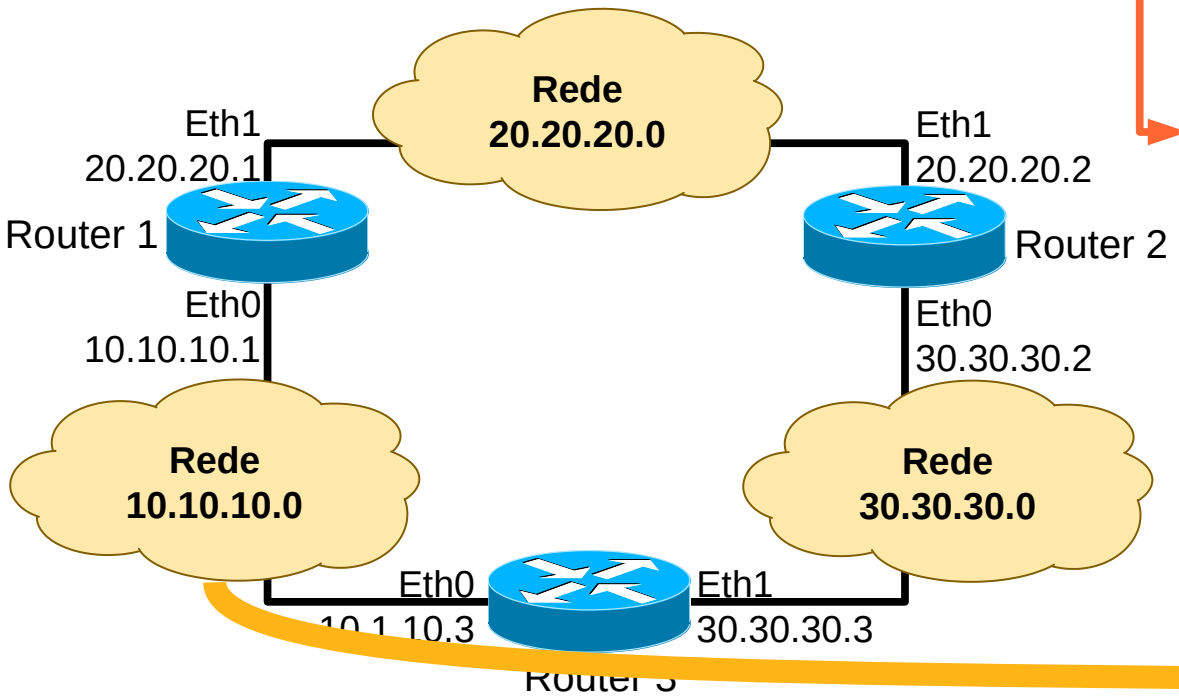
- A master and slave relationship is created between each router and its adjacent DR and BDR.
  - Only the DR exchanges and synchronizes link-state information with the routers to which it has established adjacencies.
- The master and slave routers exchange one or more DBD packets.
  - A DBD includes information about the LSA entry header that appears in the router's LSDB.
  - The entries can be about a link or about a network.
  - Each LSA entry header includes information about the link-state type, the address of the advertising router, the link's cost, and the sequence number.
  - The router uses the sequence number to determine the "newness" of the received link-state information.
- It acknowledges the receipt of the DBD using the LSAck packet.
  - It compares the information it received with the information it has in its own LSDB.
- If the DBD has a more current link-state entry, the router sends an LSR to the other router.
- The other router responds with the complete information about the requested entry in an LSU packet.
- Again, when the router receives an LSU, it sends an LSAck.
- The router adds the new link-state entries to its LSDB.

OSPF Example

OSPF activated on Router 1

OSPF activated on Router 3

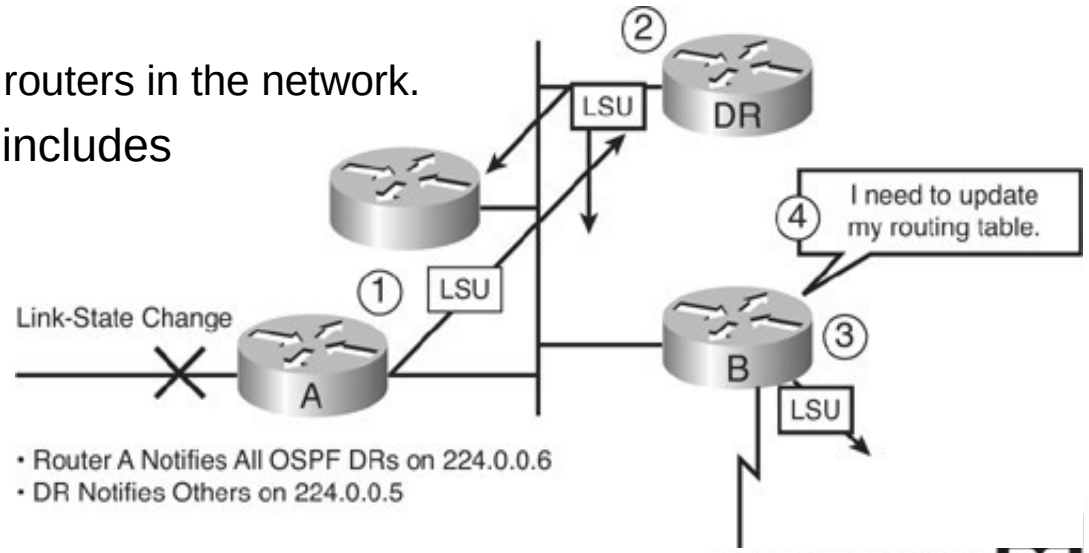
OSPF activated on Router 2



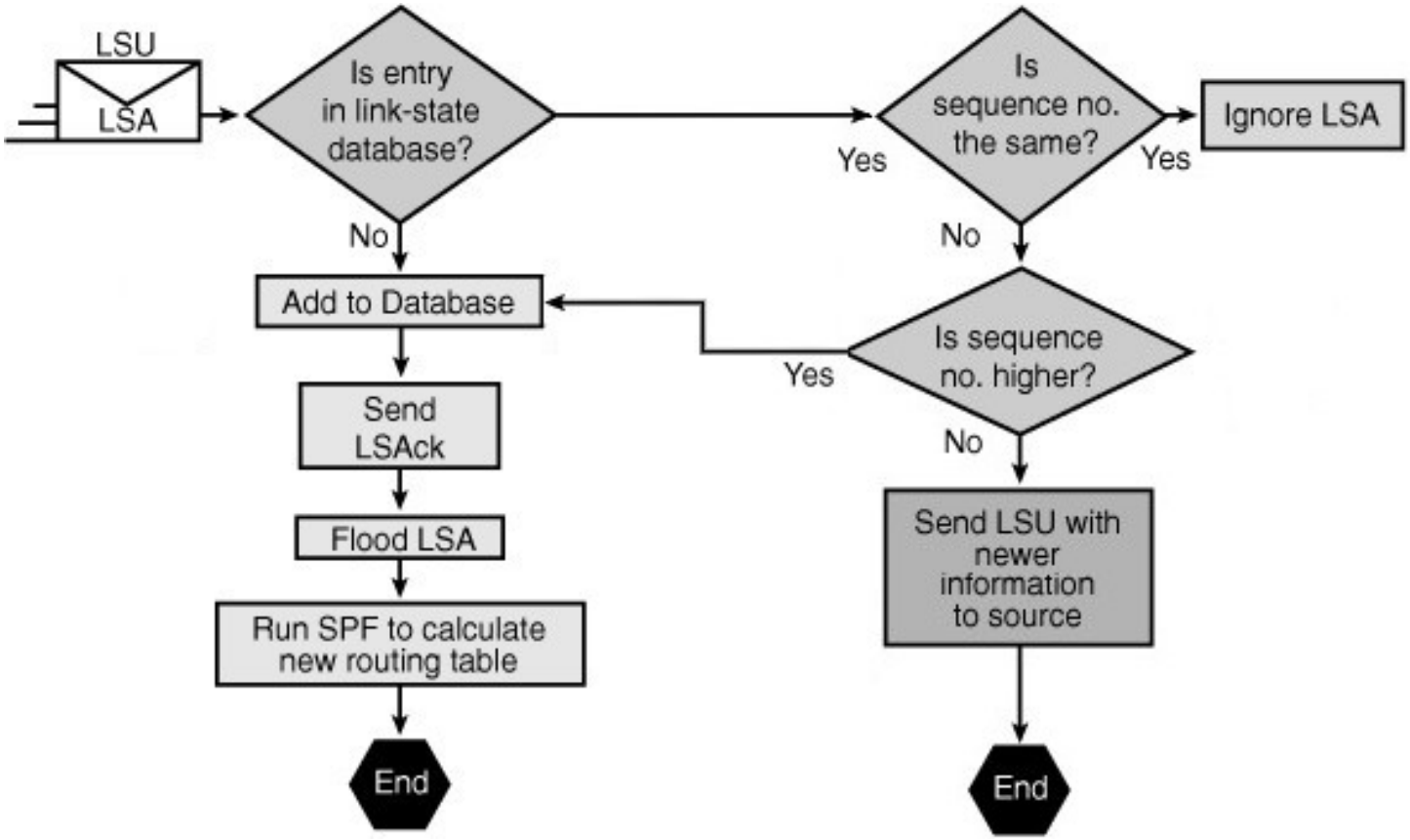

```
     Time  Source        Destination   Protocol Info
  0.000000 10.10.10.1      224.0.0.5   OSPF  Hello Packet
 10.002318 10.10.10.1      224.0.0.5   OSPF  Hello Packet
 20.003116 10.10.10.1      224.0.0.5   OSPF  Hello Packet
----------
 80.000000 10.10.10.3      224.0.0.5   OSPF  Hello Packet
 83.683033 10.10.10.3      224.0.0.5   OSPF  LS Update
 83.715683 10.10.10.3      224.0.0.5   OSPF  Hello Packet
 83.717864 10.10.10.1      10.10.10.3  OSPF  Hello Packet
 83.726166 10.10.10.3      10.10.10.1  OSPF  DB Descr.
 83.726258 10.10.10.3      10.10.10.1  OSPF  Hello Packet
 83.728433 10.10.10.1      10.10.10.3  OSPF  DB Descr.
 83.732590 10.10.10.3      10.10.10.1  OSPF  DB Descr.
 83.734733 10.10.10.1      10.10.10.3  OSPF  DB Descr.
 83.738942 10.10.10.3      10.10.10.1  OSPF  LS Request
 83.741083 10.10.10.1      10.10.10.3  OSPF  LS Update
 84.240362 10.10.10.3      224.0.0.5   OSPF  LS Update
 86.245792 10.10.10.3      224.0.0.5   OSPF  LS Acknowledge
 86.380876 10.10.10.1      224.0.0.5   OSPF  Hello Packet
 86.741036 10.10.10.1      224.0.0.5   OSPF  LS Acknowledge
 93.721376 10.10.10.3      224.0.0.5   OSPF  Hello Packet
 96.380005 10.10.10.1      224.0.0.5   OSPF  Hello Packet
----------
213.780338 10.10.10.3      224.0.0.5   OSPF  Hello Packet
216.542473 10.10.10.1      224.0.0.5   OSPF  Hello Packet
216.568852 10.10.10.1      224.0.0.5   OSPF  LS Update
217.048427 10.10.10.1      224.0.0.5   OSPF  LS Update
217.084909 10.10.10.1      224.0.0.5   OSPF  LS Update
219.067748 10.10.10.3      224.0.0.5   OSPF  LS Acknowledge
219.650308 10.10.10.1      224.0.0.5   OSPF  LS Update
222.150349 10.10.10.3      224.0.0.5   OSPF  LS Acknowledge
223.779492 10.10.10.3      224.0.0.5   OSPF  Hello Packet
224.284149 10.10.10.3      224.0.0.5   OSPF  LS Update
224.789598 10.10.10.1      224.0.0.5   OSPF  LS Update
224.789775 10.10.10.3      224.0.0.5   OSPF  LS Update
226.545718 10.10.10.1      224.0.0.5   OSPF  Hello Packet
226.785254 10.10.10.1      224.0.0.5   OSPF  LS Acknowledge
227.294756 10.10.10.3      224.0.0.5   OSPF  LS Acknowledge
233.779863 10.10.10.3      224.0.0.5   OSPF  Hello Packet
236.544658 10.10.10.1      224.0.0.5   OSPF  Hello Packet
```

Maintaining Routing Information

- Flooding process:
  - A router notices a change in a link state and multicasts an LSU packet, which includes the updated LSA entry with the sequence number incremented, to 224.0.0.6.
    - This address goes to all OSPF DRs and BDRs.
    - On point-to-point links, the LSU is multicast to 224.0.0.5.)
    - An LSU packet might contain several distinct LSAs.
  - The DR receives the LSU, processes it, acknowledges the receipt of the change and floods the LSU to other routers on the network using the OSPF multicast address 224.0.0.5.
    - After receiving the LSU, each router responds to the DR with an LSAck.
    - To make the flooding procedure reliable, each LSA must be acknowledged separately.
  - If a router is connected to other networks, it floods the LSU to those other networks by forwarding the LSU to the DR of the other network (or to the adjacent router if in a point-to-point network).
    - That DR, in turn, multicasts the LSU to the other routers in the network.
  - The router updates its LSDB using the LSU that includes the changed LSA.
  - It then recomputes the SPF algorithm against the updated database after a short delay and updates the routing table as necessary.



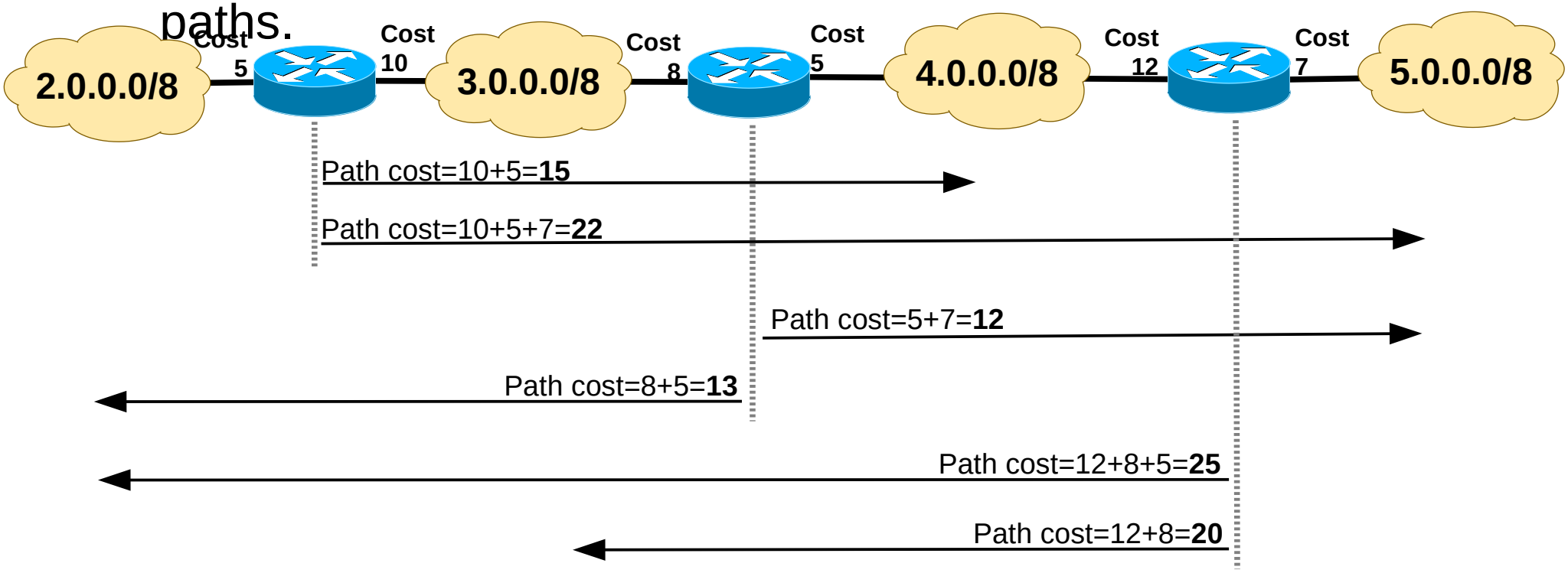
LSA Operation



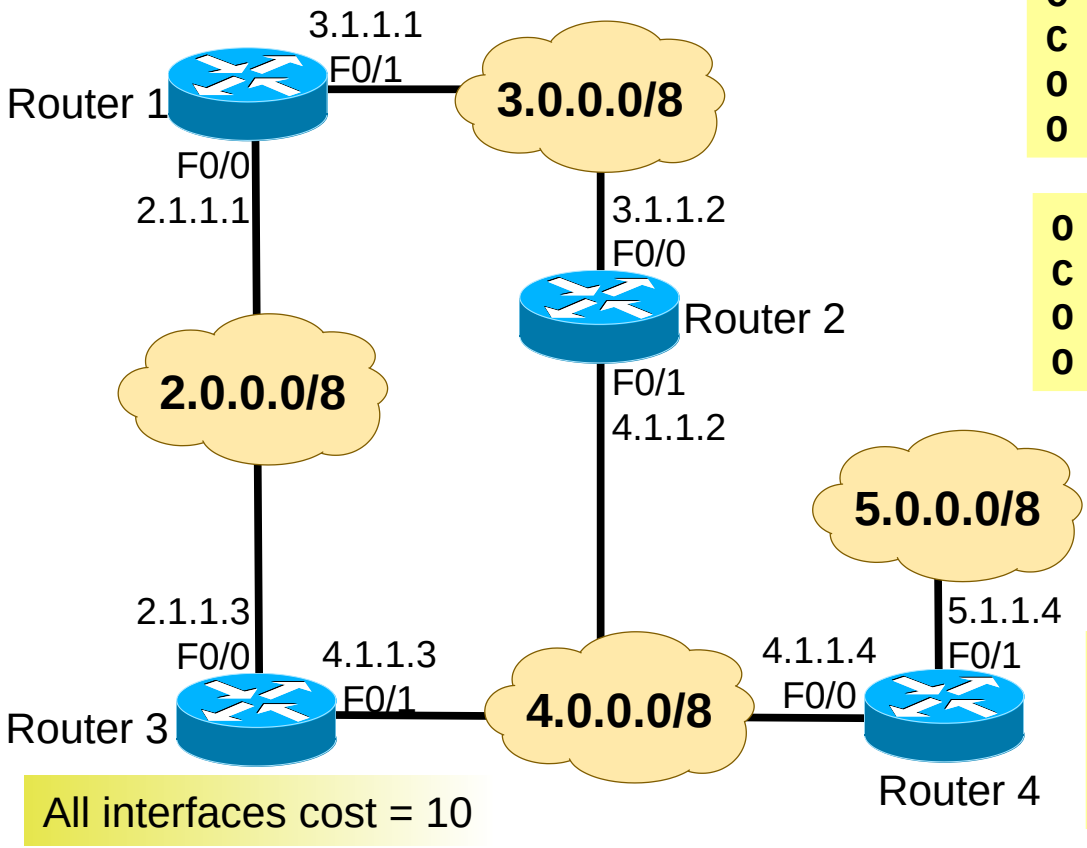
- When each router receives the LSU:
  - If the LSA entry does not already exist, the router adds the entry to its LSDB, sends back a link-state acknowledgment (LSAck), floods the information to other routers, runs SPF, and updates its routing table.
  - If the entry already exists and the received LSA has the same sequence number, the router ignores the LSA entry.
  - If the entry already exists but the LSA includes newer information (it has a higher sequence number), the router adds the entry to its LSDB, sends back an LSAck, floods the information to other routers, runs SPF, and updates its routing table.
  - If the entry already exists but the LSA includes older information, it sends an LSU to the sender with its newer information.

OSPF Path Costs

- Each router link/interface has an associated OSPF cost.
- The total cost between a router and a network is given by the sum of all OSPF costs of the (routers) output interfaces along the path.
  - Routers to access directly connect networks never use OSPF paths.



OSPF Example




```
C  2.0.0.0/8 is directly connected, F0/0
C  3.0.0.0/8 is directly connected, F0/1
O  4.0.0.0/8 [110/20] via 2.1.1.3, 00:01:18, F0/0
O  5.0.0.0/8 [110/30] via 2.1.1.3, 00:01:00, F0/0
```

```
O  2.0.0.0/8 [110/20] via 3.1.1.1, 00:01:13, F0/0
C  3.0.0.0/8 is directly connected, F0/0
O  4.0.0.0/8 [110/30] via 3.1.1.1, 00:01:13, F0/0
O  5.0.0.0/8 [110/40] via 3.1.1.1, 00:01:10, F0/0
```

Router 1 and Router 2 after disconnecting the F0/1 at Router2

```
C  2.0.0.0/8 is directly connected, F0/0
C  3.0.0.0/8 is directly connected, F0/1
O  4.0.0.0/8 [110/15] via 3.1.1.2, 00:01:13, F0/1
O  5.0.0.0/8 [110/25] via 3.1.1.2, 00:01:10, F0/1
```

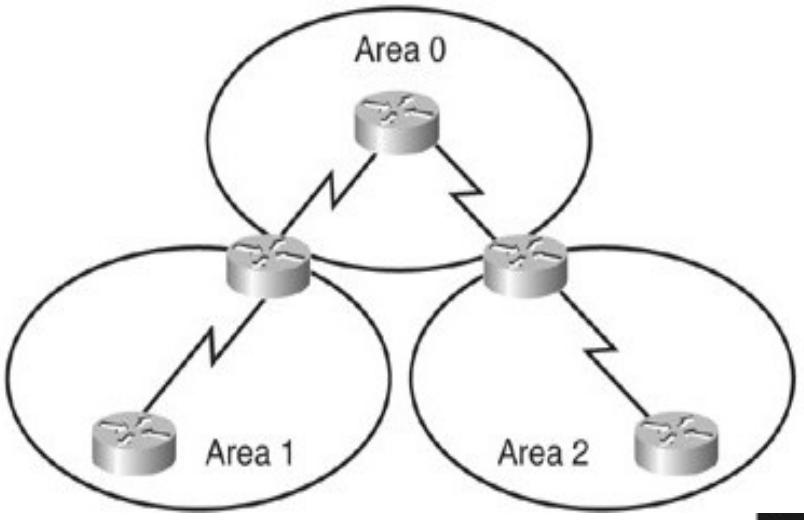
Router1, now with the cost of Router2 F0/1 interface equal to 5

```
C  2.0.0.0/8 is directly connected, F0/0
C  3.0.0.0/8 is directly connected, F0/1
O  4.0.0.0/8 [110/20] via 3.1.1.2, 00:01:13, F0/1
             [110/20] via 2.1.1.3, 00:01:31, F0/0
O  5.0.0.0/8 [110/30] via 3.1.1.2, 00:01:10, F0/1
             [110/30] via 2.1.1.3, 00:01:10, F0/0
```

Router 1 initial table

OSPF Hierarchical Routing (1)

- In small networks, the web of router links is not complex, and paths to individual destinations are easily deduced.
- In large networks, the resulting web is highly complex, and the number of potential paths to each destination is large.
  - Dijkstra calculations comparing all of these possible routes can be very complex and can take significant time.
    - Large LSDB. Because the LSDB covers the topology of the entire network, each router must maintain an entry for every network in the area, even if not every route is selected for the routing table.
    - Frequent SPF algorithm calculations. In a large network, changes are inevitable, so the routers spend many CPU cycles recalculating the SPF algorithm and updating the routing table.
    - Large routing table. OSPF does not perform route summarization by default. If the routes are not summarized, the routing tables can become very large, depending on the size of the network.
- Link-state routing protocols usually reduce the size of the Dijkstra calculations by partitioning the network into areas.



OSPF Hierarchical Routing (2)

- Using multiple OSPF areas has several important advantages:
  - Reduced frequency of SPF calculations.
    - Detailed route information only exists within each area
    - It is not necessary to flood all link-state changes to all other areas.
    - Only routers that are affected by the change need to recalculate the SPF algorithm and the impact of the change is localized within the area.
  - Reduced updates overhead.
    - Rather than send an update about each network within an area, a router can advertise a single summarized route or a small number of routes between areas, thereby reducing the overhead associated with updates when they cross areas.
  - Smaller routing tables.
    - Detailed route entries for specific networks within an area can remain in the area.
    - Routers can be configured to summarize the routes into one or more summary addresses.
    - Advertising these summaries reduces the number of messages propagated between areas but keeps all networks reachable.

Integrated System-Integrated System (IS-IS) Protocol

- IS-IS was defined in 1992 in the ISO/IEC recommendation 10589.
- IS-IS is a link-state routing protocol.
  - Provides fast convergence and excellent scalability.
  - Very efficient in its use of network bandwidth.
- Uses Dijkstra's Shortest Path First algorithm (SPF).
- Types of packets
  - IS-IS Hello packet (IIH), Link State Packet (LSP), Partial Sequence Number Packet (PSNP) and Complete Sequence Number Packet (CSNP).
- Link States are called LSPs
  - Contain all information about one router adjacencies, connected IP prefixes, OSI end systems, area addresses, etc.
  - One LSP per router (plus fragments).
  - One LSP per LAN network.
- IS-IS has 2 layers of hierarchy
  - The backbone is called level-2.
  - Areas are called level-1.
  - A router can take part in L1 and L2 inter-area routing (or inter-level routing).

Enhanced Interior Gateway Routing Protocol (EIGRP) Protocol

- EIGRP is a Cisco-proprietary protocol that combines the advantages of link-state and distance vector routing protocols.
- EIGRP has its roots as a distance vector routing protocol and is predictable in its behavior.
- What makes EIGRP an advanced distance vector protocol is the addition of several link-state features, such as dynamic neighbor discovery.
  - EIGRP Maintains a Neighbor Table, a Topology Table, and a Routing Table.
- EIGRP has Variable-length subnet masking (VLSM) support.
- Has a sophisticated metric that considers five criteria:
  - Two by default:
    - Bandwidth - The smallest (slowest) bandwidth between the source and destination.
    - Delay - The cumulative interface delay along the path.
  - Available, are not commonly used, because they typically result in frequent recalculation of the topology table:
    - Reliability - The worst reliability between the source and destination, based on keepalives.
    - Loading - The worst load on a link between the source and destination based on the packet rate and the interface's configured bandwidth.
    - Maximum transmission unit (MTU) - The smallest MTU in the path.
- A significant advantage of EIGRP (and IGRP) over other protocols is its support for unequal metric load balancing that allows administrators to better distribute traffic flow in their networks.

RIPng for IPv6 Routing

- Similar to IPv4 RIPv2:
  - Distance-vector concept, radius of 15 hops, infinity metric is 16, split-horizon, triggered update.
- Differences between RIPv2 and RIPng
  - Uses IPv6 for transport.
    - Uses link-local addresses (not the global ones).
  - IPv6 prefix, next-hop IPv6 link-local address.
  - Uses multicast group address FF02::9 (all-RIP-routers) as the destination address for RIP updates.
  - Routers always add the cost of the interface to the metric received.
    - Metric is sum of “output interfaces” costs to destination and not number of hops.
    - If all costs are 1, metric is number of “output interfaces” to destination.
  - Allows for node/interface costs other than 1.
    - Cisco calls it “cost offset” per interface (out or in direction).
    - Cost to network is given by the sum of all output interfaces costs along the path.
    - With the infinity metric value at 16, this require careful configurations.
  - Routers always announce directed connected networks.
  - in IOS Cisco
    - Activation per interface, named process, more than one active process.

IPv6 Routing Tables with RIPng

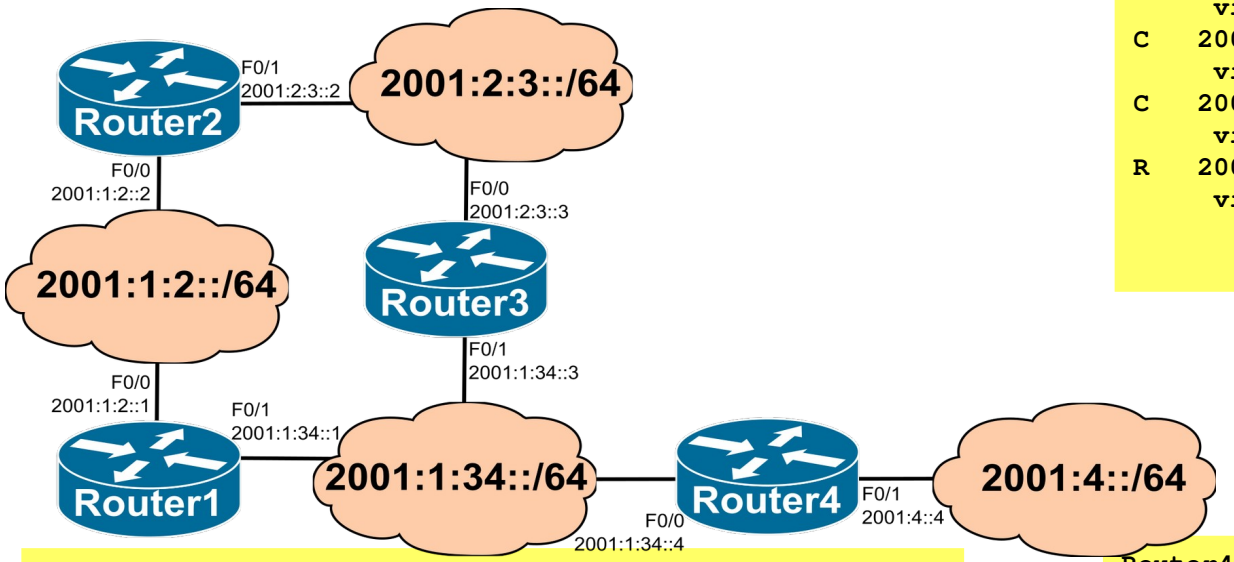
Router2

```
C   2001:1:2::/64 [0/0]
     via FastEthernet0/0, directly connected
R   2001:1:34::/64 [120/2]
     via FE80::C801:54FF:FE41:8, FastEthernet0/0
     via FE80::C803:56FF:FE0A:8, FastEthernet0/1
C   2001:2:3::/64 [0/0]
     via FastEthernet0/1, directly connected
R   2001:4::/64 [120/3]
     via FE80::C801:54FF:FE41:8, FastEthernet0/0
     via FE80::C803:56FF:FE0A:8, FastEthernet0/1
```

Assuming all interfaces with cost 1.

Router3

```
R   2001:1:2::/64 [120/2]
     via FE80::C802:54FF:FEF5:6, FastEthernet0/0
     via FE80::C801:54FF:FE41:6, FastEthernet0/1
C   2001:1:34::/64 [0/0]
     via FastEthernet0/1, directly connected
C   2001:2:3::/64 [0/0]
     via FastEthernet0/0, directly connected
R   2001:4::/64 [120/2]
     via FE80::C804:56FF:FEAD:8, FastEthernet0/1
```



Router1

```
C   2001:1:2::/64 [0/0]
     via FastEthernet0/0, directly connected
C   2001:1:34::/64 [0/0]
     via FastEthernet0/1, directly connected
R   2001:2:3::/64 [120/2]
     via FE80::C802:54FF:FEF5:8, FastEthernet0/0
     via FE80::C803:56FF:FE0A:6, FastEthernet0/1
R   2001:4::/64 [120/2]
     via FE80::C804:56FF:FEAD:8, FastEthernet0/1
```

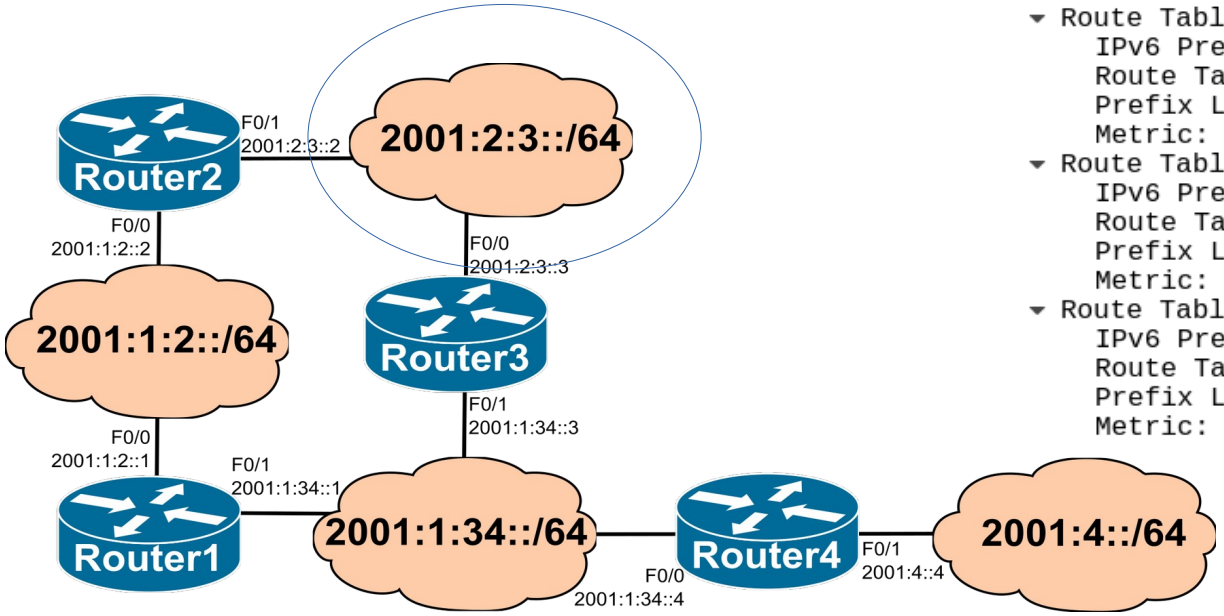
Router4

```
R   2001:1:2::/64 [120/2]
     via FE80::C801:54FF:FE41:6, FastEthernet0/0
C   2001:1:34::/64 [0/0]
     via FastEthernet0/0, directly connected
R   2001:2:3::/64 [120/2]
     via FE80::C803:56FF:FE0A:6, FastEthernet0/0
C   2001:4::/64 [0/0]
     via FastEthernet0/1, directly connected
```

RIPng Messages (Example)

Sent by Router2 with Split-Horizon

```
▸ Internet Protocol Version 6, Src: fe80::c802:54ff:fef5:6, Dst: ff02::9
▸ User Datagram Protocol, Src Port: 521, Dst Port: 521
▾ RIPng
    Command: Response (2)
    Version: 1
    Reserved: 0000
  ▾ Route Table Entry: IPv6 Prefix: 2001:1:2::/64 Metric: 1
      IPv6 Prefix: 2001:1:2::
      Route Tag: 0x0000
      Prefix Length: 64
      Metric: 1
  ▾ Route Table Entry: IPv6 Prefix: 2001:2:3::/64 Metric: 1
      IPv6 Prefix: 2001:2:3::
      Route Tag: 0x0000
      Prefix Length: 64
      Metric: 1
```



Sent by Router3 with Split-Horizon

```
▸ Internet Protocol Version 6, Src: fe80::c803:56ff:fe0a:8, Dst: ff02::9
▸ User Datagram Protocol, Src Port: 521, Dst Port: 521
▾ RIPng
    Command: Response (2)
    Version: 1
    Reserved: 0000
  ▾ Route Table Entry: IPv6 Prefix: 2001:2:3::/64 Metric: 1
      IPv6 Prefix: 2001:2:3::
      Route Tag: 0x0000
      Prefix Length: 64
      Metric: 1
  ▾ Route Table Entry: IPv6 Prefix: 2001:1:34::/64 Metric: 1
      IPv6 Prefix: 2001:1:34::
      Route Tag: 0x0000
      Prefix Length: 64
      Metric: 1
  ▾ Route Table Entry: IPv6 Prefix: 2001:4::/64 Metric: 2
      IPv6 Prefix: 2001:4::
      Route Tag: 0x0000
      Prefix Length: 64
      Metric: 2
```

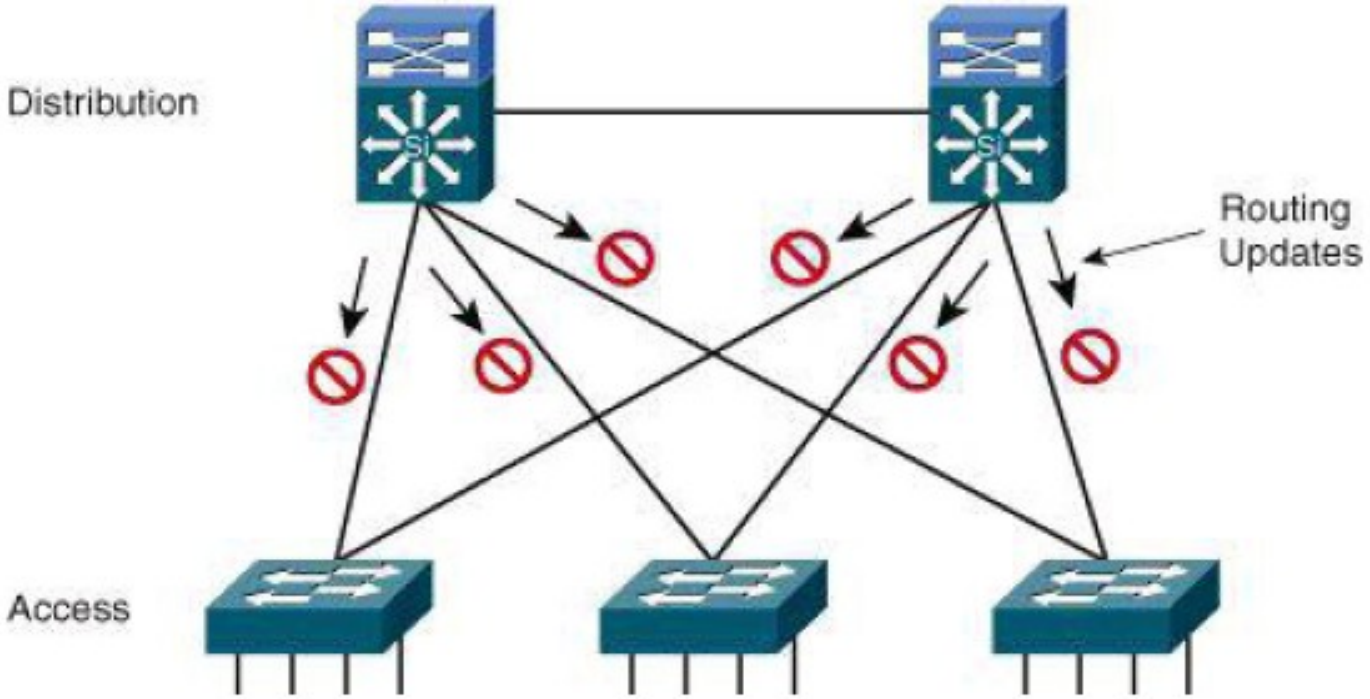
Routing - OSPFv3

- Based on OSPFv2, with enhancements:
  - Uses IPv6 for transport
  - Distributes IPv6 prefixes
  - Uses multicast group addresses FF02::5 (OSPF IGP) and FF02::6 (OSPF IGP Designated Routers)
  - Runs over a link rather than a subnet
  - Multiple instances per link
  - Topology not IPv6-specific
    - Router ID, Area ID, Link ID remain a 4 bytes number
    - Neighbors are always identified by Router ID (4 bytes)
    - With an additional table with mapping between IPv6 prefixes and Link IDs
  - Uses link-local addresses as IPv6 source addresses

OSPFv3 - LSA Types

- Link LSA (Type 8)
  - Informs neighbors of link local address
  - Informs neighbors of IPv6 prefixes on link
- Intra-Area Prefix LSA (Type 9)
  - Associates IPv6 prefixes with a network or router
- Flooding scope for LSAs has been generalized
  - Three flooding scopes for LSAs
    - Link-local
    - Area
    - AS
- LSA Type encoding expanded to 16 bits
  - Includes flooding scope

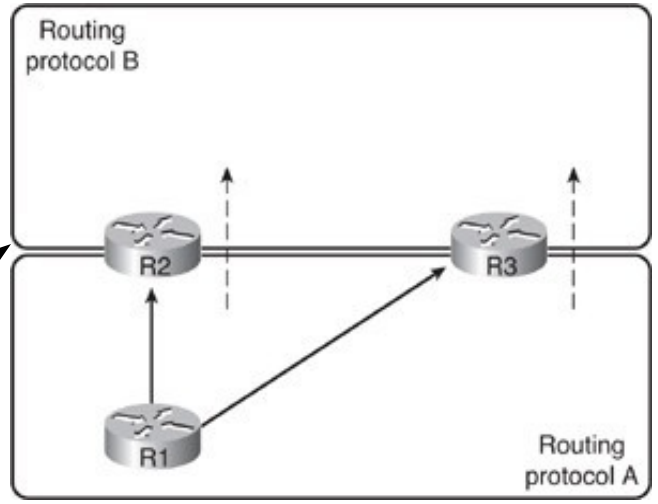
Passive Interfaces on Access Layer

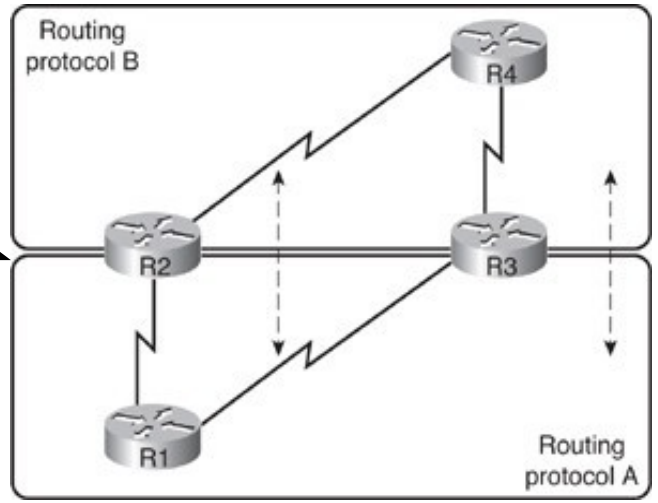


- As a recommended practice, limit unnecessary L3 routing peer adjacencies by configuring the ports toward Layer 2 access switches as passive.
  - Suppress the advertising of routing updates.
  - If a distribution switch does not receive L3 routing updates from a potential peer on a specific interface, it does not form a neighbor adjacency with the potential peer across that interface.

Route Redistribution

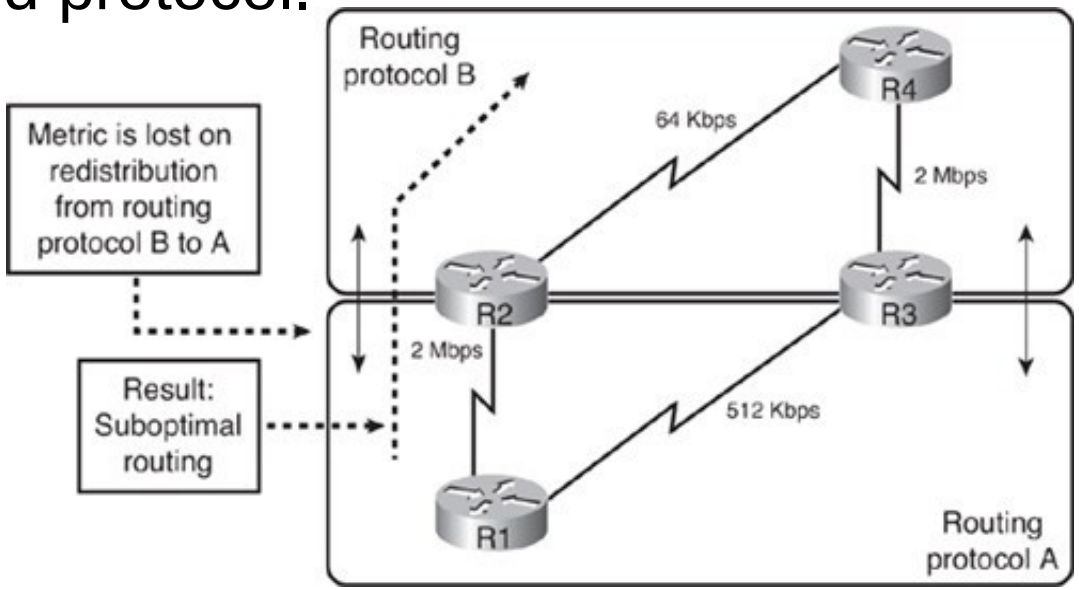
- Domains with difference routing protocols can exchange routes.
  - This is called route redistribution.
    - One-way redistribution - Redistributes only the networks learned from one routing protocol into the other routing protocol.
      - Uses a default or static route so that devices in that other part of the network can reach the first part of the network
    - Two-way redistribution - Redistributes routes between the two routing processes in both directions
  - Static routes can also be redistributed.





Redistribution Issues

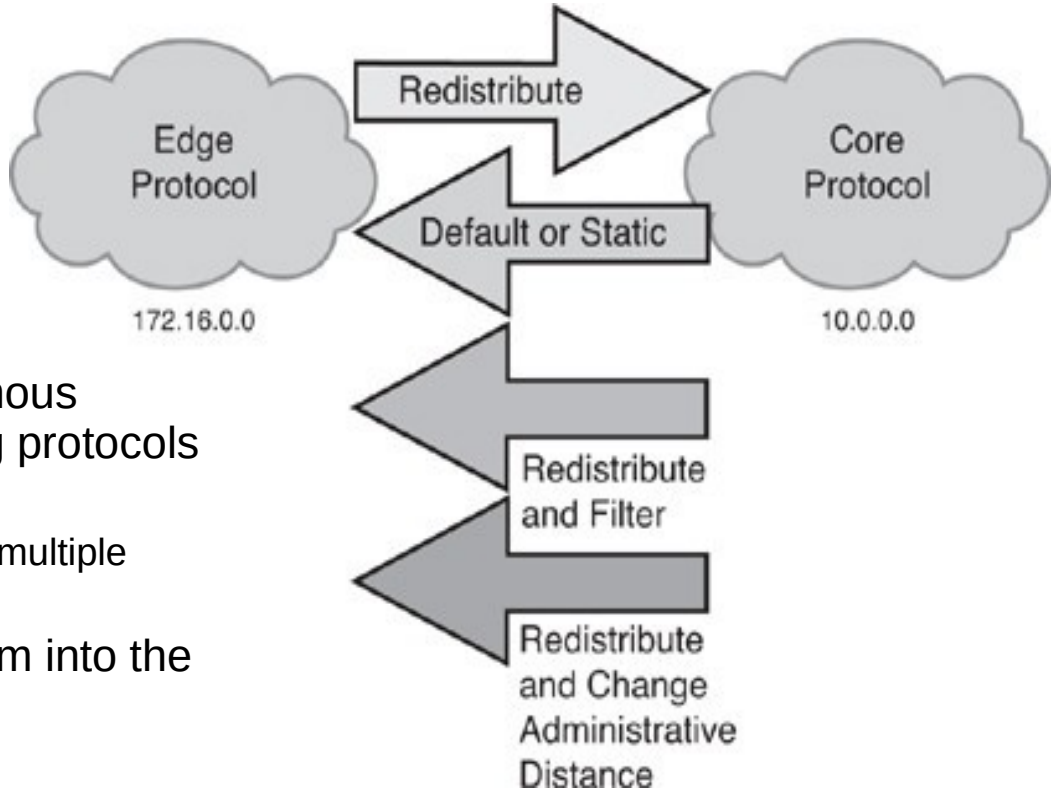
- Lost metric from redistributed protocol.
  - It is not possible to achieve an optimal overall routing.



- Preventing Routing Loops in a Redistribution Environment.
  - Safest way to perform redistribution is to redistribute routes in only one direction, on only one boundary router within the network.
    - However, that this results in a single point of failure in the network.
  - If redistribution must be done in both directions or on multiple boundary routers, the redistribution should be tuned to avoid problems such as suboptimal routing and routing loops.

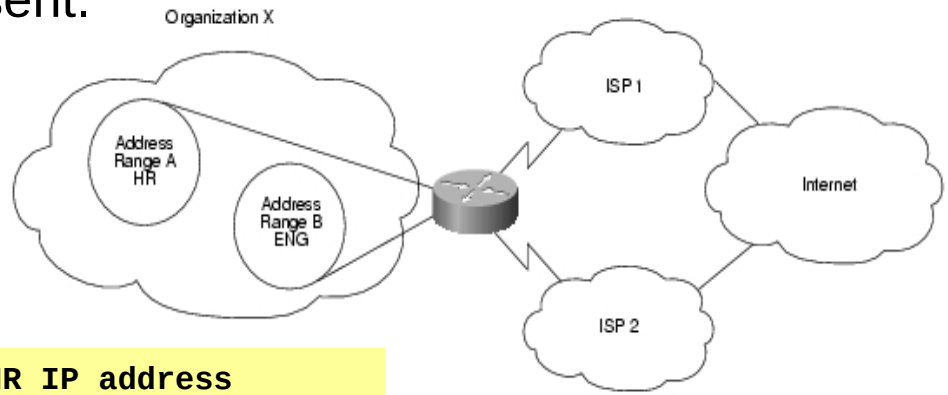
Redistribution Techniques

- Redistribute a default route from the core autonomous system into the edge autonomous system, and redistribute routes from the edge routing protocols into the core routing protocol.
  - This technique helps prevent route feedback, suboptimal routing, and routing loops.
- Redistribute multiple static routes about the core autonomous system networks into the edge autonomous system, and redistribute routes from the edge routing protocols into the core routing protocol.
  - This method works if there is only one redistribution point; multiple redistribution points might cause route feedback.
- Redistribute routes from the core autonomous system into the edge autonomous system with filtering to block out inappropriate routes.
  - For example, when there are multiple boundary routers, routes redistributed from the edge autonomous system at one boundary router should not be redistributed back into the edge autonomous system from the core at another redistribution point.
- Redistribute all routes from the core autonomous system into the edge autonomous system, and from the edge autonomous system into the core autonomous system, and then modify the administrative distance associated with redistributed routes so that they are not the selected routes when multiple routes exist for the same destination.



Policy-Based Routing (PBR)

- PBR allows the operator to define routing policy other than basic destination-based routing using the routing table.
- PBR rules can be used to match source and destination addresses, protocol types, and end-user applications.
- When a match occurs, a set command can be used to define the interface or next-hop address to which the packet should be sent.




```
access-list 1 permit 209.165.200.225        !From HR IP address
access-list 2 permit 209.165.200.226        !From ENG IP address
!
interface ethernet 1
 ip policy route-map ChooseISP
!
route-map ChooseISP permit 10
 match ip address 1
 set ip next-hop 209.165.200.227            !To ISP2 next-hop
!
route-map ChooseISP permit 20
 match ip address 2
 set ip next-hop 209.165.200.228            !To ISP1 next-hop
```

Defines order of the rules