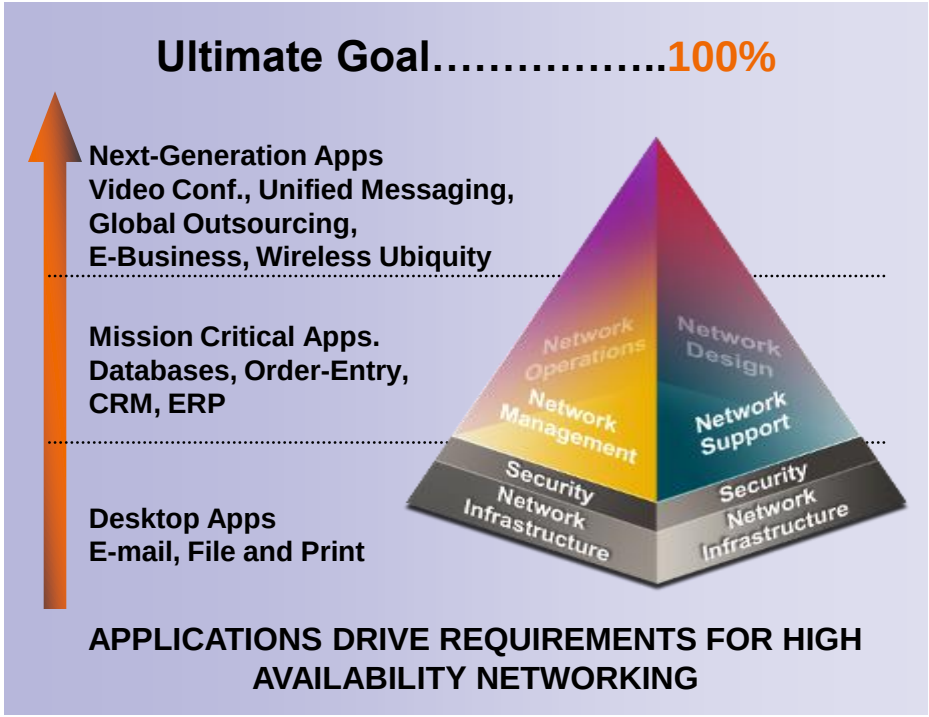
Multilayer Campus Architectures & Design Principles

BRKCRS - 2031

Enterprise-Class Availability

Resilient Campus Communication Fabric

- Network-level redundancy
- System-level resiliency
- Enhanced management
- Human ear notices the difference in voice within 150–200 msec—10 consecutive G711 packet loss
- Video loss is even more noticeable
- 200-msec end-to-end campus convergence



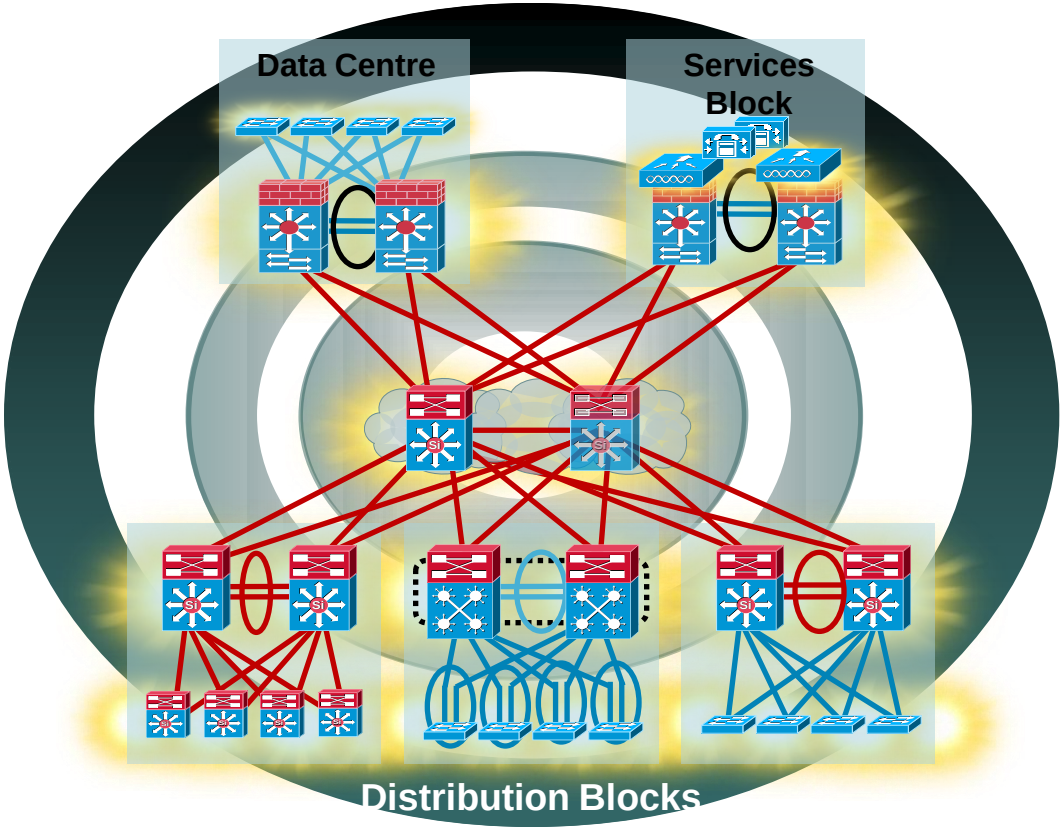
Next-Generation Campus Design

Unified Communications Evolution

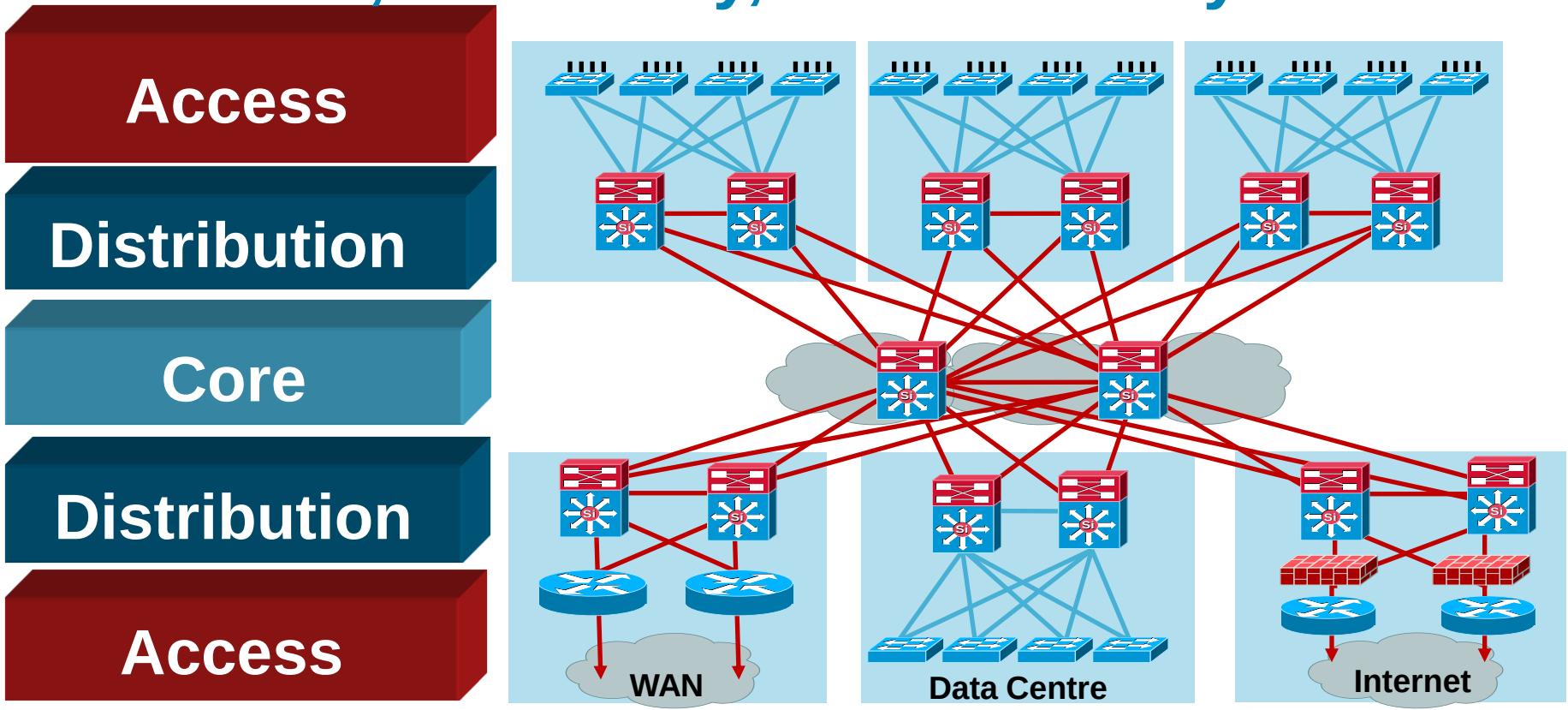
- VoIP is now a mainstream technology
- Ongoing evolution to the full spectrum of Unified Communications
- High-definition executive communication application requires stringent Service-Level Agreement (SLA)
  - –Reliable service—high availability infrastructure
  - –Application service management—QoS

Agenda

- Multilayer Campus Design Principles
- Foundation Services
- Campus Design Best Practices
- VSS Distribution Block
- Security Considerations
- Putting It All Together
- Summary



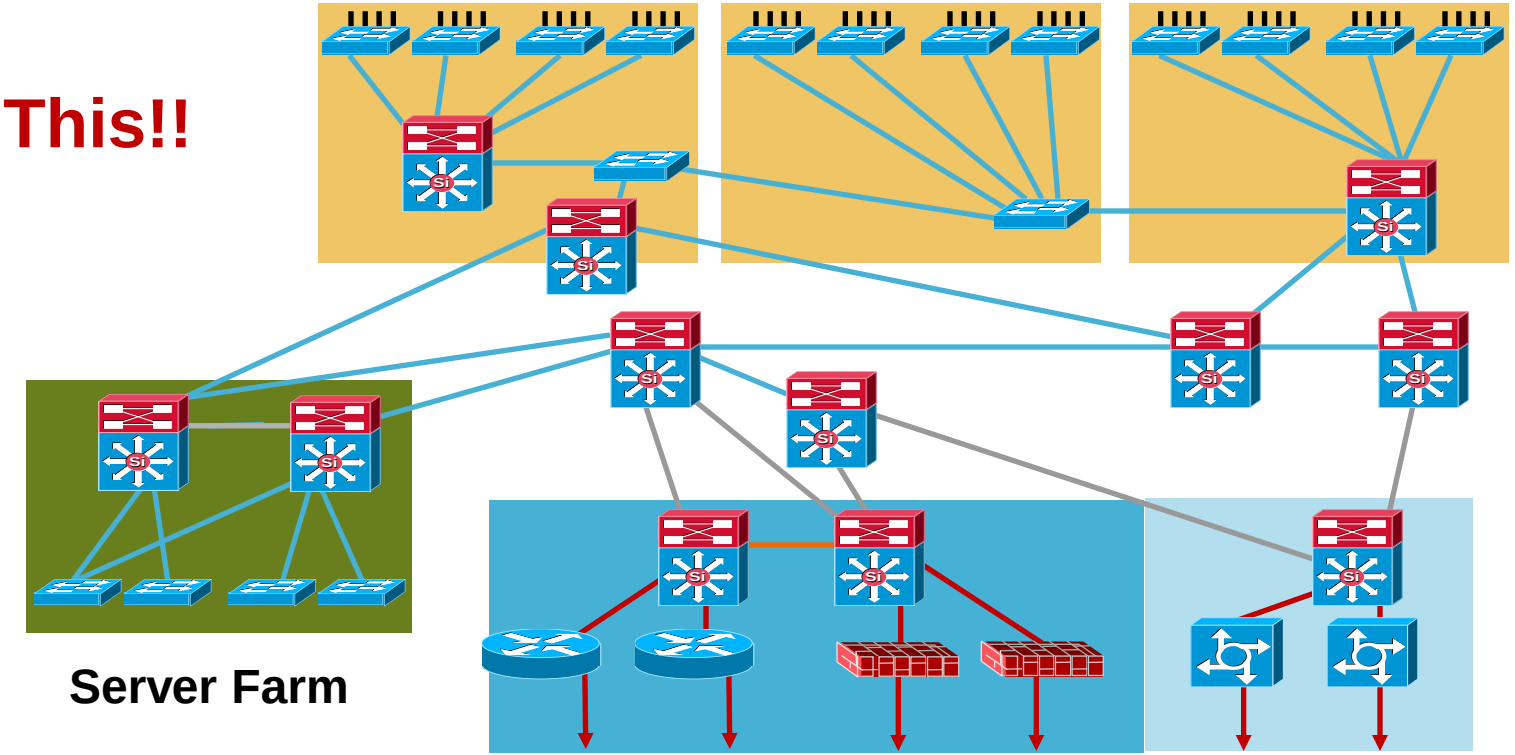
High-Availability Campus Design Structure, Modularity, and Hierarchy



Hierarchical Campus Network

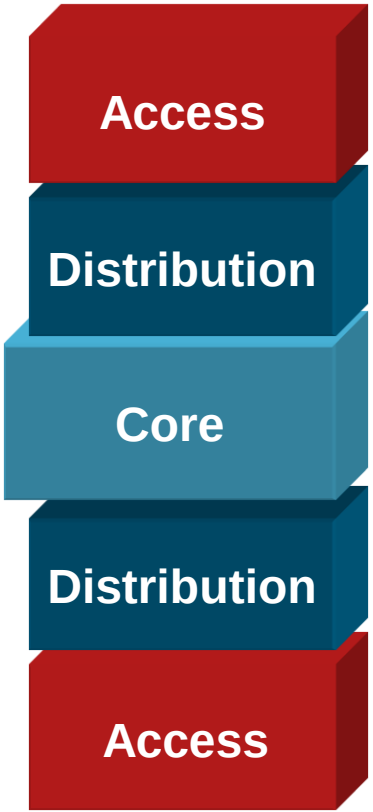
Structure, Modularity and Hierarchy

Not This!!

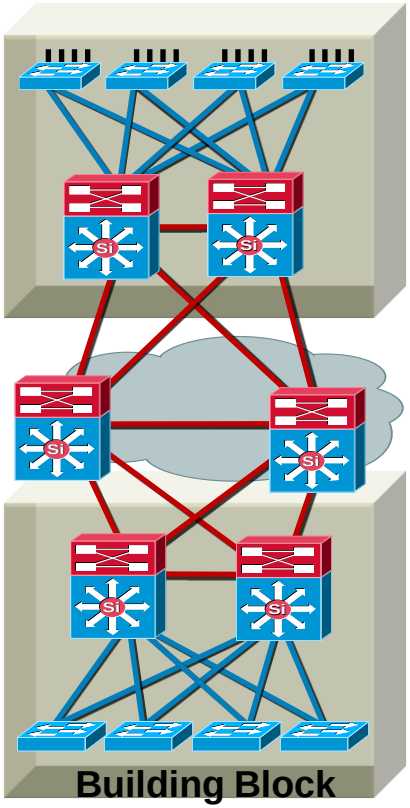


Hierarchical Network Design

Without a Rock Solid Foundation the Rest Doesn't Matter



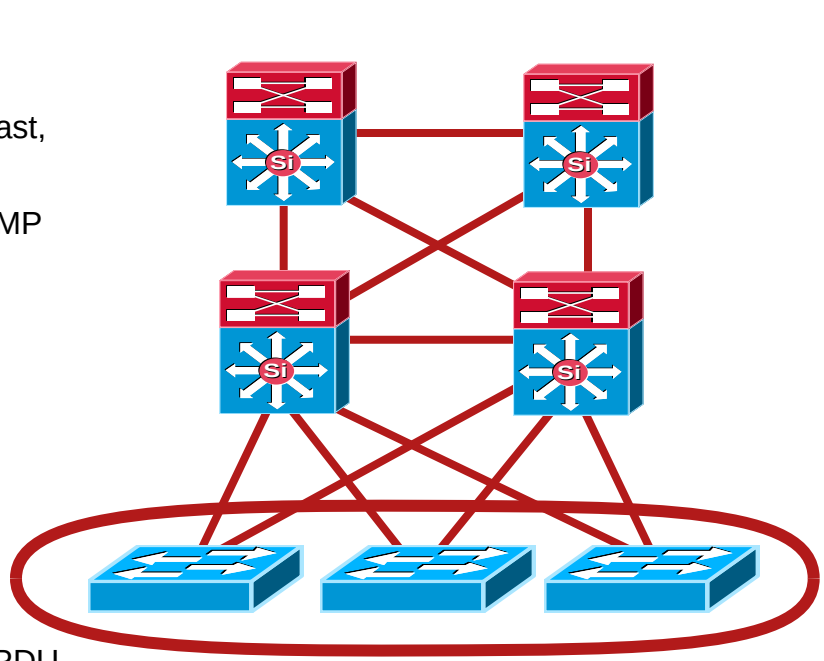
- Offers hierarchy—each layer has specific role
- Modular topology—building blocks
- Easy to grow, understand, and troubleshoot
- Creates small fault domains—clear demarcations and isolation
- Promotes load balancing and redundancy
- Promotes deterministic traffic patterns
- Incorporates balance of both Layer 2 and Layer 3 technology, leveraging the strength of both
- Utilises Layer 3 routing for load balancing, fast convergence, scalability, and control



Access Layer

Feature Rich Environment

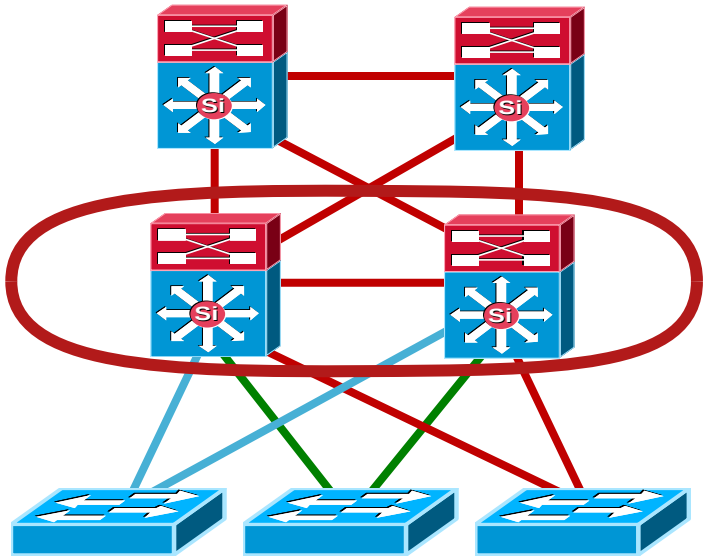
- It's not just about connectivity
- Layer 2/Layer 3 feature rich environment; convergence, HA, security, QoS, IP multicast, etc.
- Intelligent network services: QoS, trust boundary, broadcast suppression, IGMP snooping
- Intelligent network services: PVST+, Rapid PVST+, EIGRP, OSPF, DTP, PAgP/LACP, UDLD, FlexLink, etc.
- Cisco Catalyst® integrated security features IBNS (802.1x), (CISF): port security, DHCP snooping, DAI, IPSG, etc.
- Automatic phone discovery, conditional trust boundary, power over Ethernet, auxiliary VLAN, etc.
- Spanning tree toolkit: PortFast, UplinkFast, BackboneFast, LoopGuard, BPDU Guard, BPDU Filter, RootGuard, etc.



Distribution Layer

Policy, Convergence, QoS, and High Availability

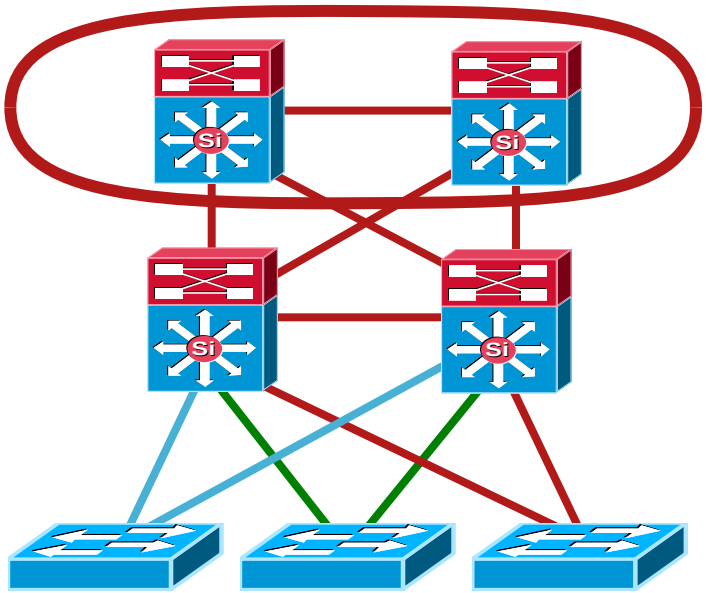
- Availability, load balancing, QoS and provisioning are the important considerations at this layer
- Aggregates wiring closets (access layer) and uplinks to core
- Protects core from high density peering and problems in access layer
- Route summarsiation, fast convergence, redundant path load sharing
- HSRP or GLBP to provide first hop redundancy



Core Layer

Scalability, High Availability, and Fast Convergence

- Backbone for the network—connects network building blocks
- Performance and stability vs. complexity—less is more in the core
- Aggregation point for distribution layer
- Separate core layer helps in scalability during future growth
- Keep the design technology-independent

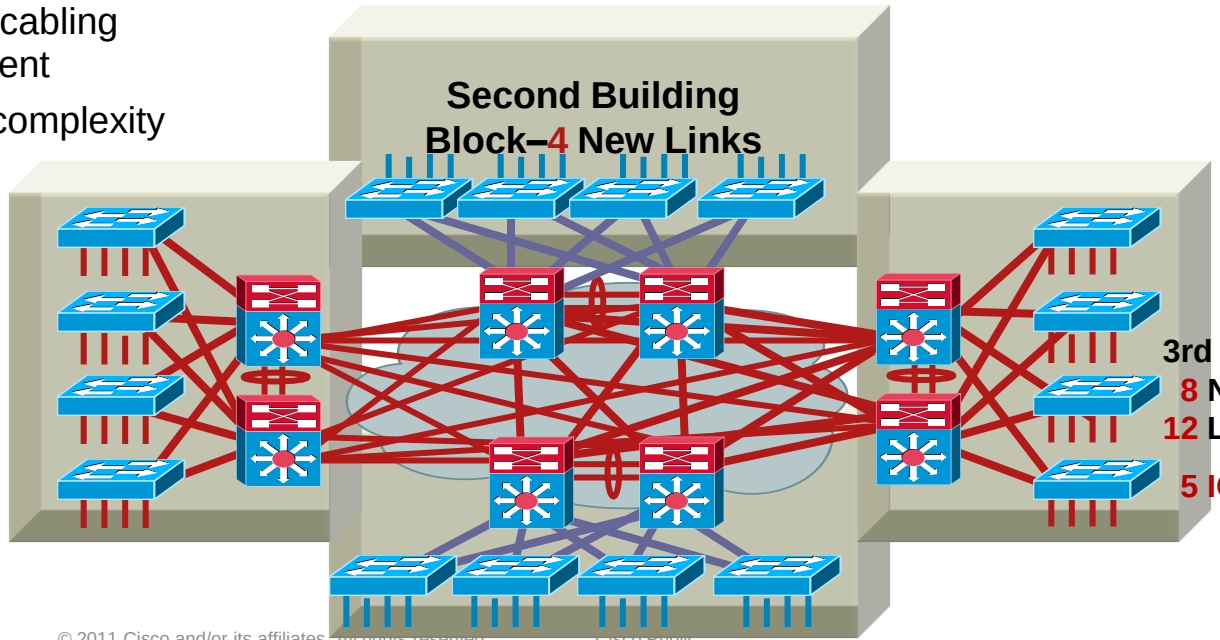


Do I Need a Core Layer?

It's Really a Question of Scale, Complexity, and Convergence

No Core

- Fully-meshed distribution layers
- Physical cabling requirement
- Routing complexity

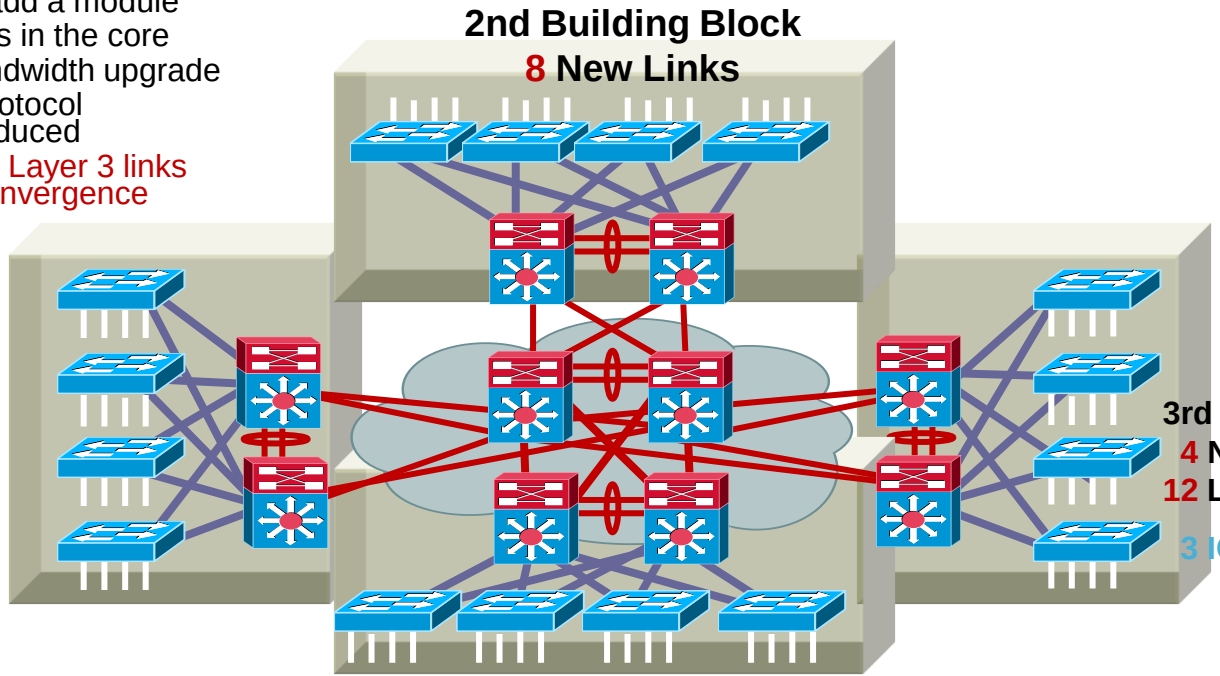


Do I Need a Core Layer?

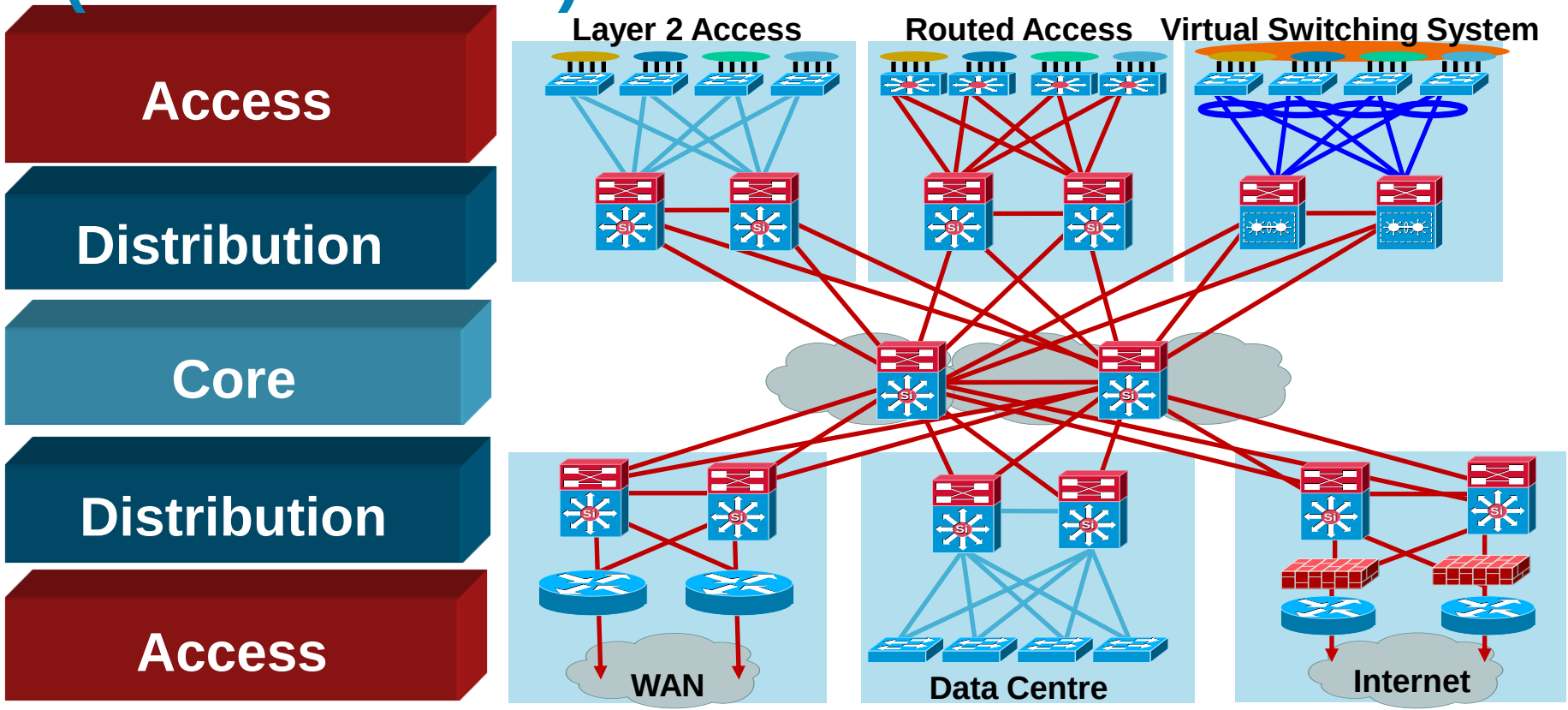
It's Really a Question of Scale, Complexity, and Convergence

Dedicated Core Switches

- Easier to add a module
- Fewer links in the core
- Easier bandwidth upgrade
- Routing protocol peering reduced
- Equal cost Layer 3 links for best convergence



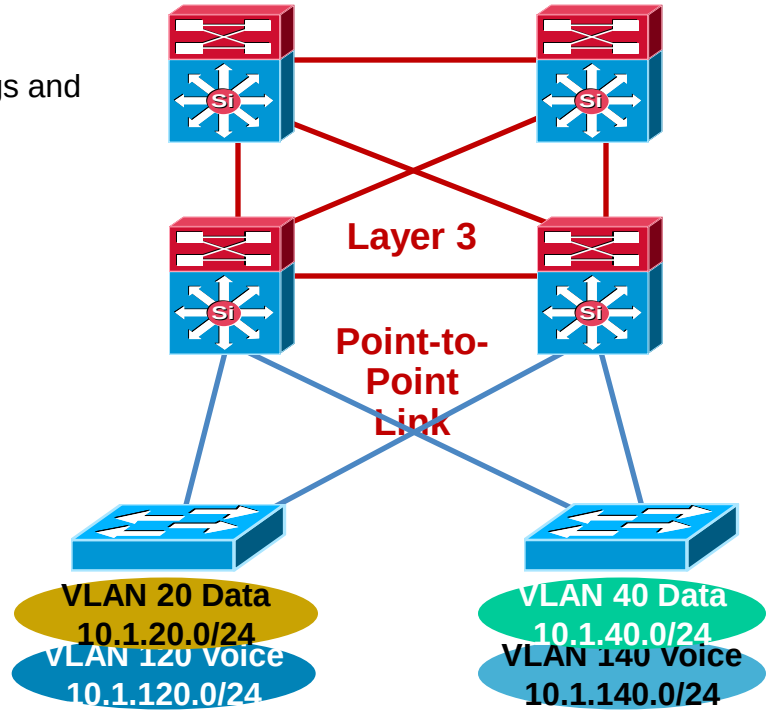
Design Alternatives Come Within a Building (or Distribution) Block



Layer 3 Distribution Interconnection

Layer 2 Access—No VLANs Span Access Layer

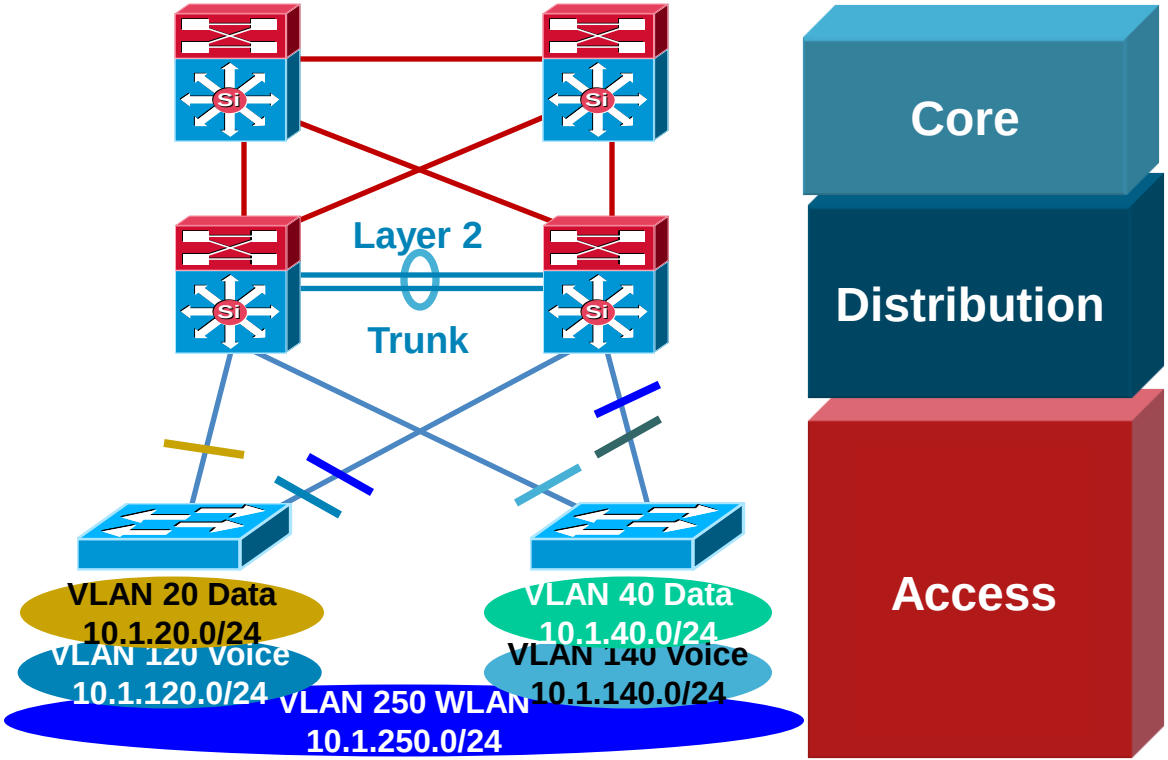
- Tune CEF load balancing
- Match CatOS/IOS EtherChannel settings and tune load balancing
- Summarise routes towards core
- Limit redundant IGP peering
- STP Root and HSRP primary tuning or GLBP to load balance on uplinks
- Set trunk mode on/no-negotiate
- Disable EtherChannel unless needed
- Set port host on access layer ports:
  - Disable trunking
    Disable EtherChannel
    Enable PortFast
- RootGuard or BPDU-Guard
- Use security features



Layer 2 Distribution Interconnection

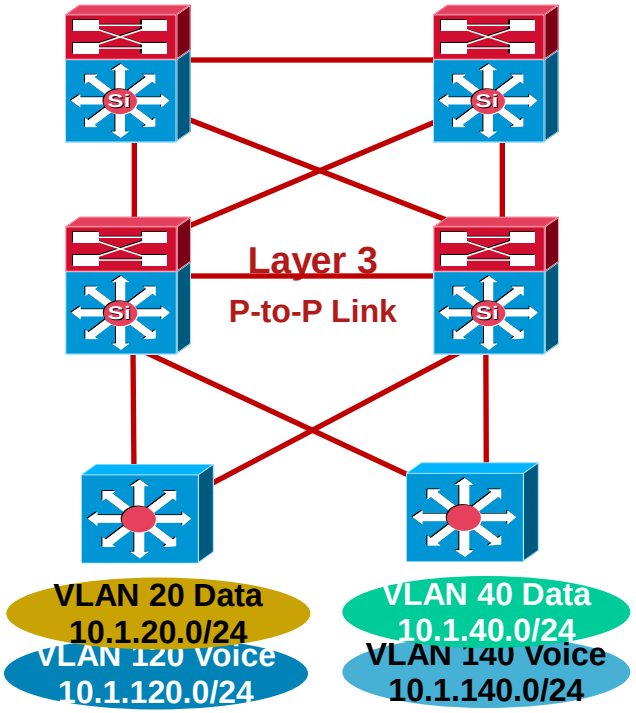
Layer 2 Access—Some VLANs Span Access Layer

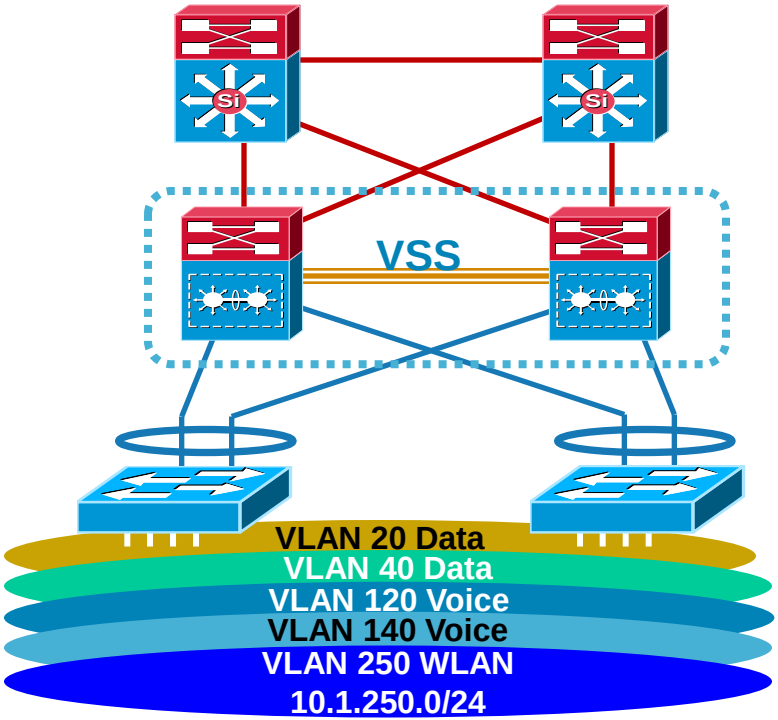
- Tune CEF load balancing
- Match CatOS/IOS EtherChannel settings and tune load balancing
- Summarise routes towards core
- Limit redundant IGP peering
- STP Root and HSRP primary or GLBP and STP port cost tuning to load balance on uplinks
- Set trunk mode on/no-negotiate
- Disable EtherChannel unless needed
- RootGuard on downlinks
- LoopGuard on uplinks
- Set port host on access Layer ports:
  - Disable trunking
    Disable EtherChannel
    Enable PortFast
- RootGuard or BPDU-Guard
- Use security features



Routed Access and Virtual Switching System

Evolutions of and Improvements to Existing Designs





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- Campus Design Best Practices
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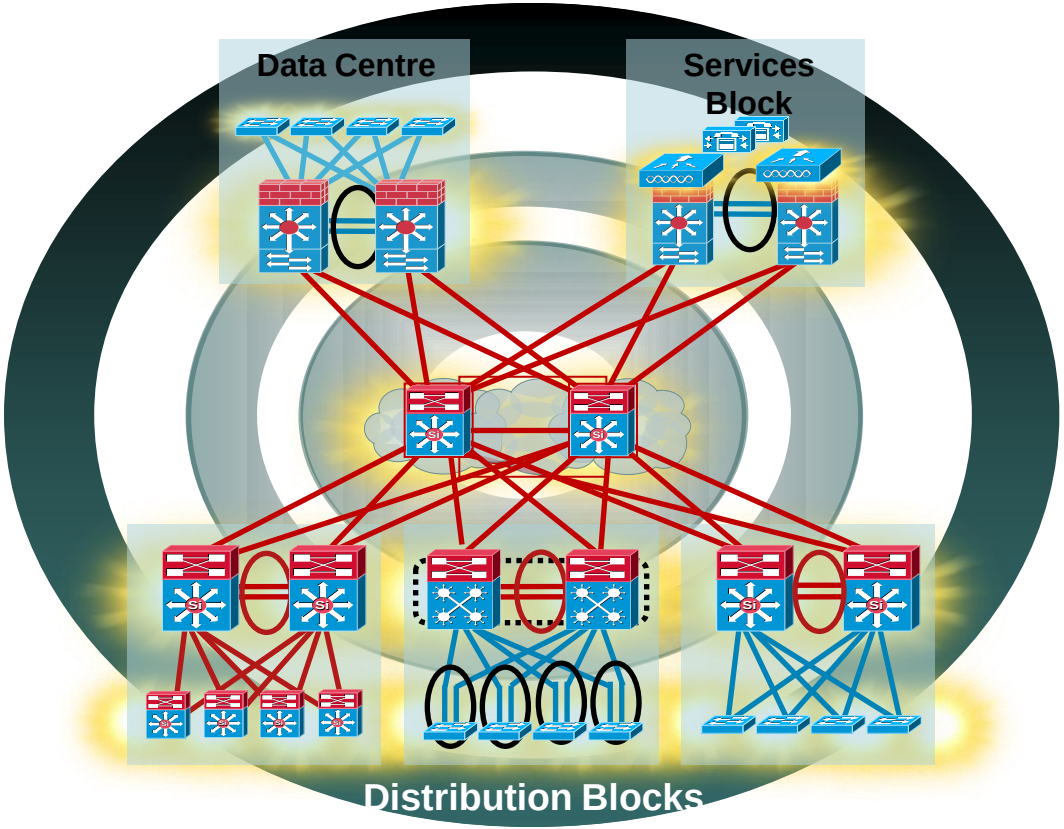


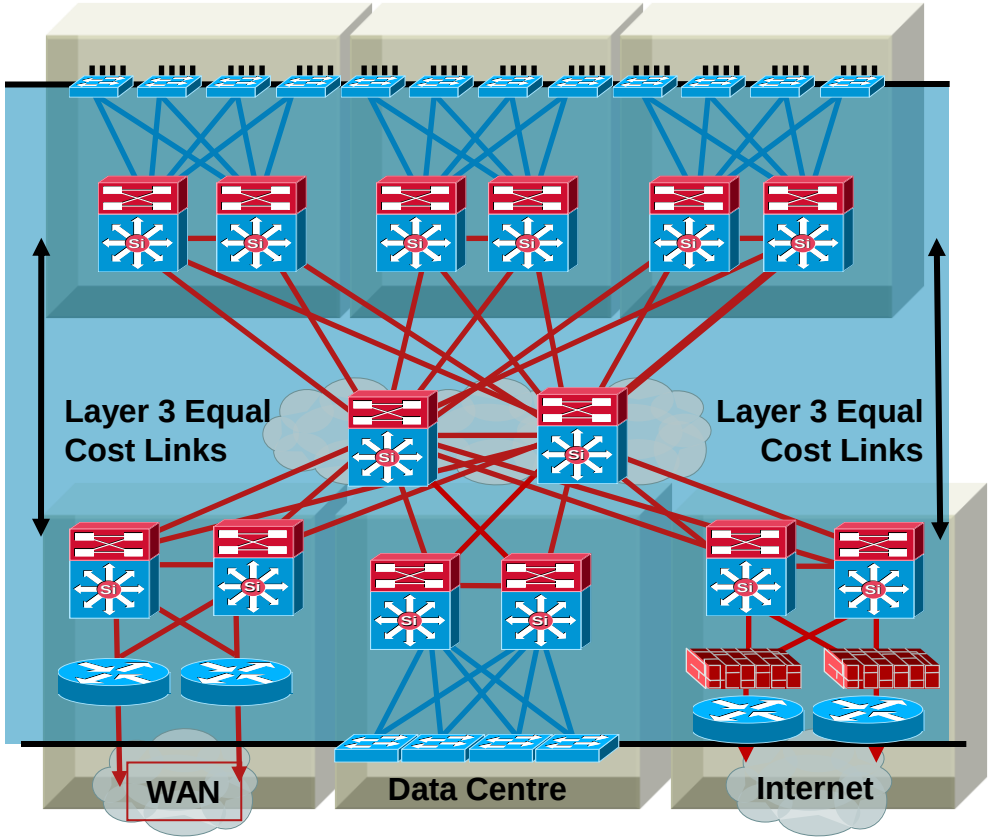
Foundation Services

- Layer 1 physical things
- Layer 2 redundancy—spanning tree
- Layer 3 routing protocols
- Trunking protocols—(ISL/.1q)
- Unidirectional link detection
- Load balancing
  - EtherChannel link aggregation
  - CEF equal cost load balancing
- First hop redundancy protocols
  - VRRP, HSRP, and GLBP

Best Practices

Layer 1 Physical Things

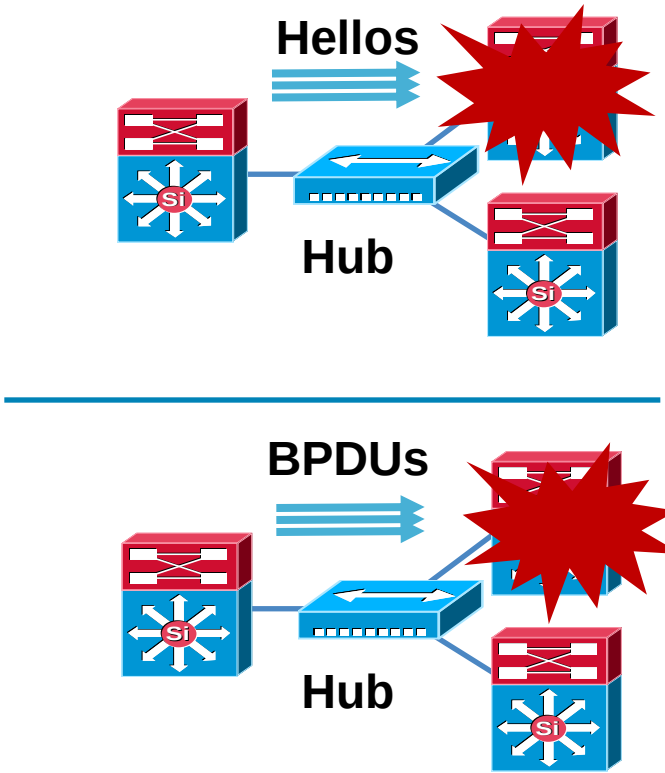
- Use point-to-point interconnections—no L2 aggregation points between nodes
- Use fibre for best convergence (debounce timer)
- Tune carrier delay timer
- Use configuration on the physical interface not VLAN/SVI when possible



Redundancy and Protocol Interaction

Link Neighbour Failure Detection

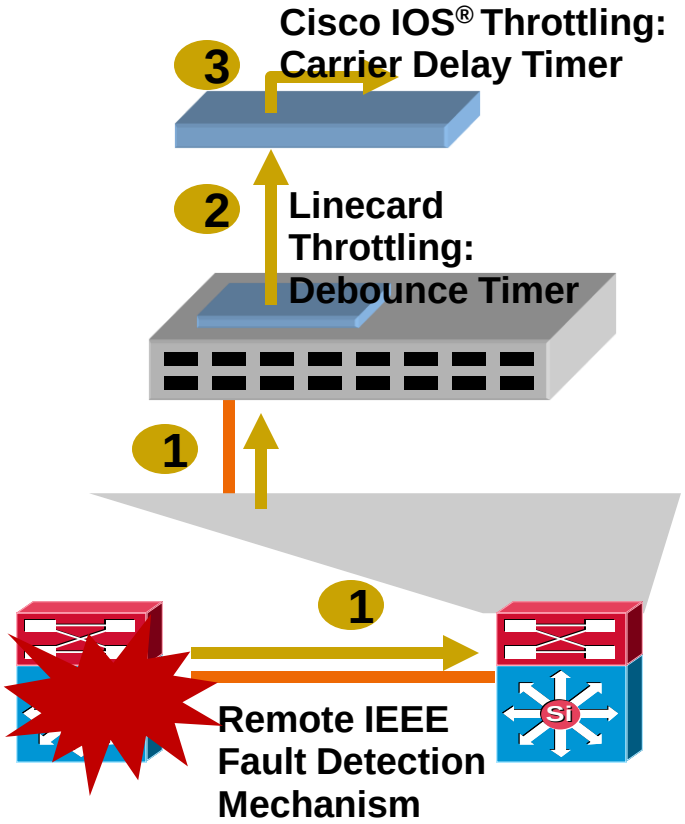
- Indirect link failures are harder to detect
- With no direct HW notification of link loss or topology change convergence times are dependent on SW notification
- Indirect failure events in a bridged environment are detected by spanning tree hellos
- In certain topologies the need for TCN updates or dummy multicast flooding (uplink fast) is necessary for convergence
- You should not be using hubs in a high-availability design



Redundancy and Protocol Interaction

Link Redundancy and Failure Detection

- Direct point-to-point fibre provides for fast failure detection
- IEEE 802.3z and 802.3ae link negotiation define the use of remote fault indicator and link fault signalling mechanisms
- Bit D13 in the Fast Link Pulse (FLP) can be set to indicate a physical fault to the remote side
- Do not disable auto-negotiation on GigE and 10GigE interfaces
- The default debounce timer on GigE and 10GigE fibre linecards is 10 msec
- The minimum debounce for copper is 300 msec
- Carrier-delay
  - 3560, 3750, and 4500—0 msec
  - 6500—leave it set at default



Redundancy and Protocol Interaction

Layer 2 and 3—Why Use Routed Interfaces

- Configuring L3 routed interfaces provides for faster convergence than an L2 switch port with an associated L3 SVI

1. Link Down
2. Interface Down
3. Routing Update

~ 8 msec loss

```
21:38:37.042 UTC: %LINEPROTO-5-UPDOWN: Line protocol on Interface GigabitEthernet3/1, changed state to down
21:38:37.050 UTC: %LINK-3-UPDOWN: Interface GigabitEthernet3/1, changed state to down
21:38:37.050 UTC: IP-EIGRP(Default-IP-Routing-Table:100): Callback: route_adjust GigabitEthernet3/1
```

1. Link Down
2. Interface Down
3. Autostate
4. SVI Down
5. Routing Update

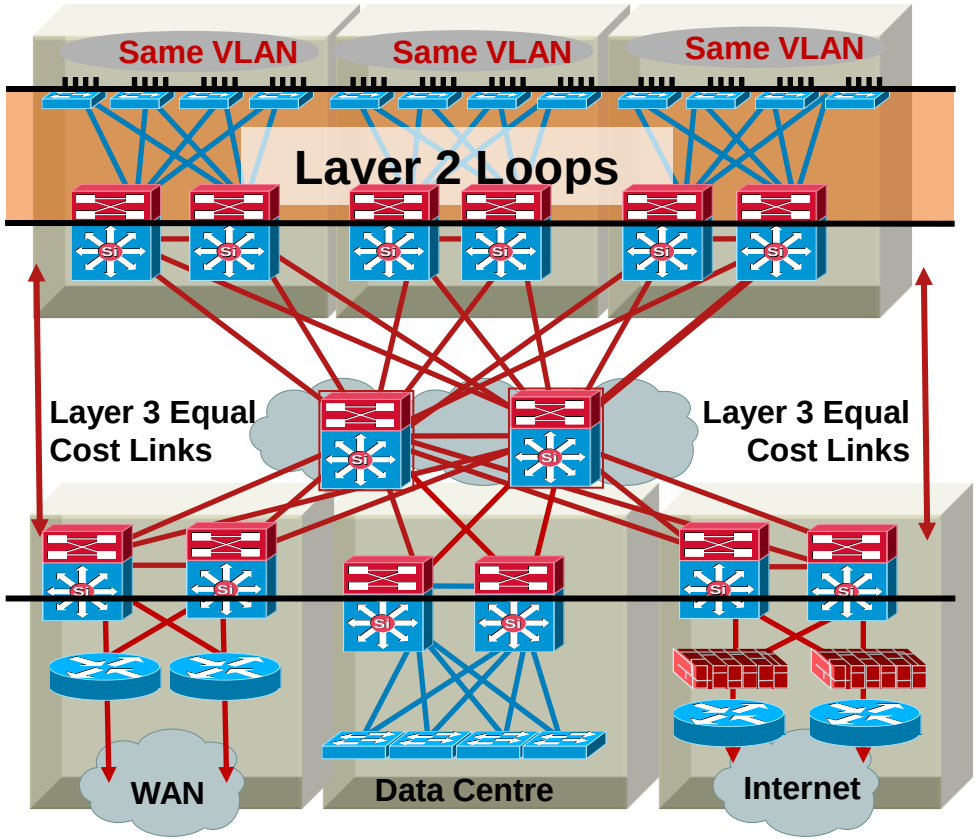
~ 150–200 msec loss

```
21:32:47.813 UTC: %LINEPROTO-5-UPDOWN: Line protocol on Interface GigabitEthernet2/1, changed state to down
21:32:47.821 UTC: %LINK-3-UPDOWN: Interface GigabitEthernet2/1, changed state to down
21:32:48.069 UTC: %LINK-3-UPDOWN: Interface Vlan301, changed state to down
21:32:48.069 UTC: IP-EIGRP(Default-IP-Routing-Table:100): Callback: route, adjust Vlan301
```

Best Practices

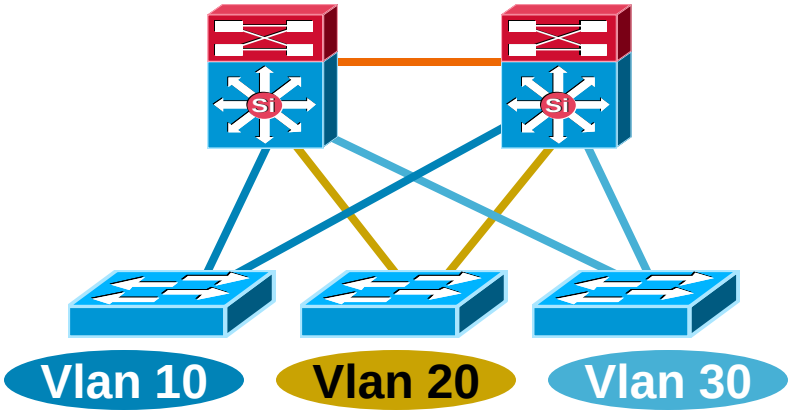
Spanning Tree Configuration

- **Only** span VLAN across multiple access layer switches when you have to!
- Use rapid PVST+ for best convergence
- More common in the Data Centre
- Required to protect against user side loops
- Required to protect against operational accidents (misconfiguration or hardware failure)
- Take advantage of the spanning tree toolkit

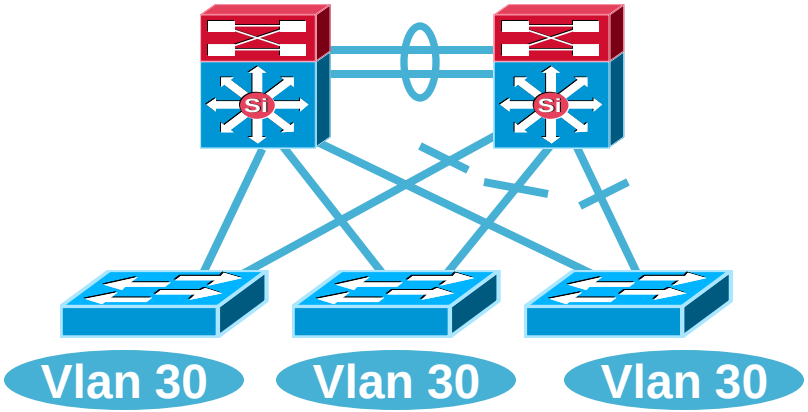


Multilayer Network Design

Layer 2 Access with Layer 3 Distribution



- Each access switch has unique VLANs
- No Layer 2 loops
- Layer 3 link between distribution
- No blocked links

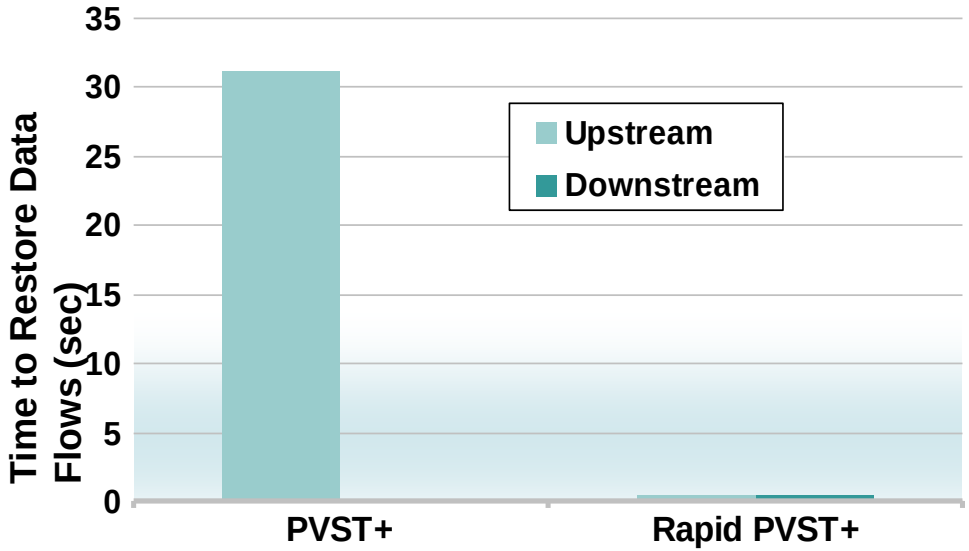


- At least some VLANs span multiple access switches
- Layer 2 loops
- Layer 2 and 3 running over link between distribution
- Blocked links

Optimising L2 Convergence

PVST+, Rapid PVST+ or MST

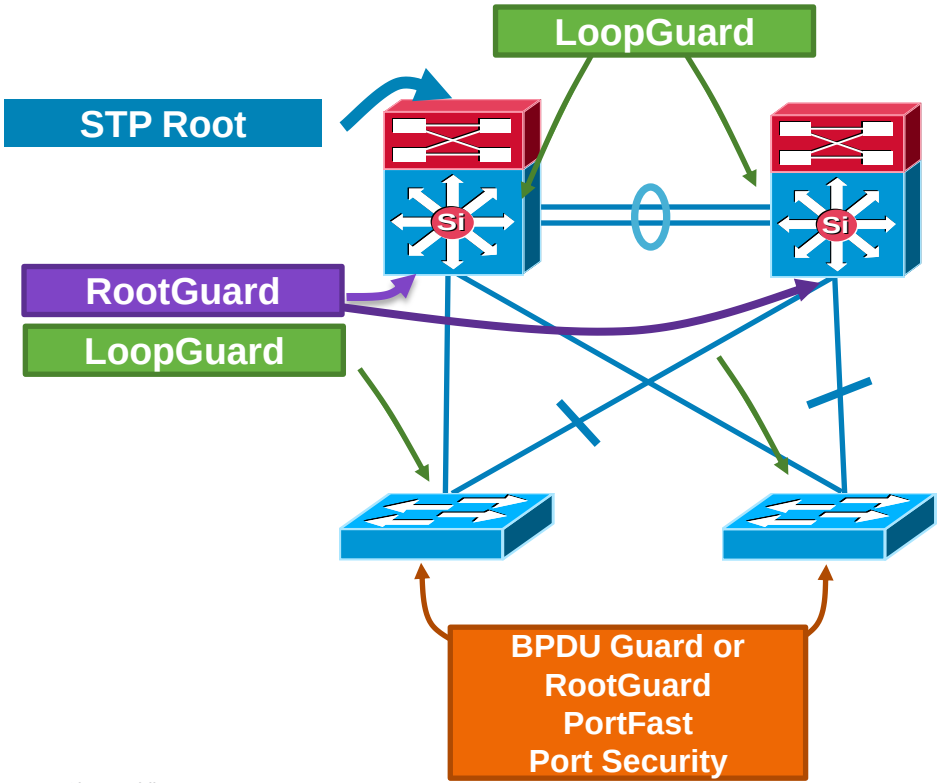
- Rapid-PVST+ greatly improves the restoration times for any VLAN that requires a topology convergence due to link UP
- Rapid-PVST+ also greatly improves convergence time over backbone fast for any indirect link failures
- PVST+ (802.1d)
  - –Traditional spanning tree implementation
- Rapid PVST+ (802.1w)
  - –Scales to large size (~10,000 logical ports)
  - **–Easy to implement, proven, scales**
- MST (802.1s)
  - –Permits very large scale STP implementations (~30,000 logical ports)
  - **–Not as flexible as rapid PVST+**



Layer 2 Hardening

Spanning Tree Should Behave the Way You Expect

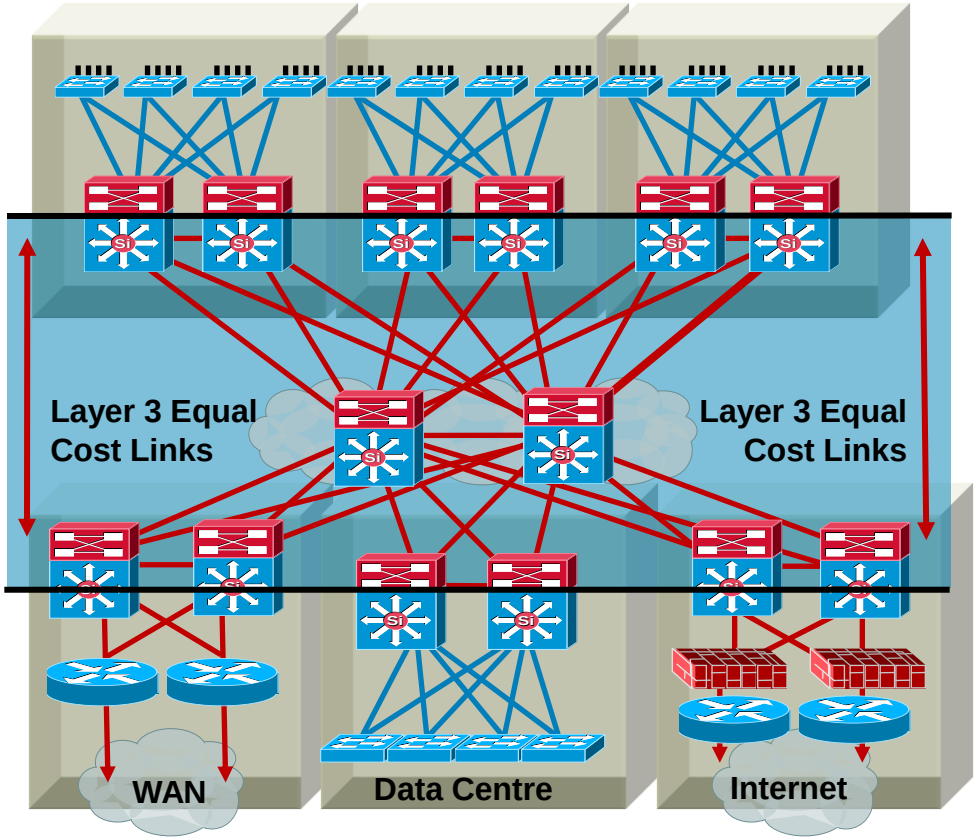
- Place the root where you want it
  - Root primary/secondary macro
- The root bridge should stay where you put it
  - RootGuard
  - LoopGuard
  - UplinkFast
  - UDLD
- Only end-station traffic should be seen on an edge port
  - BPDU Guard
  - RootGuard
  - PortFast
  - Port-security



Best Practices

Layer 3 Routing Protocols

- Typically deployed in distribution to core, and core-to-core interconnections
- Used to quickly reroute around failed node/links while providing load balancing over redundant paths
- Build triangles not squares for deterministic convergence
- Only peer on links that you intend to use as transit
- Insure redundant L3 paths to avoid black holes
- Summarise distribution to core to limit EIGRP query diameter or OSPF LSA propagation
- Tune CEF L3/L4 load balancing hash to achieve maximum utilisation of equal cost paths (CEF polarisation)

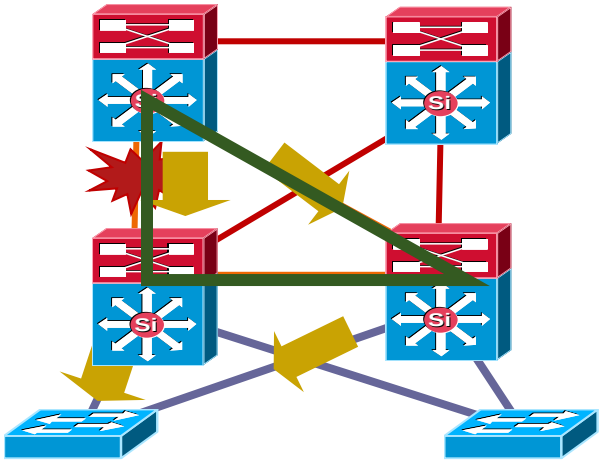


Best Practice

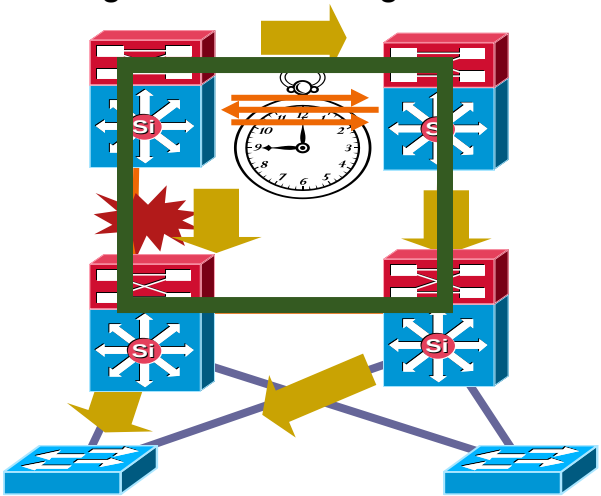
Build Triangles not Squares

Deterministic vs. Non-Deterministic

Triangles: Link/Box Failure Does not Require Routing Protocol Convergence



Squares: Link/Box Failure Requires Routing Protocol Convergence



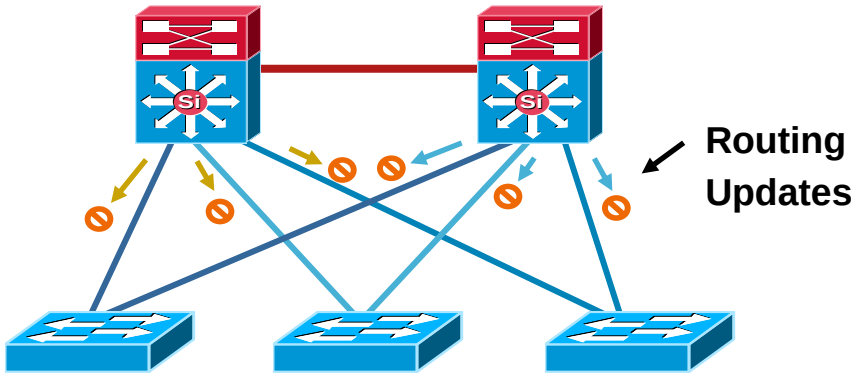
- Layer 3 redundant equal cost links support fast convergence
- Hardware based—fast recovery to remaining path
- Convergence is extremely fast (dual equal-cost paths: no need for OSPF or EIGRP to recalculate a new path)

Best Practice

Passive Interfaces for IGP

Limit OSPF and EIGRP Peering Through the Access Layer

- Limit unnecessary peering using passive interface:
  - Four VLANs per wiring closet
  - 12 adjacencies total
  - Memory and CPU requirements increase with no real benefit
  - Creates overhead for IGP



OSPF Example:

```
Router(config)#routerospf 1
Router(config-router)#passive-interfaceVlan 99

Router(config)#routerospf 1
Router(config-router)#passive-interface default
Router(config-router)#no passive-interface Vlan 99
```

EIGRP Example:

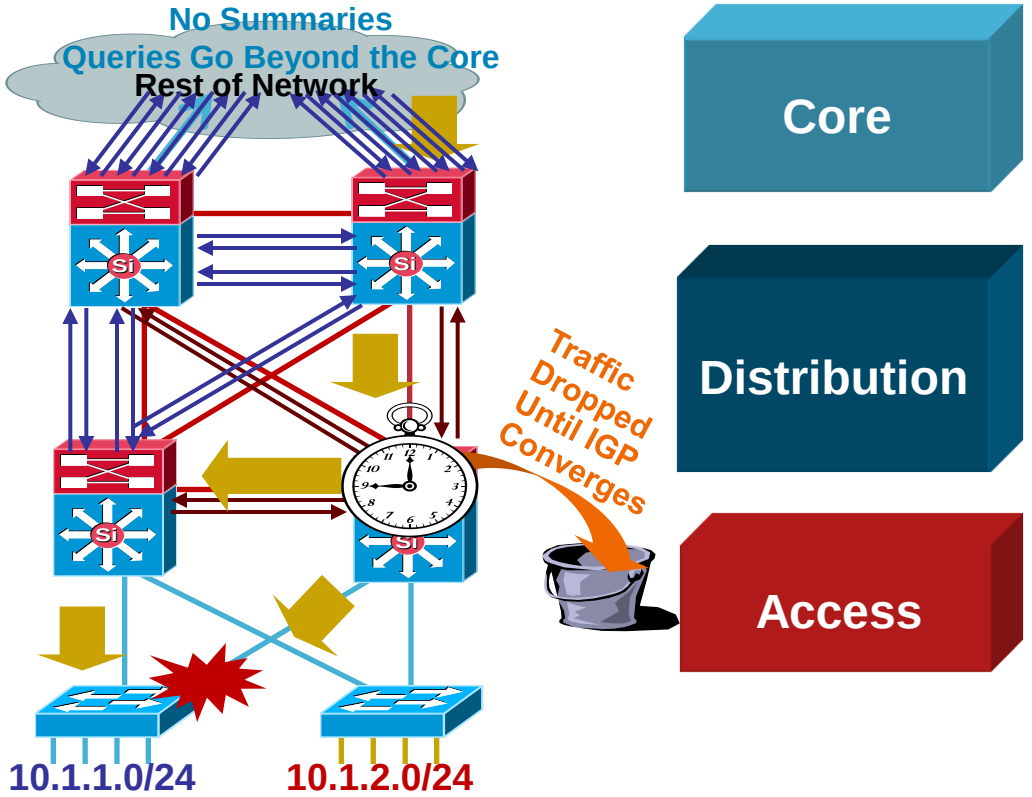
```
Router(config)#routereigrp 1
Router(config-router)#passive-interfaceVlan 99

Router(config)#routereigrp 1
Router(config-router)#passive-interface default
Router(config-router)#no passive-interface Vlan 99
```

Why You Want to Summarise at the Distribution

Limit EIGRP Queries and OSPF LSA Propagation

- It is important to force summarisation at the distribution towards the core
- For return path traffic an OSPF or EIGRP re-route is required
- By limiting the number of peers an EIGRP router must query or the number of LSAs an OSPF peer must process we can optimise this reroute
- EIGRP example:

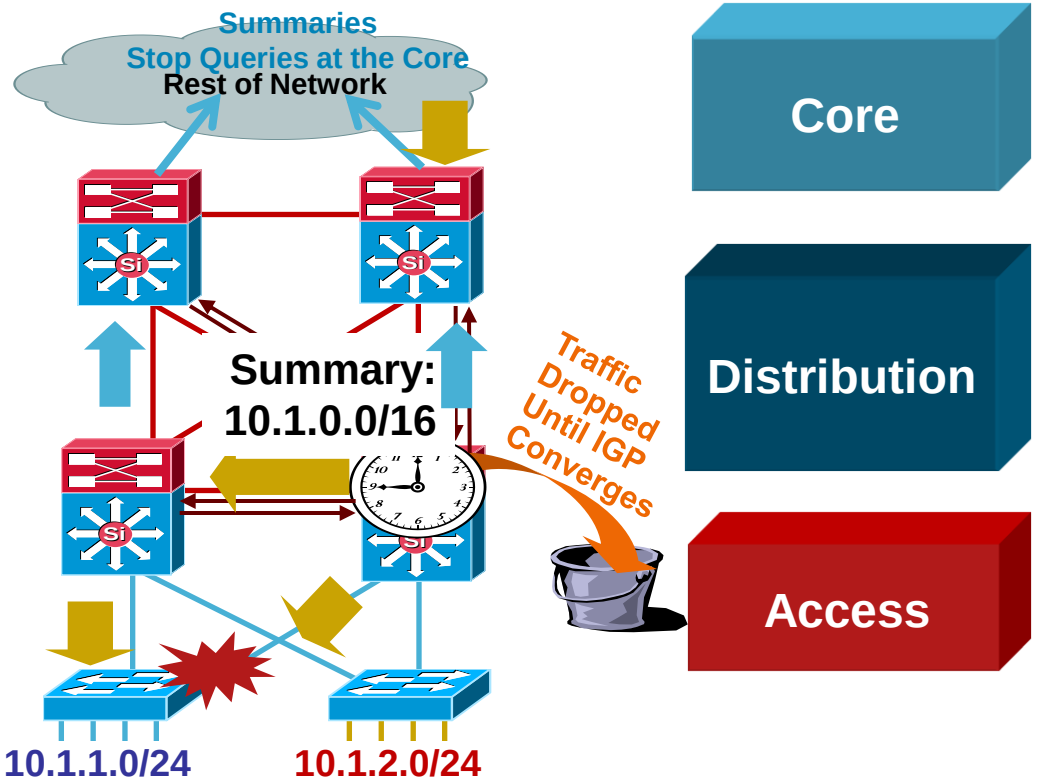
```
interface Port-channel1
description to Core#1
ip address 10.122.0.34
255.255.255.252
ip hello-interval eigrp 100 1
ip hold-time eigrp 100 3
ip summary-address eigrp 100 10.1.0.0
255.255.0.0 5
```



Why You Want to Summarise at the Distribution

Reduce the Complexity of IGP Convergence

- It is important to force summarisation at the distribution towards the core
- For return path traffic an OSPF or EIGRP re-route is required
- By limiting the number of peers an EIGRP router must query or the number of LSAs an OSPF | peer must process we can optimise his reroute
- For EIGRP if we summarise at the distribution we stop queries at the core boxes for an access layer flap
- For OSPF when we summarise at the distribution (area border or L1/L2 border) the flooding of LSAs is limited to the distribution switches; SPF now deals with one LSA not three

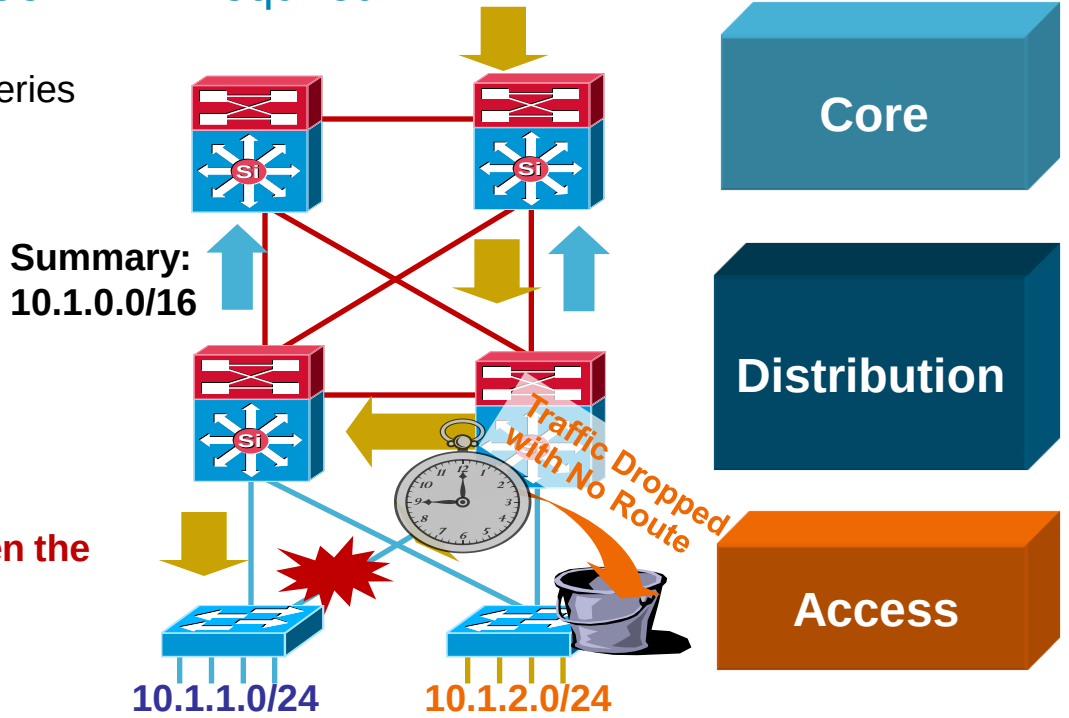


Best Practice

Summarise at the Distribution

Gotcha—Distribution-to-Distribution Link Required

- Best practice—summarise at the distribution layer to limit EIGRP queries or OSPF LSA propagation
- Gotcha:
  - Upstream: HSRP on left distribution takes over when link fails
  - Return path: old router still advertises summary to core
  - Return traffic is dropped on right distribution switch
- **Summarising requires a link between the distribution switches**
- Alternative design: use the access layer for transit



Equal-Cost Multipath

Optimising CEF Load-Sharing

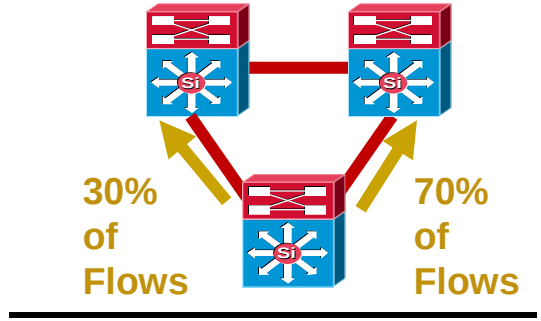
- Depending on the traffic flow patterns and IP Addressing in use one algorithm may provide better load-sharing results than another
- Be careful not to introduce polarisation in a multi-tier design by changing the default to the same thing in all tiers/layers of the

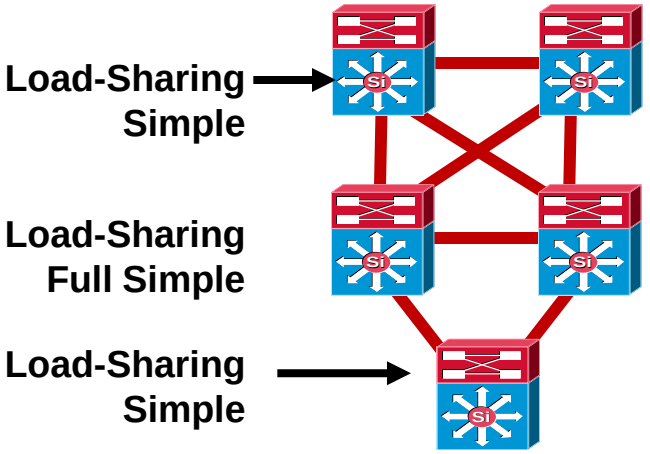
Catalyst 4500 Load-Sharing Options	
Original	Src IP + Dst IP
Universal*	Src IP + Dst IP + Unique ID
Include Port	Src IP + Dst IP + (Src or Dst Port) + Unique ID

Catalyst 6500 PFC3** Load-Sharing Options	
Default*	Src IP + Dst IP + Unique ID
Full	Src IP + Dst IP + Src Port + Dst Port
Full Exclude Port	Src IP + Dst IP + (Src or Dst Port)
Simple	Src IP + Dst IP
Full Simple	Src IP + Dst IP + Src Port + Dst Port

* = Default Load-Sharing Mode

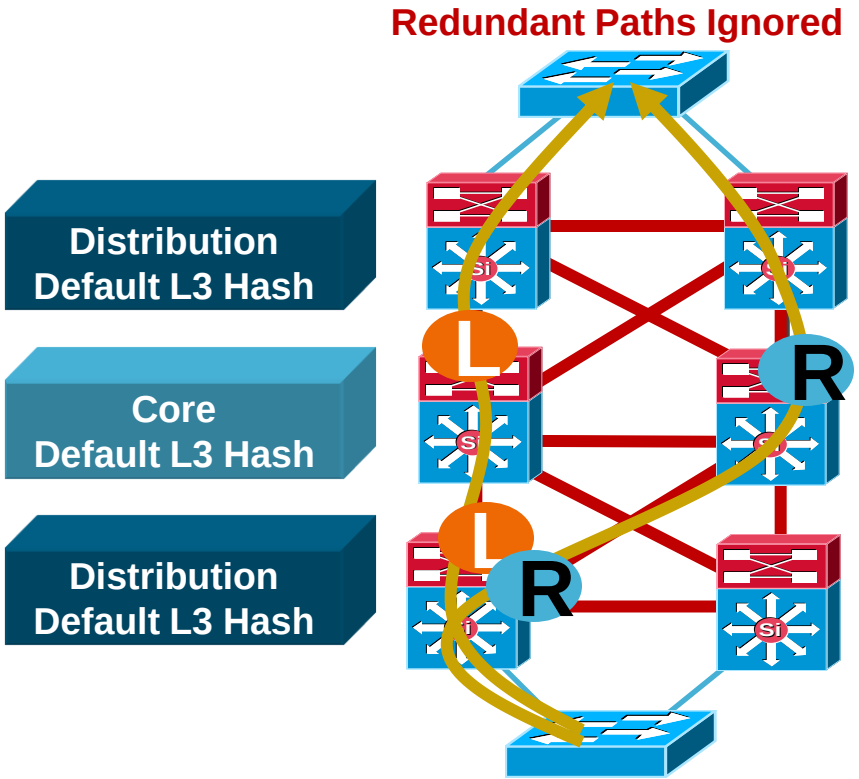
** = PFC3 in Sup720 and Sup32 Supervisors





CEF Load Balancing

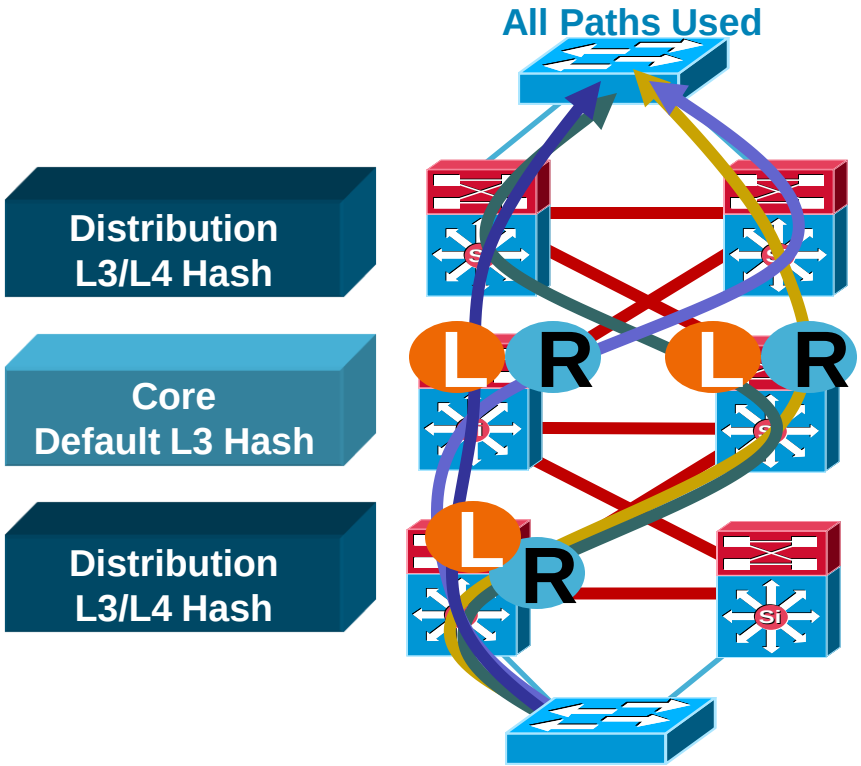
Avoid Underutilising Redundant Layer 3 Paths



- CEF polarisation: without some tuning CEF will select the same path left/left or right/right
- Imbalance/overload could occur
- Redundant paths are ignored/underutilised
- The default CEF hash input is L3
- We can change the default to use L3 + L4 information as input to the hash derivation

CEF Load Balancing

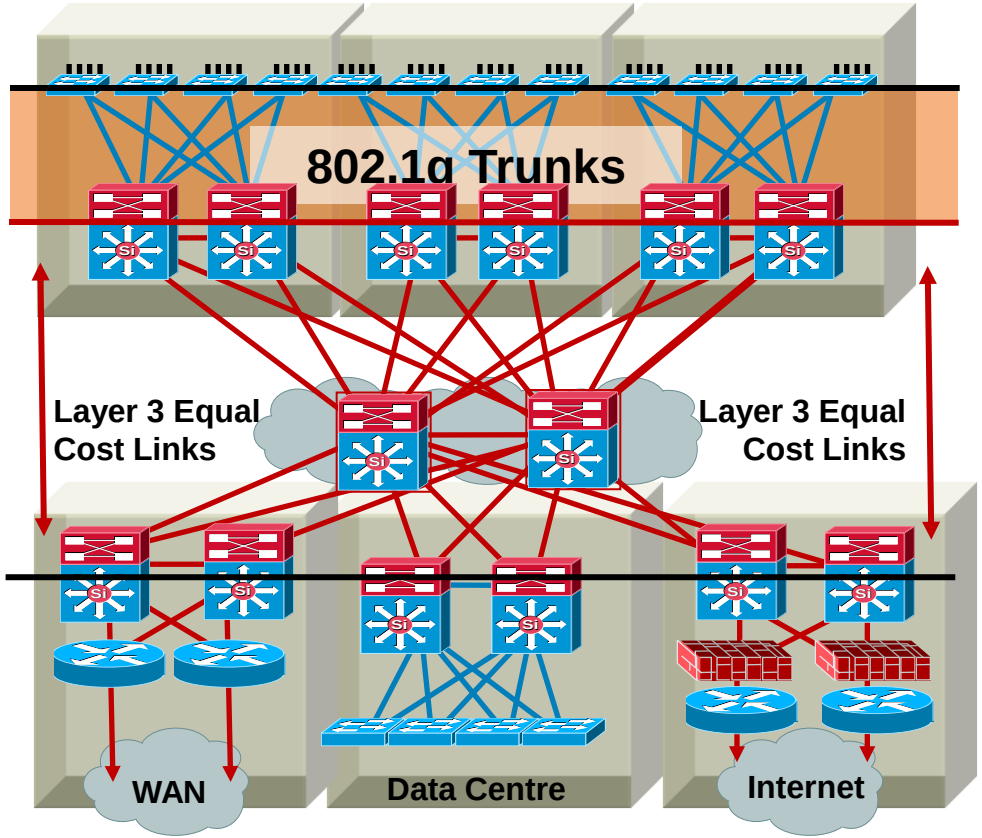
Avoid Underutilising Redundant Layer 3 Paths



- The default will for Sup720/32 and latest hardware (unique ID added to default). However, depending on IP addressing, and flows imbalance could occur
- Alternating L3/L4 hash and L3 hash will give us the best load balancing results
- Use **simple** in the core and **full simple** in the distribution to add L4 information to the algorithm at the distribution and maintain differentiation tier-to-tier

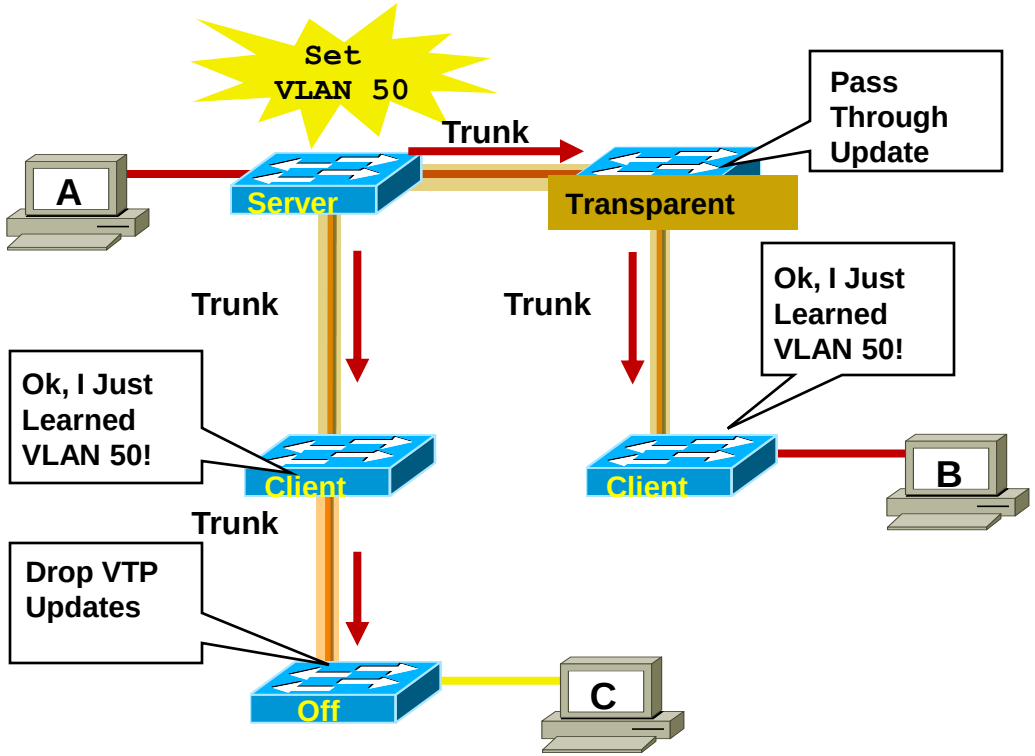
Best Practices—Trunk Configuration

- Typically deployed on interconnection between access and distribution layers
- Use VTP transparent mode to decrease potential for operational error
- Hard set trunk mode to on and encapsulation negotiate off for optimal convergence
- Change the native VLAN to something unused to avoid VLAN hopping
- Manually prune all VLANS except those needed
- Disable on host ports:
  - Cisco IOS: `switchport host`



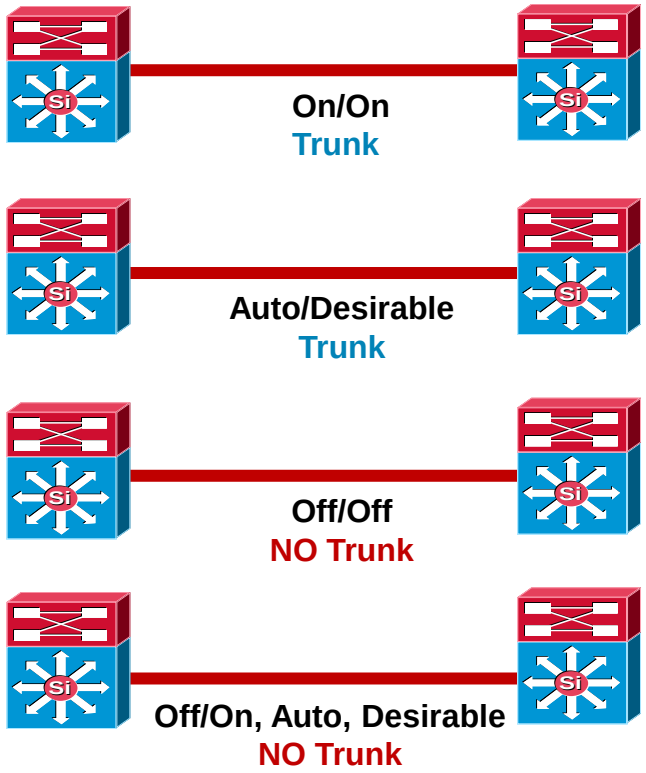
VTP Virtual Trunk Protocol

- Centralised VLAN management
- VTP server switch propagates VLAN database to VTP client switches
- Runs only on trunks
- Four modes:
  - **Server:** updates clients and servers
  - **Client:** receive updates—cannot make changes
  - **Transparent:** let updates pass through
  - **Off:** ignores VTP updates



DTP Dynamic Trunk Protocol

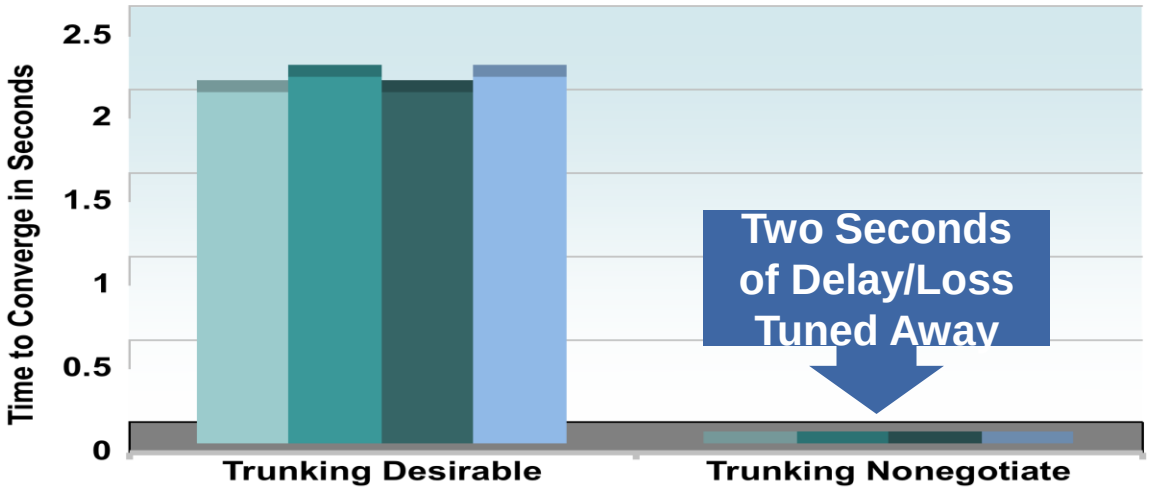
- Automatic formation of trunked switch-to-switch interconnection
  - On: always be a trunk
  - Desirable: ask if the other side can/will
  - Auto: if the other sides asks I will
  - Off: don't become a trunk
- Negotiation of 802.1Q or ISL encapsulation
  - ISL: try to use ISL trunk encapsulation
  - 802.1q: try to use 802.1q encapsulation
  - Negotiate: negotiate ISL or 802.1q encapsulation with peer
  - Non-negotiate: always use encapsulation that is hard set

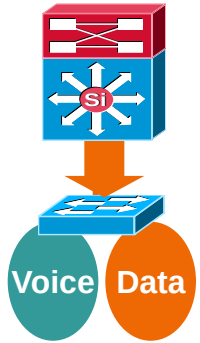


Optimising Convergence: Trunk Tuning

Trunk Auto/Desirable Takes Some Time

- DTP negotiation tuning improves link up convergence time
  - `IOS(config-if)# switchport mode trunk`
  - `IOS(config-if)# switchport nonegotiate`





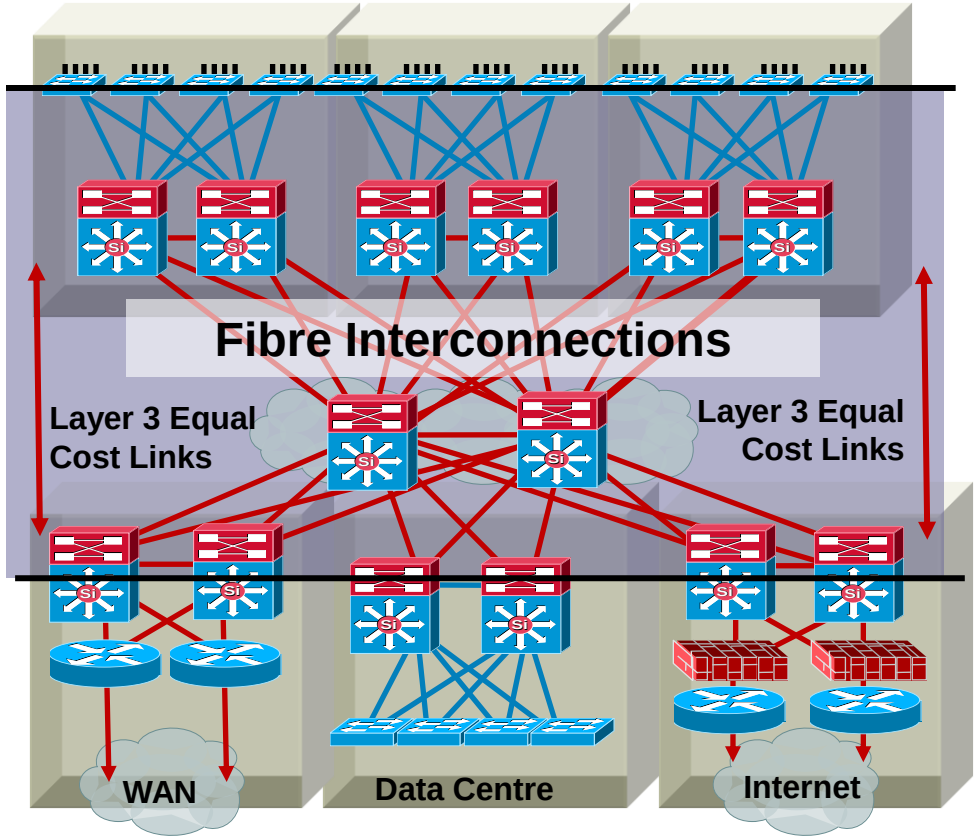
Trunking/VTP/DTP—Quick Summary

- VTP transparent should be used; there is a trade off between administrative overhead and the temptation to span existing VLANS across multiple access layer switches
- Emerging technologies that do VLAN assignment by name (IBNS, NAC, etc.) require a unique VLAN database per access layer switch if the rule: A VLAN = A Subnet = AN access layer switch is going to be followed
- One can consider a configuration that uses DTP **ON/ON** and **NO NEGOTIATE**; there is a trade off between performance/HA impact and maintenance and operations implications
- An **ON/ON** and **NO NEGOTIATE** configuration is faster from a link up (restoration) perspective than a desirable/desirable alternative. However, in this configuration DTP is not actively monitoring the state of the trunk and a misconfigured trunk is not easily identified
- It's really a balance between fast convergence and your ability to manage configuration and change control …

Best Practices—UDLD Configuration

- Typically deployed on any fibre optic interconnection
- Use UDLD aggressive mode for most aggressive protection
- Turn on in global configuration to avoid operational error/misses
- Config example
  - Cisco IOS:

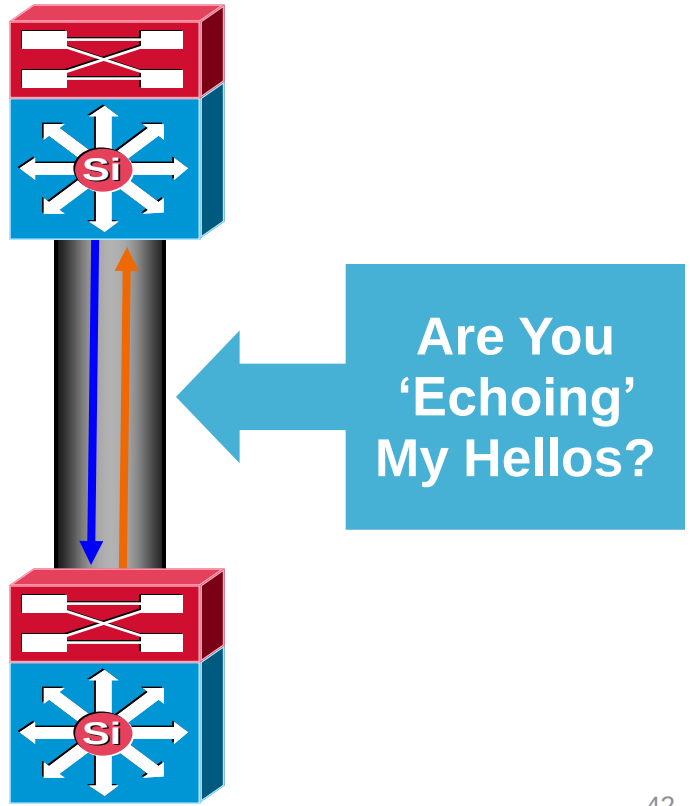
```
udld aggressive
```



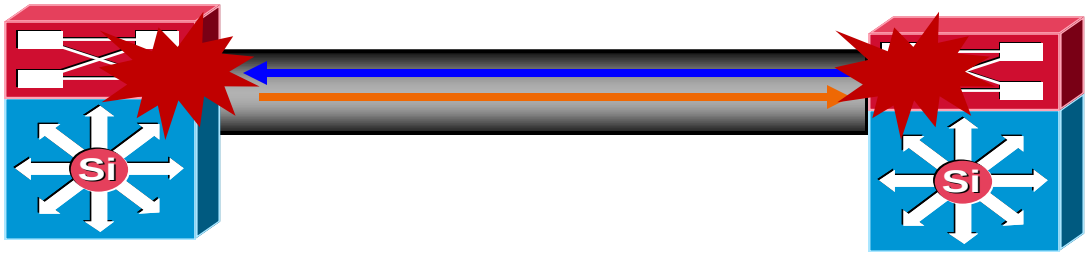
Unidirectional Link Detection

Protecting Against One-Way Communication

- Highly-available networks require UDLD to protect against one-way communication or partially failed links and the effect that they could have on protocols like STP and RSTP
- Primarily used on fibre optic links where patch panel errors could cause link up/up with mismatched transmit/receive pairs
- Each switch port configured for UDLD will send UDLD protocol packets (at L2) containing the port's own device/port ID, and the neighbour's device/port IDs seen by UDLD on that port
- Neighbouring ports should see their own device/port ID (echo) in the packets received from the other side
- If the port does not see its own device/port ID in the incoming UDLD packets for a specific duration of time, the link is considered unidirectional and is shutdown



UDLD Aggressive and UDLD Normal

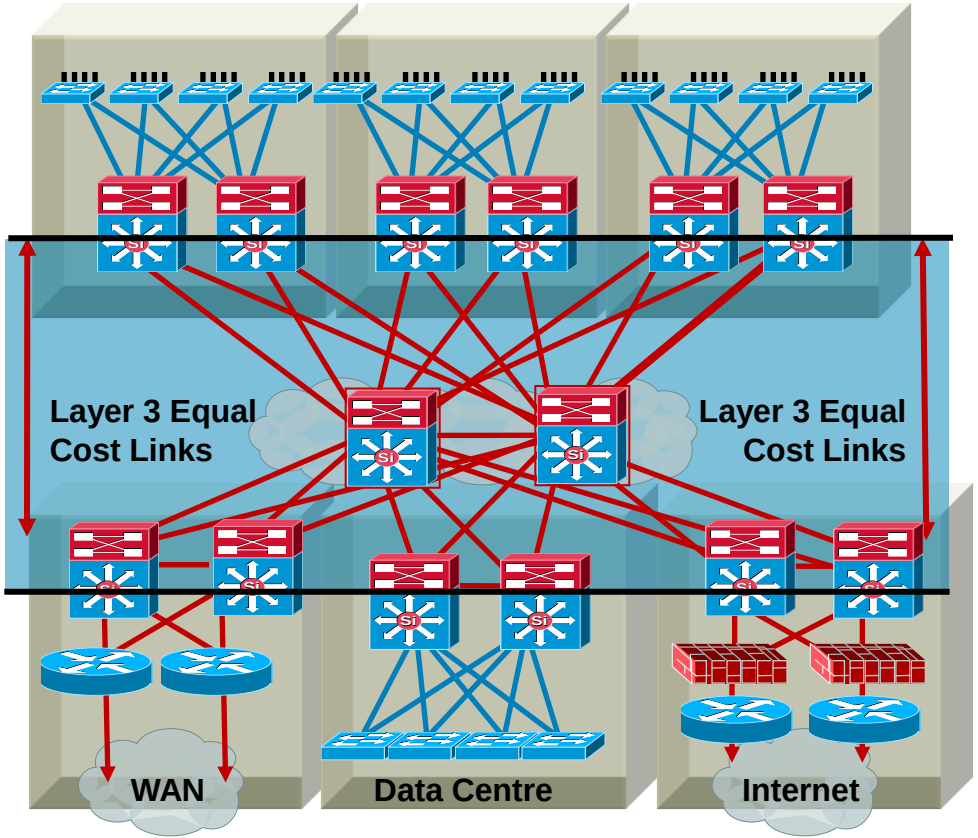


- Timers are the same—15-second hellos by default
- Aggressive Mode—after aging on a previously bi-directional link—tries eight times (once per second) to reestablish connection then err-disables port
- UDLD—Normal Mode—only err-disable the end where UDLD detected other end just sees the link go down
- UDLD—Aggressive—err-disable **both** ends of the connection due to err-disable when aging and re-establishment of UDLD communication fails

Best Practices

EtherChannel Configuration

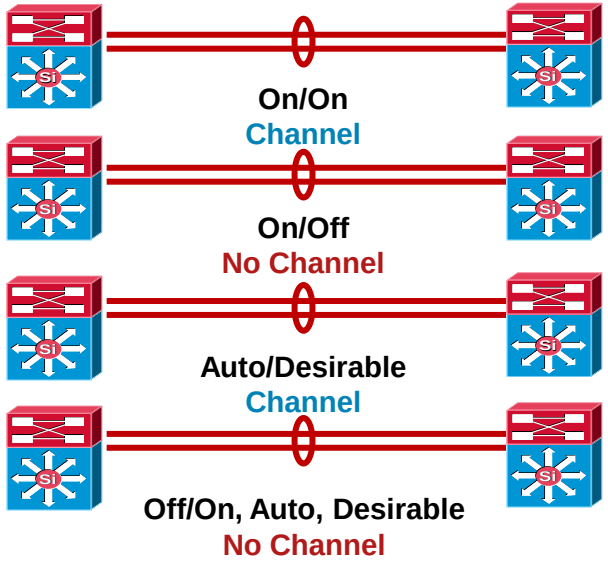
- Typically deployed in distribution to core, and core to core interconnections
- Used to provide link redundancy—while reducing peering complexity
- Tune L3/L4 load balancing hash to achieve maximum utilisation of channel members
- Deploy in powers of two (two, four, or eight)
- Match CatOS and Cisco IOS PAgP settings
- 802.3ad LACP for interop if you need it
- Disable unless needed
  - Cisco IOS: `switchport host`



Understanding EtherChannel

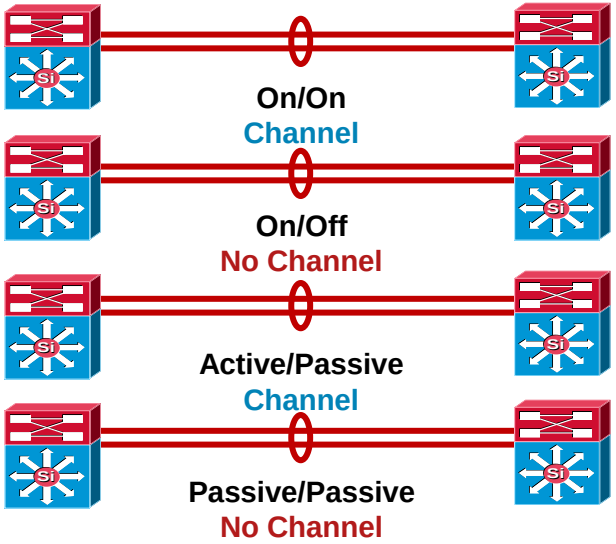
Link Negotiation Options—PAgP and LACP

Port Aggregation Protocol



On: always be a channel/bundle member
Desirable: ask if the other side can/will
Auto: if the other side asks I will
Off: don't become a member of a channel/bundle

Link Aggregation Protocol



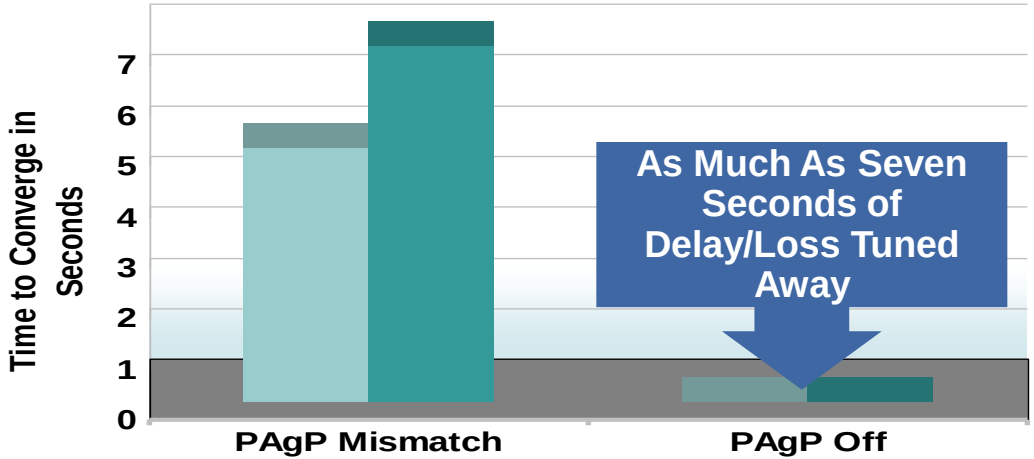
On: always be a channel/bundle member
Active: ask if the other side can/will
Passive: if the other side asks I will
Off: don't become a member of a channel/bundle

PAgP Tuning

PAgP Default Mismatches

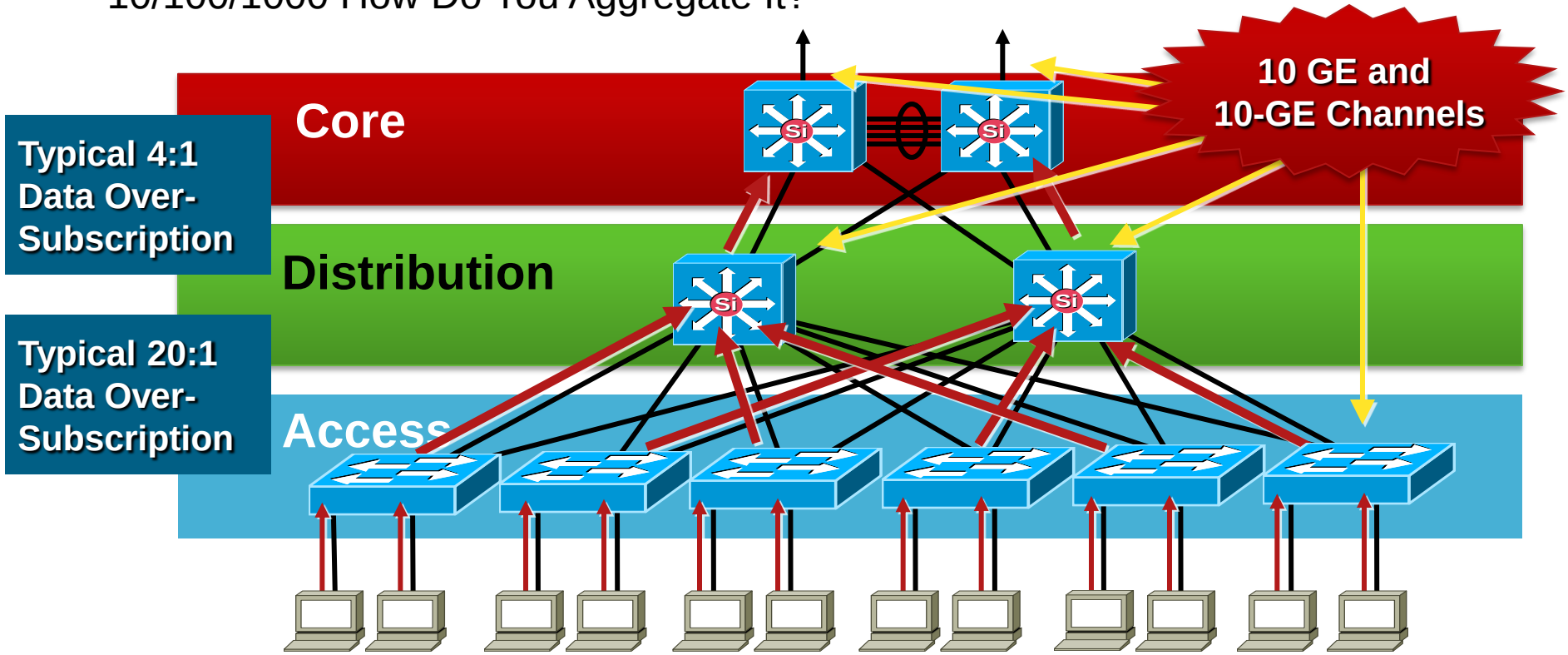
Matching EtherChannel Configuration on Both Sides Improves Link Restoration Convergence Times

```
set port channel <mod/port> off
```



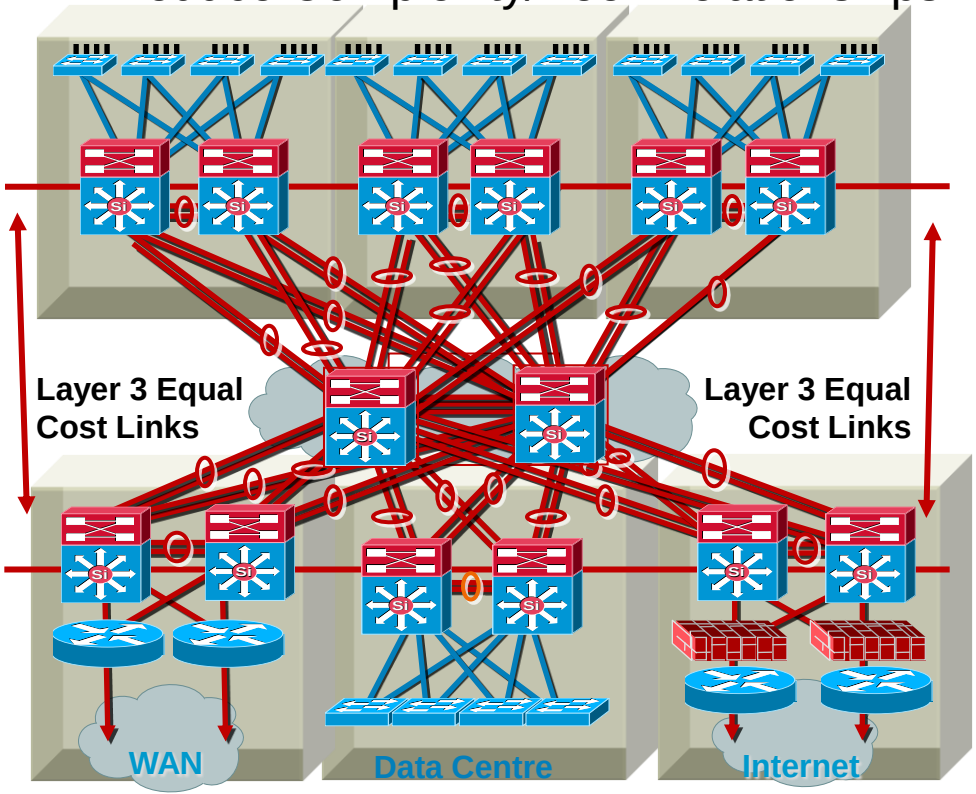
EtherChannels or Equal Cost Multipath

10/100/1000 How Do You Aggregate It?



EtherChannels or Equal Cost Multipath

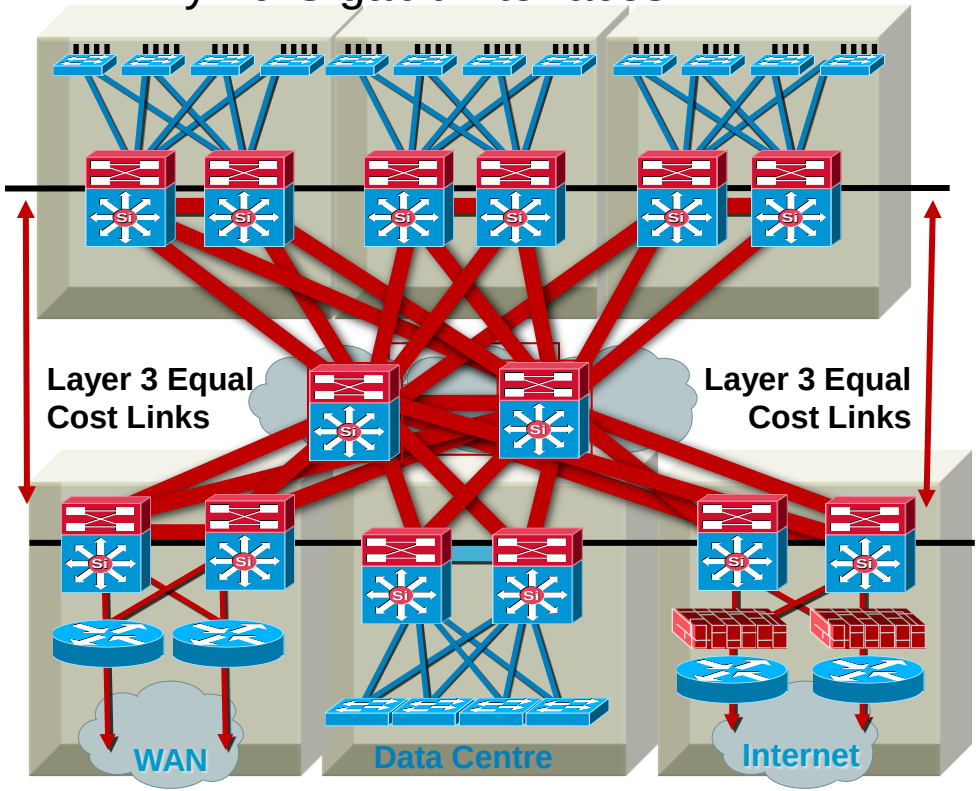
Reduce Complexity/Peer Relationships



- More links = more routing peer relationships and associated overhead
- EtherChannels allow you to reduce peers by creating single logical interface to peer over
- On single link failure in a bundle
  - OSPF running on a Cisco IOS-based switch will reduce link cost and reroute traffic
  - OSPF running on a hybrid switch will **not** change link cost and may overload remaining links
  - EIGRP **may not** change link cost and may overload remaining links

EtherChannels or Equal Cost Multipath

Why 10-Gigabit Interfaces



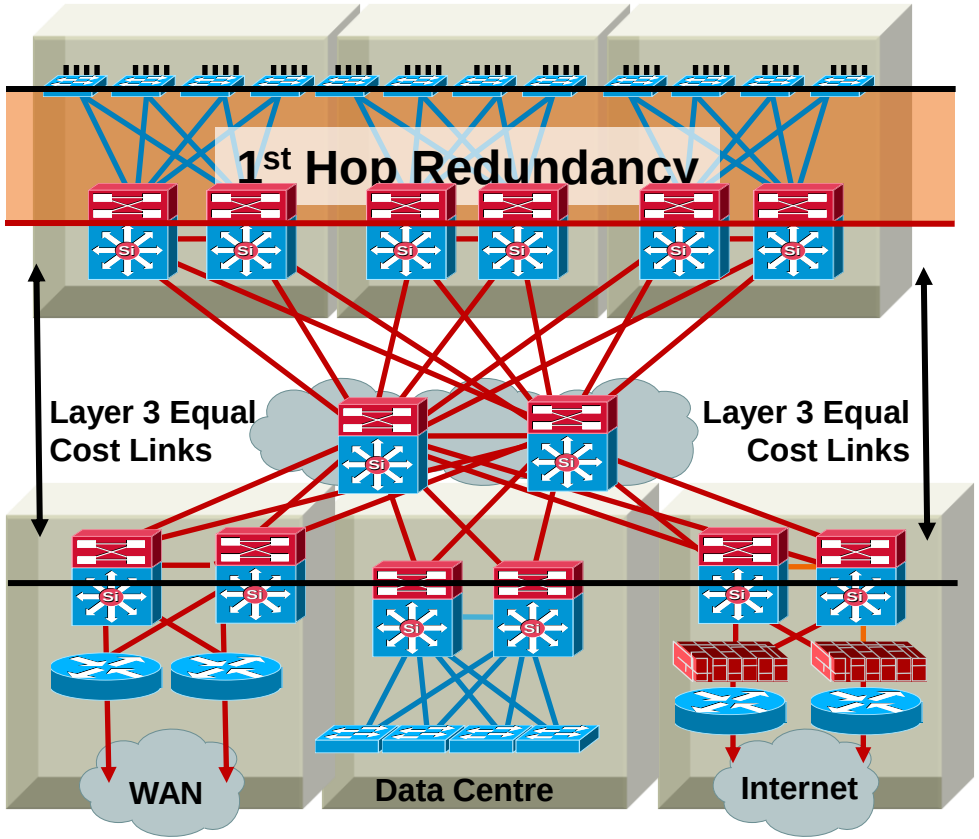
- More links = more routing peer relationships and associated overhead
- EtherChannels allow you to reduce peers by creating single logical interface to peer over
- However, a single link failure is not taken into consideration by routing protocols. Overload possible
- Single 10-gigabit links address both problems. Increased bandwidth without increasing complexity or compromising routing protocols ability to select best path

EtherChannels—Quick Summary

- For Layer 2 EtherChannels: Desirable/Desirable is the recommended configuration so that PAgP is running across all members of the bundle **insuring** that an individual link failure will not result in an STP failure
- For Layer 3 EtherChannels: one can consider a configuration that uses ON/ON. There is a trade-off between performance/HA impact and maintenance and operations implications
- An ON/ON configuration is faster from a link-up (restoration) perspective than a Desirable/Desirable alternative. However, in this configuration PAgP is not actively monitoring the state of the bundle members and a misconfigured bundle is not easily identified
- Routing protocols may not have visibility into the state of an individual member of a bundle. LACP and the minimum links option can be used to bring the entire bundle down when the capacity is diminished.
  - –OSPF has visibility to member loss (best practices pending investigation). EIGRP does not…
- When used to increase bandwidth—no individual flow can go faster than the speed of an individual member of the link
- Best used to eliminate single points of failure (i.e., link or port) dependencies from a topology

Best Practices—First Hop Redundancy

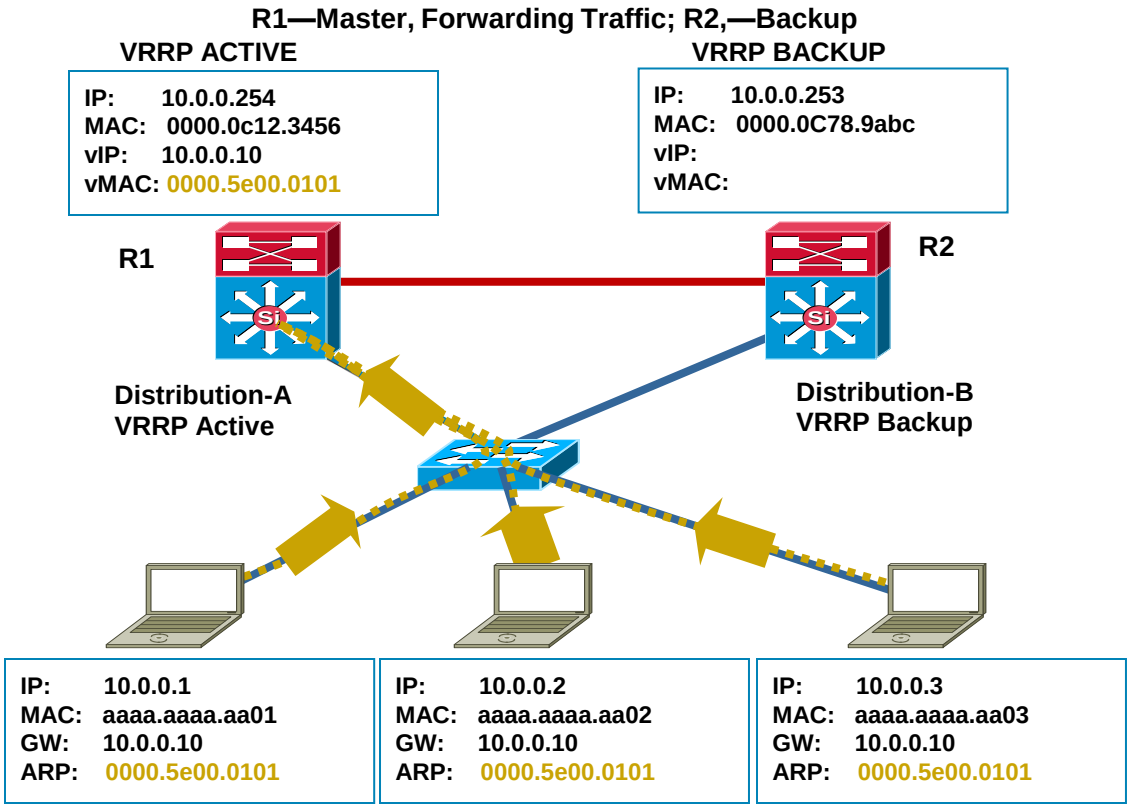
- Used to provide a resilient default gateway/first hop address to end-stations
- HSRP, VRRP, and GLBP alternatives
- VRRP, HSRP, and GLBP provide millisecond timers and excellent convergence performance
- VRRP if you need multivendor interoperability
- GLBP facilitates uplink load balancing
- Preempt timers need to be tuned to avoid black-holed traffic



First Hop Redundancy with VRRP

IETF Standard RFC 2338 (April 1998)

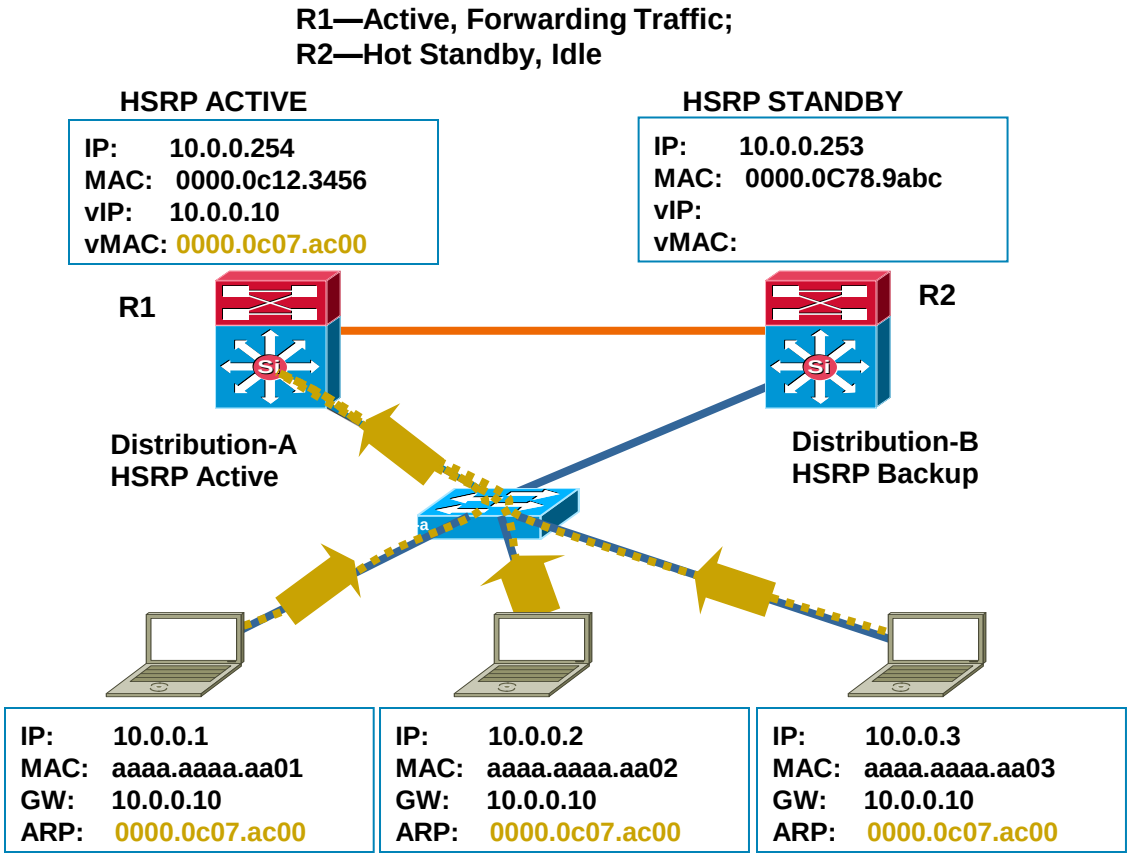
- A group of routers function as one virtual router by sharing **one** virtual IP address and one virtual MAC address
- One (master) router performs packet forwarding for local hosts
- The rest of the routers act as back up in case the master router fails
- Backup routers stay idle as far as packet forwarding from the client side is concerned



First Hop Redundancy with HSRP

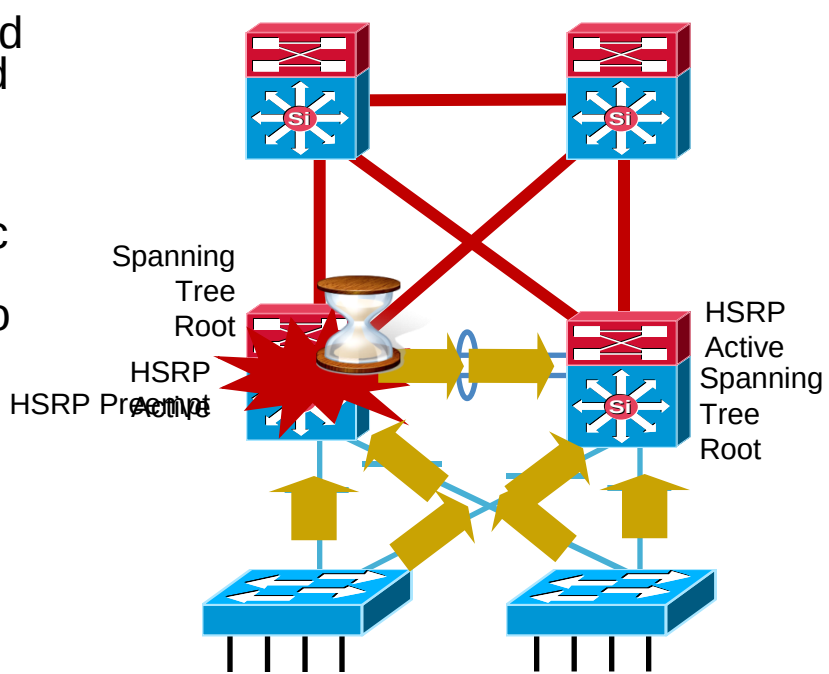
RFC 2281 (March 1998)

- A group of routers function as one virtual router by sharing **one** virtual IP address and one virtual MAC address
- One (active) router performs packet forwarding for local hosts
- The rest of the routers provide hot standby in case the active router fails
- Standby routers stay idle as far as packet forwarding from the client side is concerned



Why You Want HSRP Preemption

- Spanning tree root and HSRP primary aligned
- When spanning tree root is re-introduced, traffic will take a two-hop path to HSRP active
- HSRP preemption will allow HSRP to follow spanning tree topology



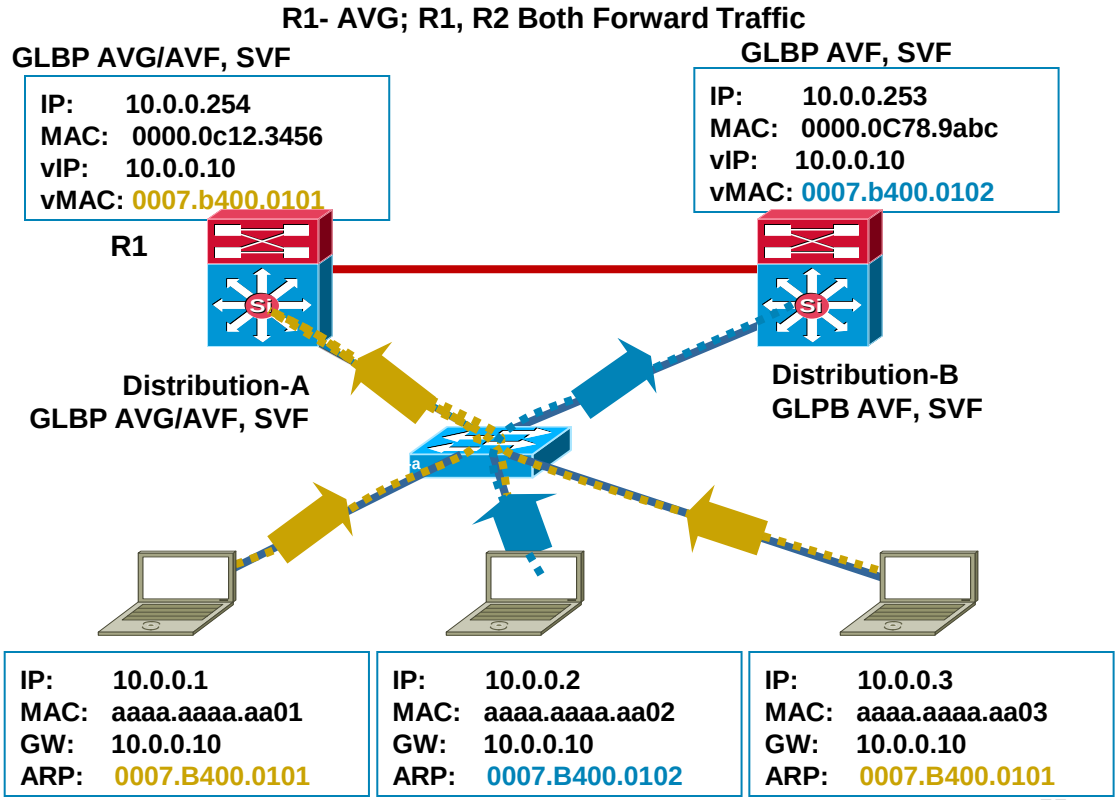
Without Preempt Delay HSRP Can Go Active Before Box Completely Ready to Forward Traffic: L1 (Boards), L2 (STP), L3 (IGP Convergence)

```
standby 1 preempt delay minimum 180
```

First Hop Redundancy with GLBP

Cisco Designed, Load Sharing, Patent Pending

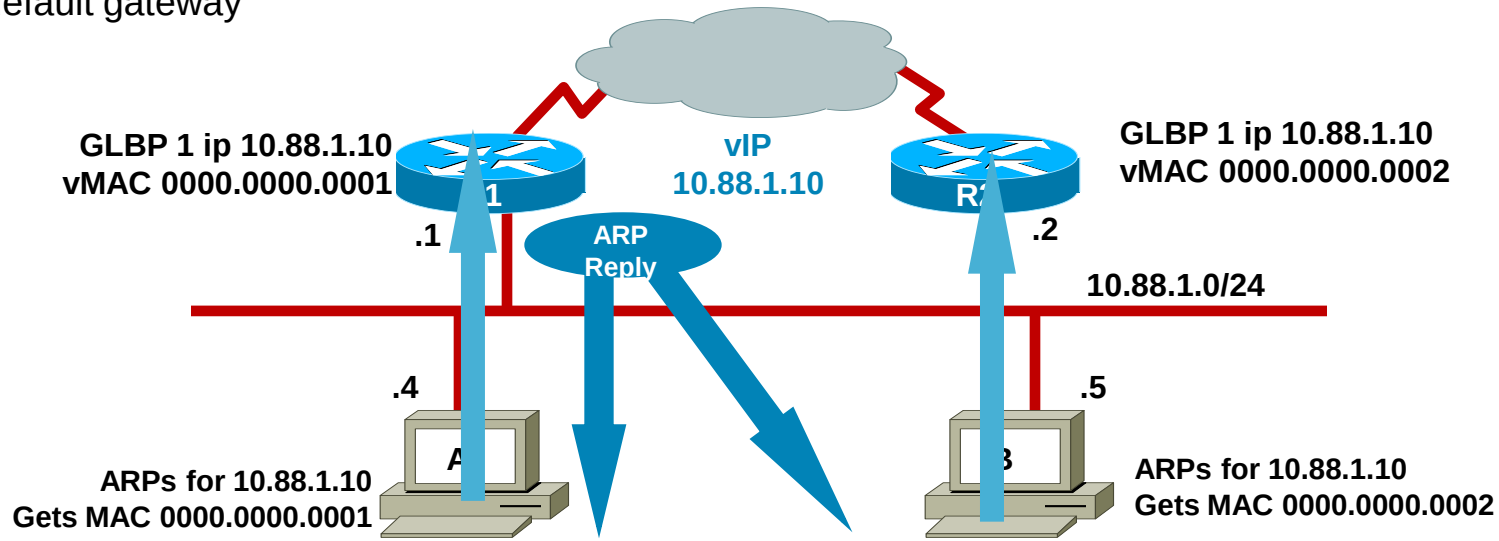
- All the benefits of HSRP plus load balancing of default gateway → utilises all available bandwidth
- A group of routers function as one virtual router by sharing one virtual IP address but using multiple virtual MAC addresses for traffic forwarding
- Allows traffic from a single common subnet to go through multiple redundant gateways using a single virtual IP address



First Hop Redundancy with Load Balancing

Cisco Gateway Load Balancing Protocol (GLBP)

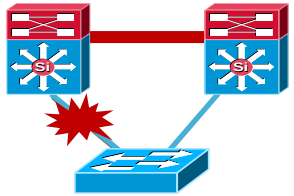
- Each member of a GLBP redundancy group owns a unique virtual MAC address for a common IP address/default gateway
- When end-stations ARP for the common IP address/default gateway they are given a load-balanced virtual MAC address
- Host A and host B send traffic to different GLBP peers but have the same default gateway

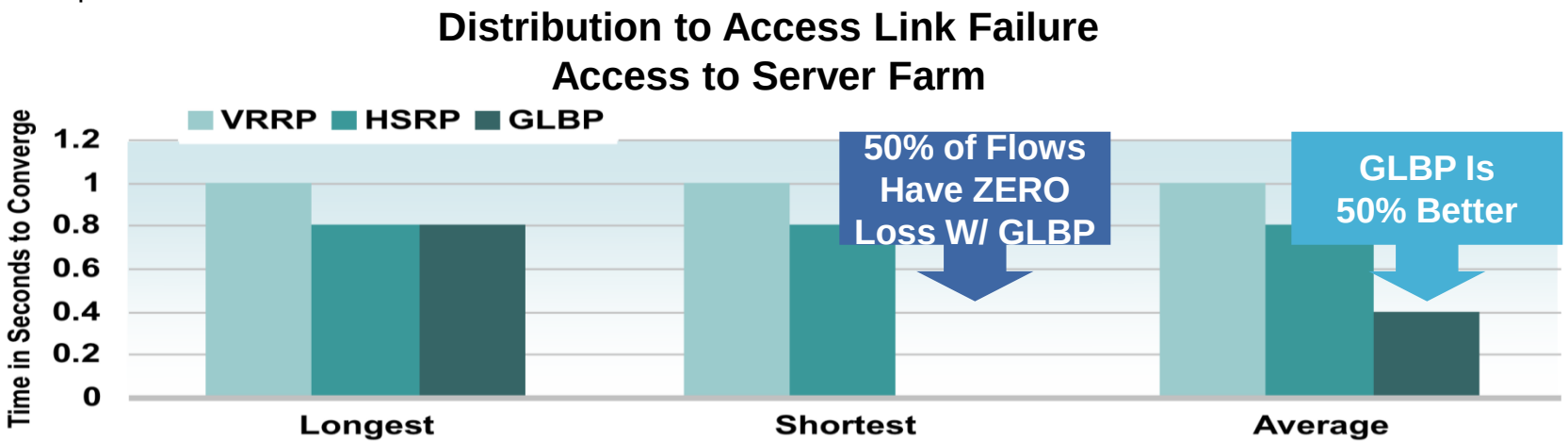


Optimising Convergence:
VRRP, HSRP, GLBP

Mean, Max, and Min—Are There Differences?

- VRRP not tested with sub-second timers and all flows go through a common VRRP peer; mean, max, and min are equal
- HSRP has sub-second timers; however all flows go through same HSRP peer so there is no difference between mean, max, and min
- GLBP has sub-second timers and distributes the load amongst the GLBP peers; so 50% of the clients are not affected by an uplink failure

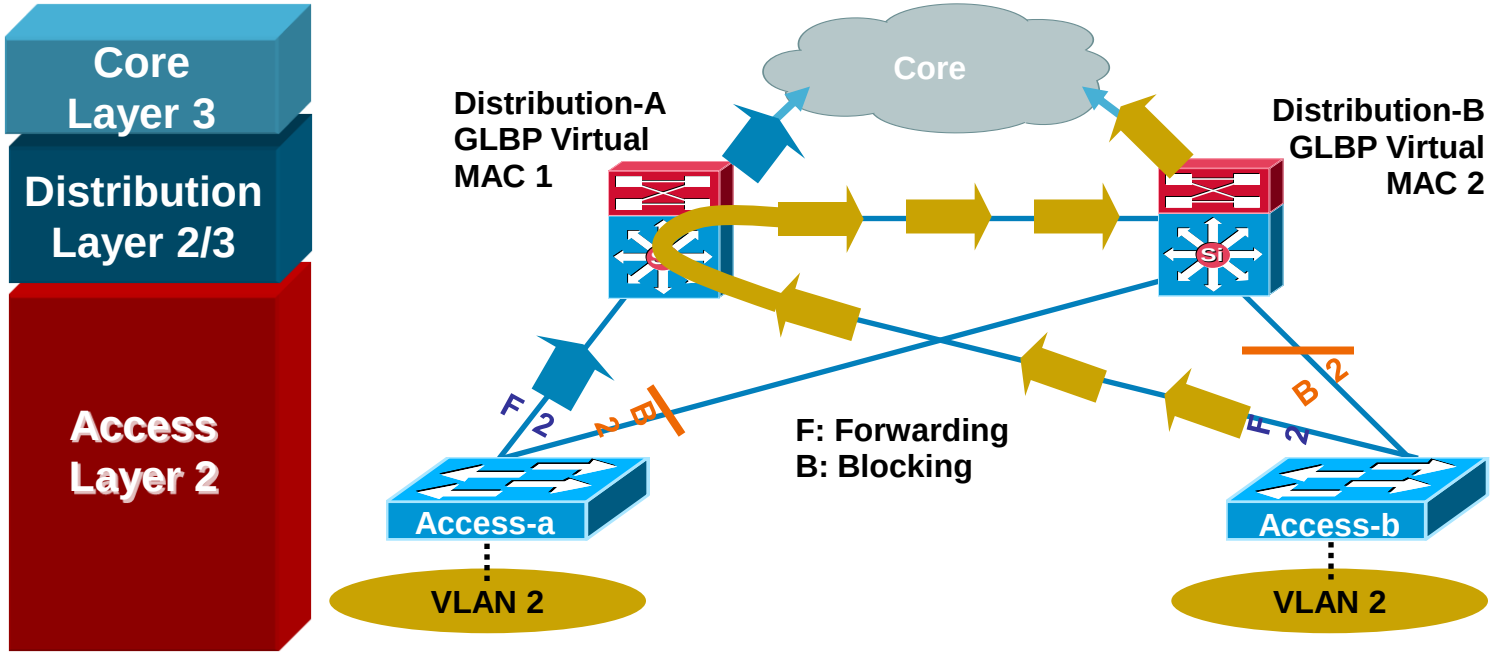




If You Span VLANS, Tuning Required

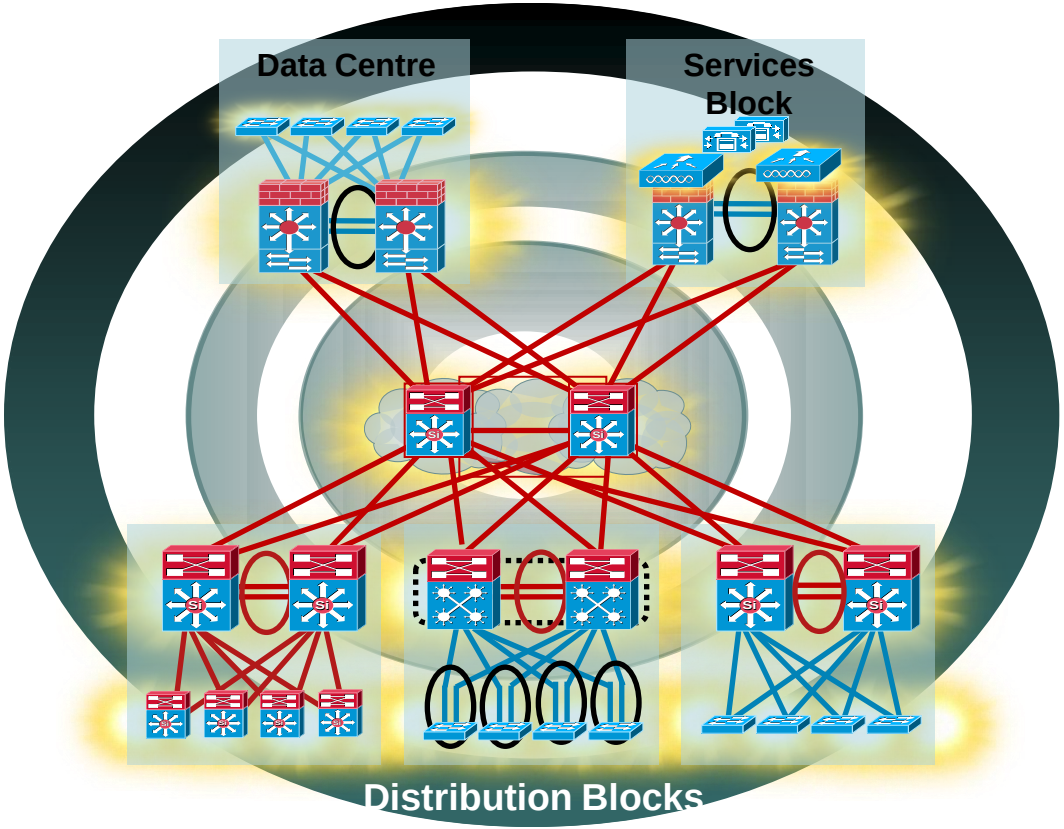
By Default, Half the Traffic Will Take a Two-Hop L2 Path

- Both distribution switches act as default gateway
- Blocked uplink caused traffic to take less than optimal path



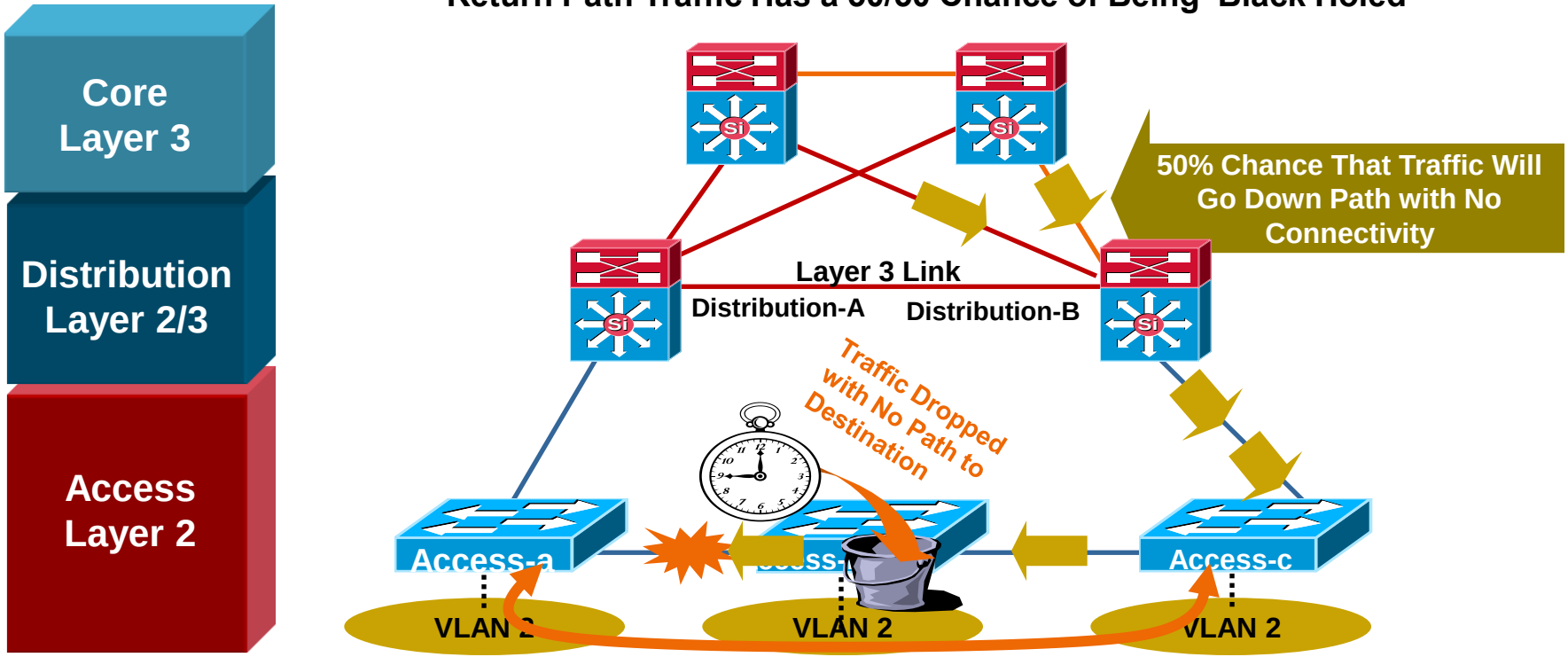
Agenda

- Multilayer Campus Design Principles
- Foundation Services
- Campus Design Best Practices
- VSS Distribution Block
- Security Considerations
- Putting It All Together
- Summary



Daisy Chaining Access Layer Switches

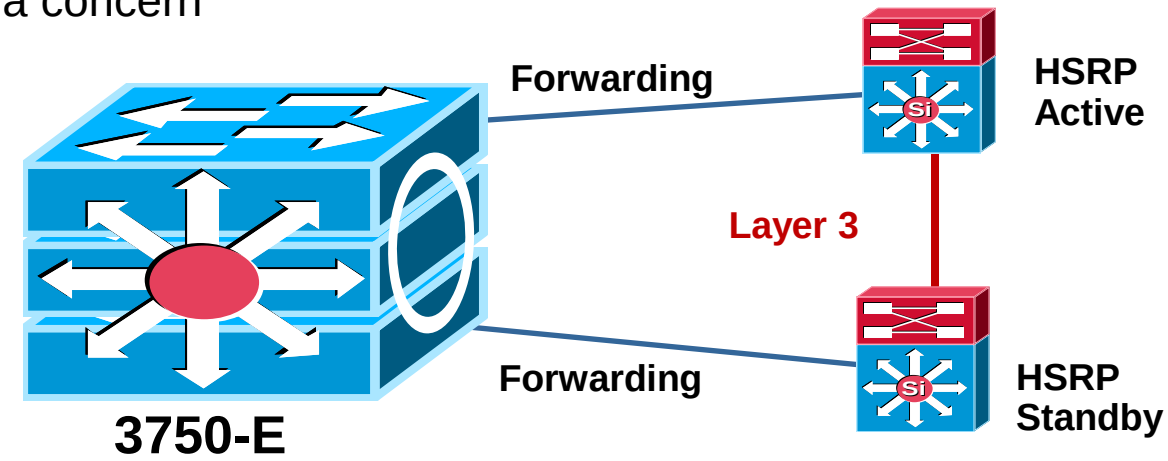
Avoid Potential Black Holes



Daisy Chaining Access Layer Switches

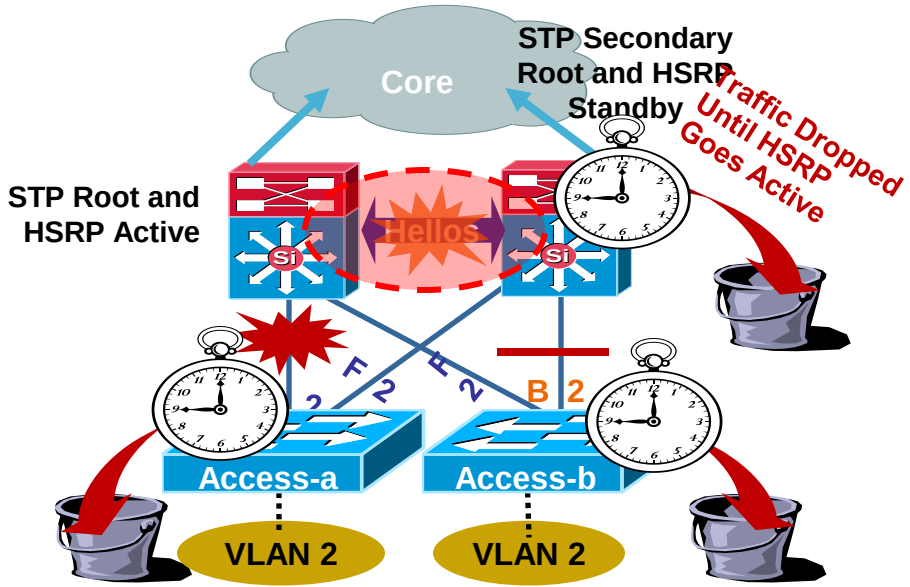
New Technology Addresses Old Problems

- **Stackwise/Stackwise-Plus** technology eliminates the concern
  - Loopback links not required
  - No longer forced to have L2 link in distribution
- If you use modular (chassis-based) switches, these problems are not a concern



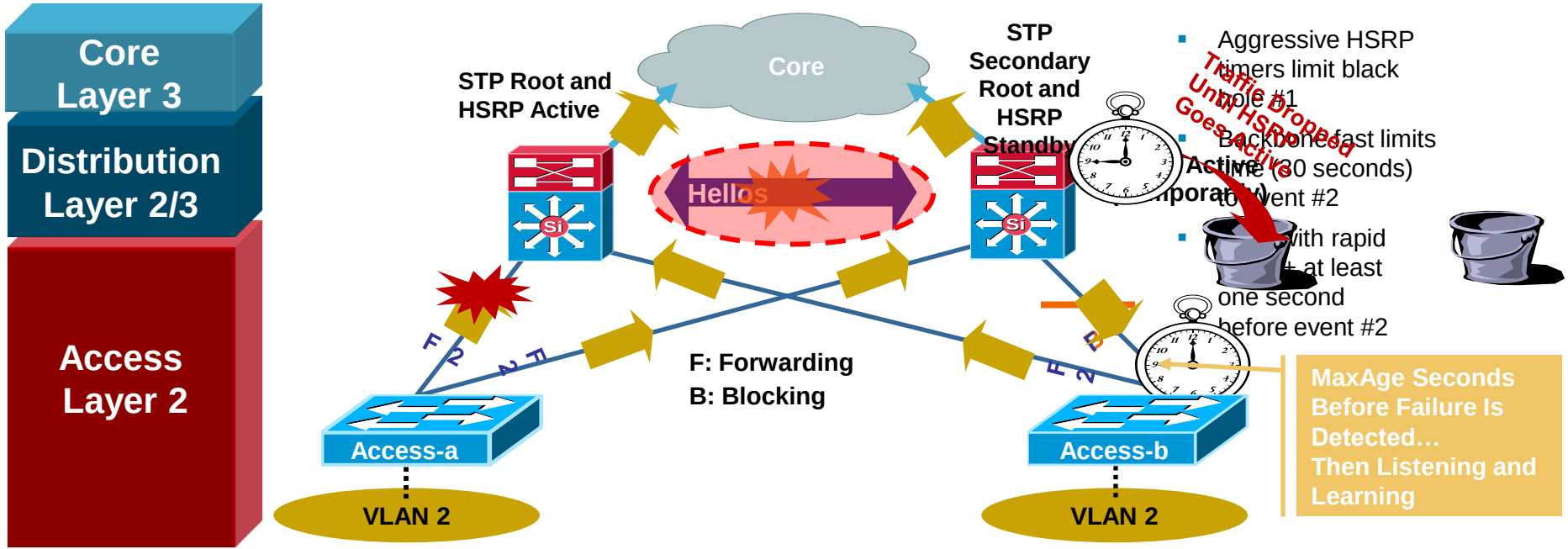
What Happens if You Don't Link the Distributions?

- STPs slow convergence can cause considerable periods of traffic loss
- STP could cause non-deterministic traffic flows/link load engineering
- STP convergence will cause Layer 3 convergence
- STP and Layer 3 timers are independent
- Unexpected Layer 3 convergence and reconvergence could occur
- Even if you do link the distribution switches dependence on STP and link state/connectivity can cause HSRP irregularities and unexpected state transitions



What if You Don't?

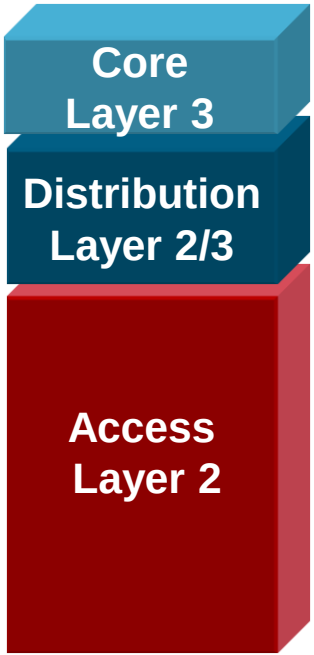
Black Holes and Multiple Transitions …

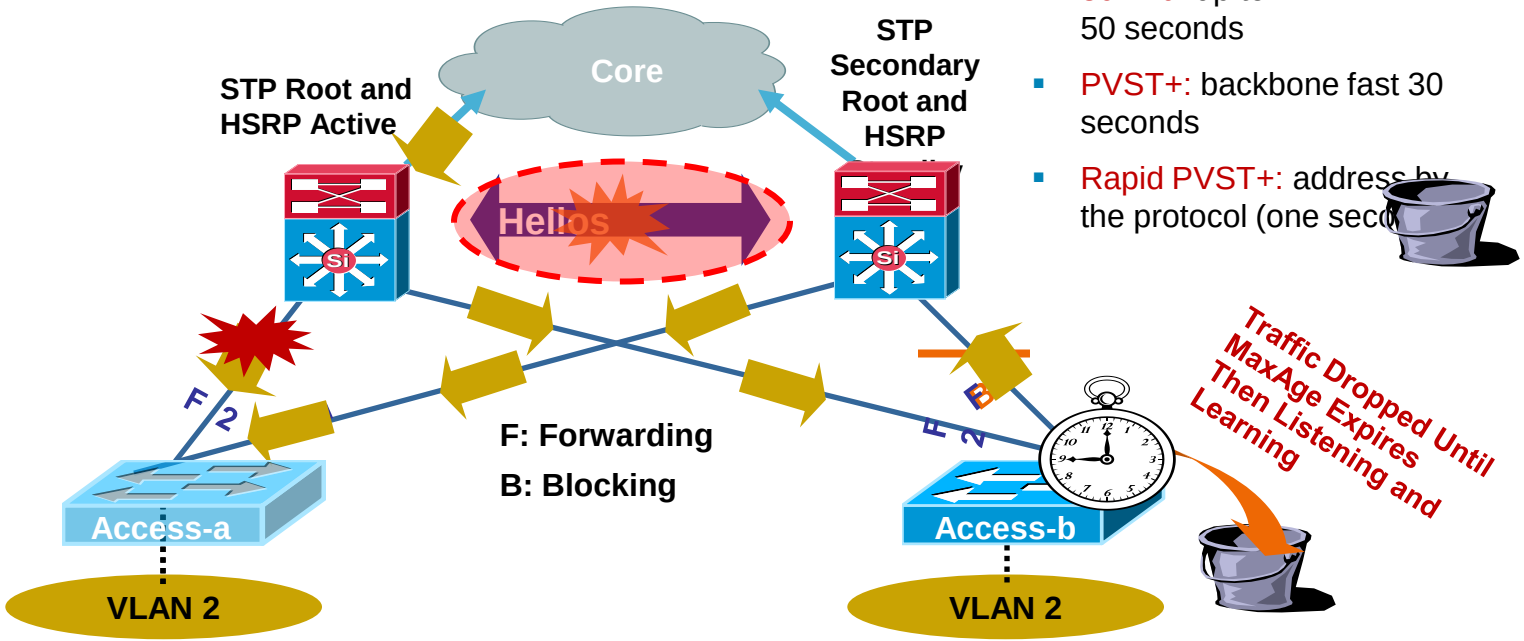


- **Blocking link on access-b will take 50 seconds to move to forwarding → traffic black hole until HSRP goes active on standby HSRP peer**
- **After MaxAge expires (or backbone fast or Rapid PVST+) converges HSRP preempt causes another transition**
- **Access-b used as transit for access-a's traffic**

What If You Don't?

Return Path Traffic Black Holed …



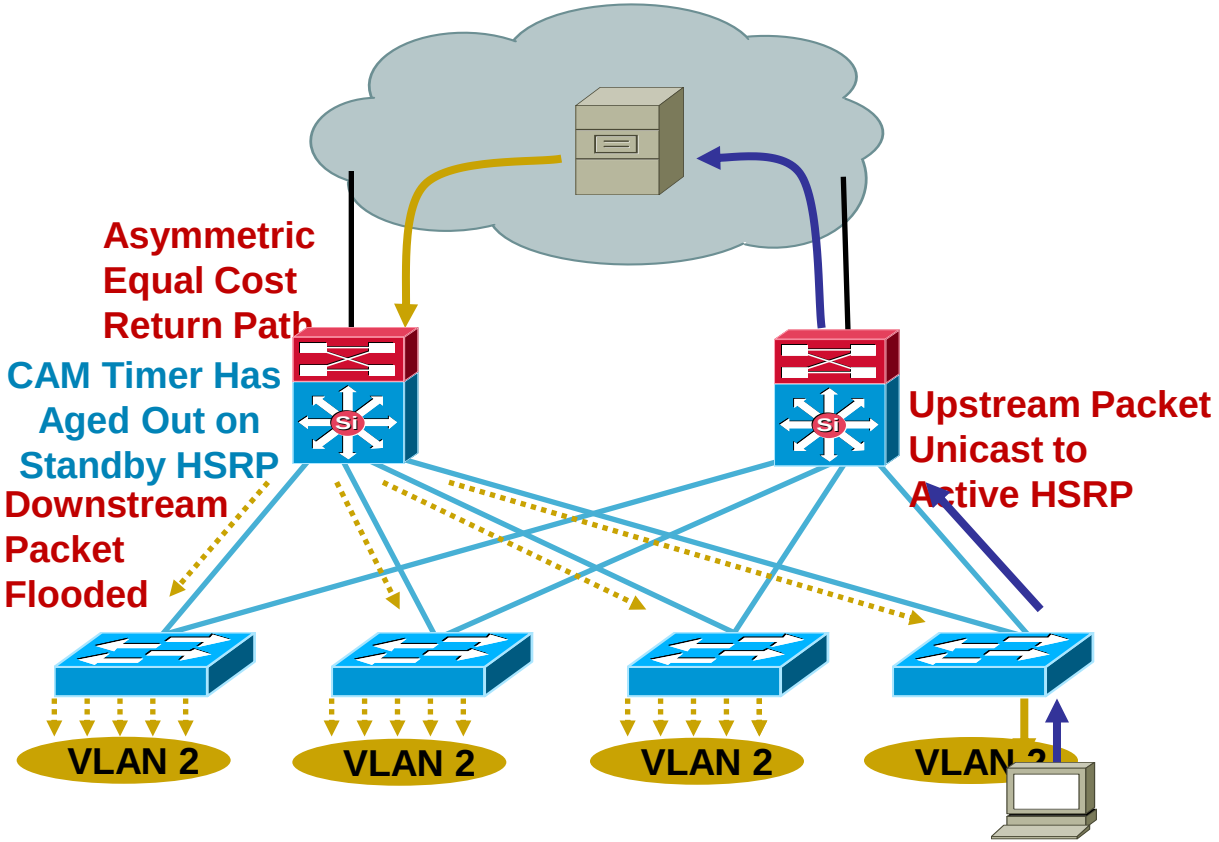


- 802.1d: up to 50 seconds
- PVST+: backbone fast 30 seconds
- Rapid PVST+: address by the protocol (one sec

- Blocking link on access-b will take 50 seconds to move to forwarding → return traffic black hole until then

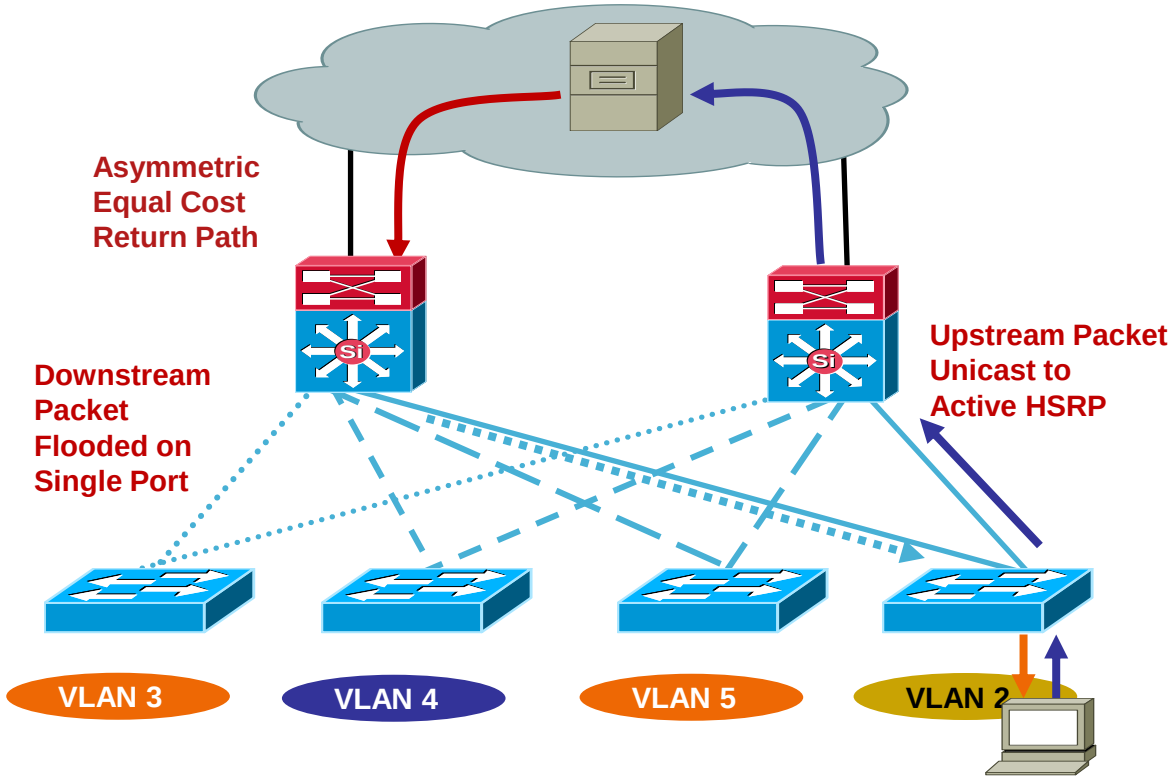
Asymmetric Routing (Unicast Flooding)

- Affects redundant topologies with shared L2 access
- One path upstream and two paths downstream
- CAM table entry ages out on standby HSRP
- Without a CAM entry packet is flooded to all ports in the VLAN



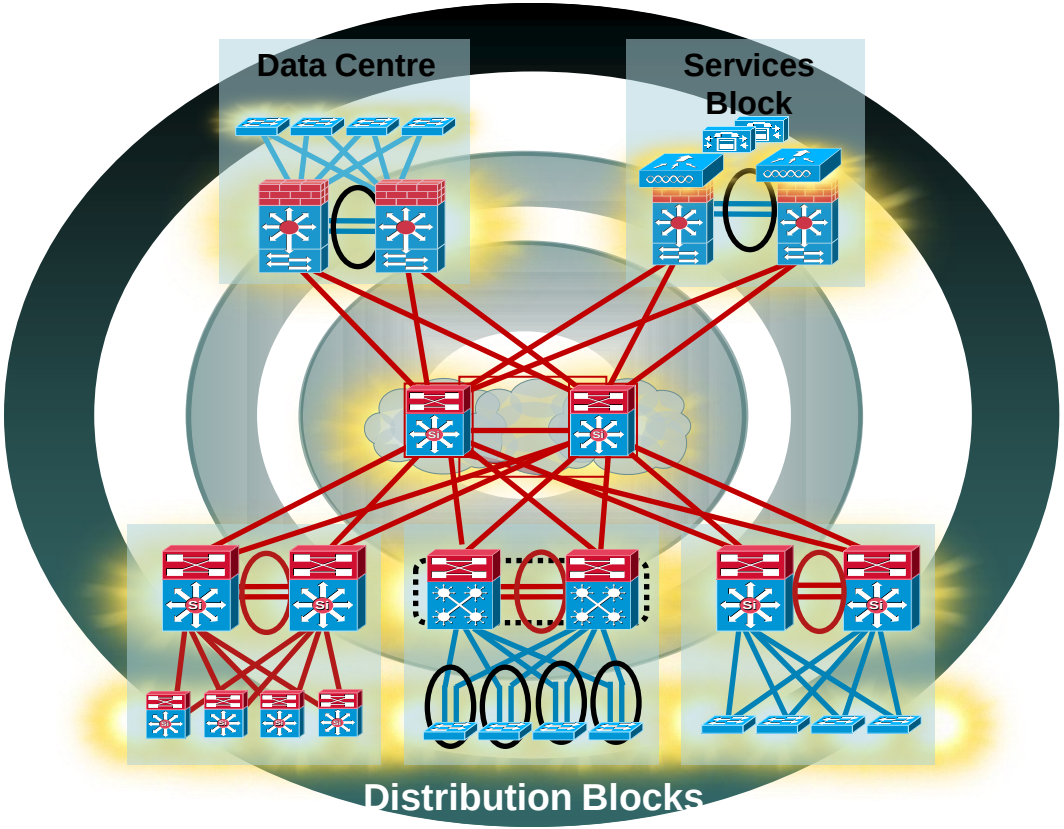
Best Practices Prevent Unicast Flooding

- Assign one unique data and voice VLAN to each access switch
- Traffic is now only flooded down one trunk
- Access switch unicasts correctly; no flooding to all ports
- If you have to:
  - Tune ARP and CAM aging timers; CAM timer exceeds ARP timer
  - Bias routing metrics to remove equal cost routes



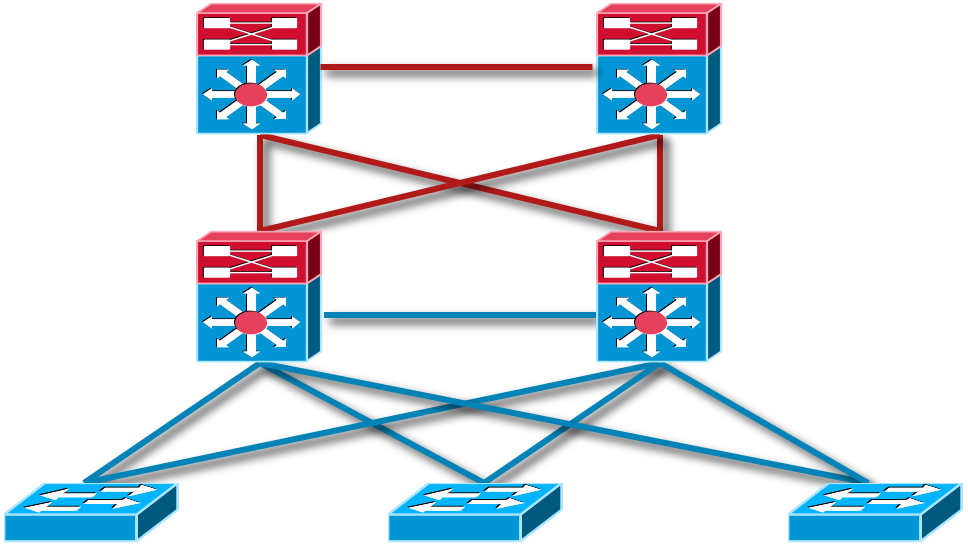
Agenda

- Multilayer Campus Design Principles
- Foundation Services
- Campus Design Best Practices
- VSS Distribution Block
- Security Considerations
- Putting It All Together
- Summary



Current Network Challenges
Enterprise Campus

Traditional Enterprise Campus deployments have been designed in such a way that allows for scalability, differentiated services and high availability. However they also face many challenges, some of which are listed in the below diagram…



Extensive routing topology, Routing reconvergence

FHRP, STP, Asymmetric routing, Policy Management

Single active uplink per VLAN (PVST), L2 reconvergence

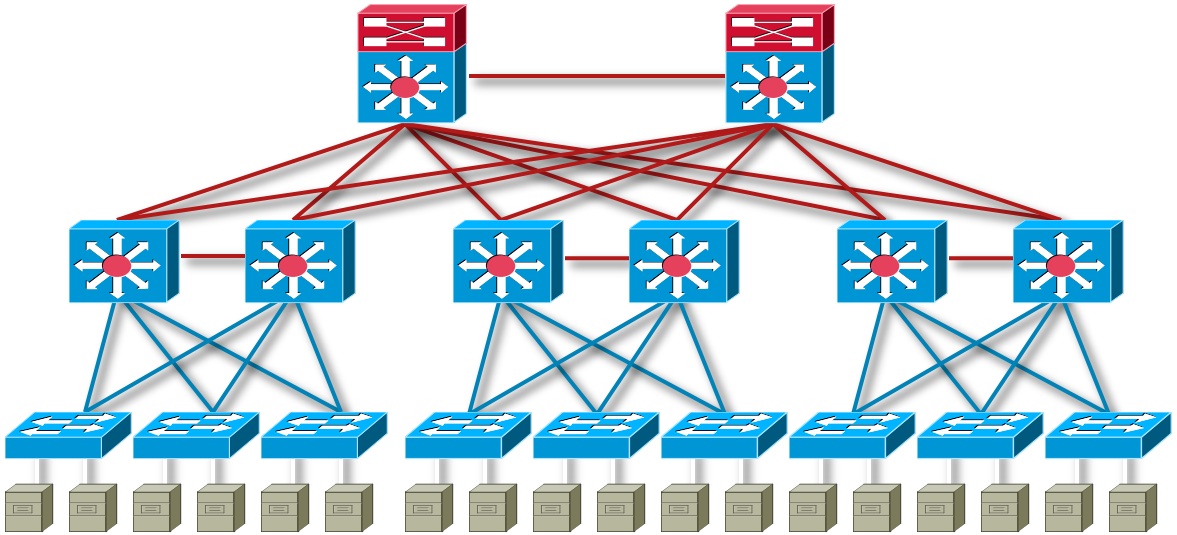
Current Network Challenges
Data Centre

Traditional Data Centre designs are increasingly requiring Layer 2 adjacencies between Server nodes due to the use of Server Virtualisation technology. However, these designs are pushing the limits of Layer 2 networks, placing more burden on loop-detection protocols such as Spanning Tree…

FHRP, HSRP, VRRP
Spanning Tree
Policy Management

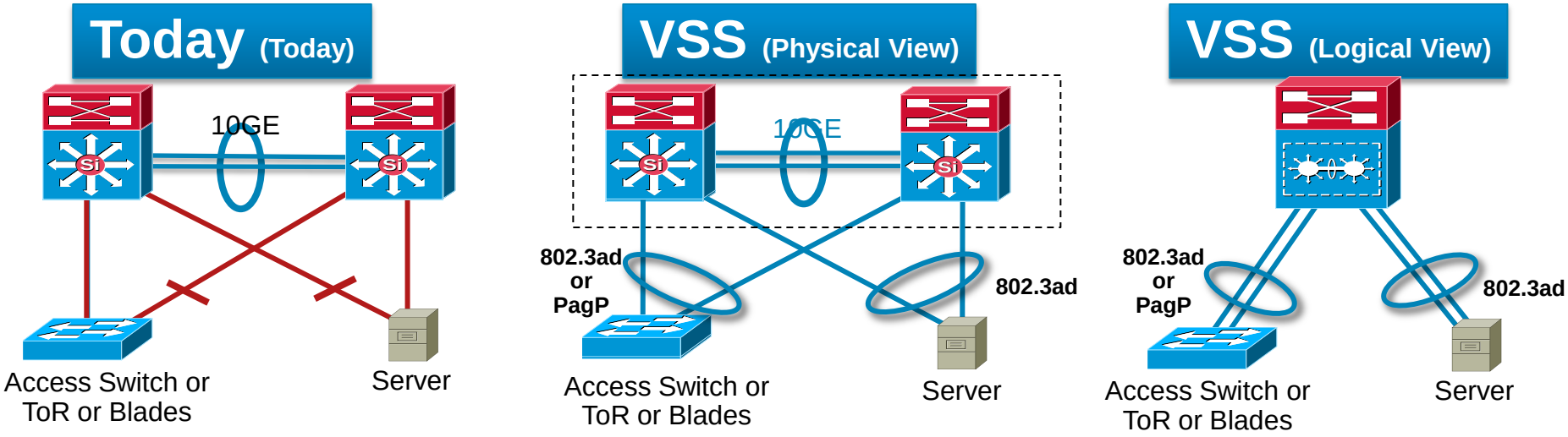
Single active uplink per VLAN (PVST), L2 reconvergence, excessive BPDUs

Dual-Homed Servers to single switch, Single active uplink per VLAN (PVST), L2 reconvergence



Catalyst 6500 Virtual Switching System

Overview



Simplifies operational Manageability via Single point of Management, Elimination of STP, FHRP etc

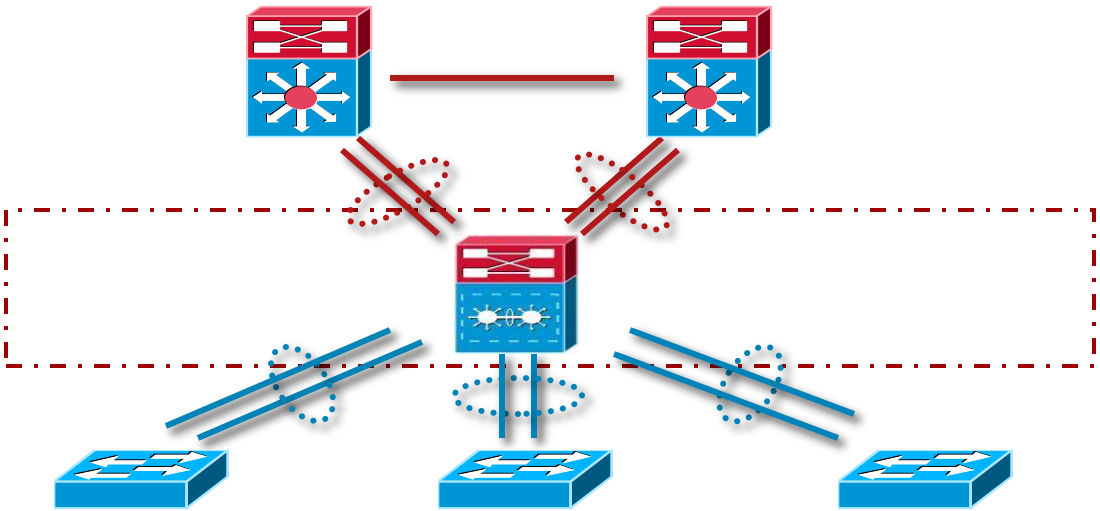
Doubles bandwidth utilisation with Active-Active Multi-Chassis Etherchannel (802.3ad/PagP) Reduce Latency

Minimises traffic disruption from switch or uplink failure with Deterministic subsecond Stateful and Graceful Recovery (SSO/NSF)

Virtual Switching System

Enterprise Campus

A Virtual Switching System-enabled Enterprise Campus network takes on multiple benefits including simplified management & administration, facilitating greater high availability, while maintaining a flexible and scalable architecture…



Reduced routing neighbours, Minimal L3 reconvergence

No FHRPs
No Looped topology
Policy Management

Multiple active uplinks per VLAN, No STP convergence

Virtual Switching System

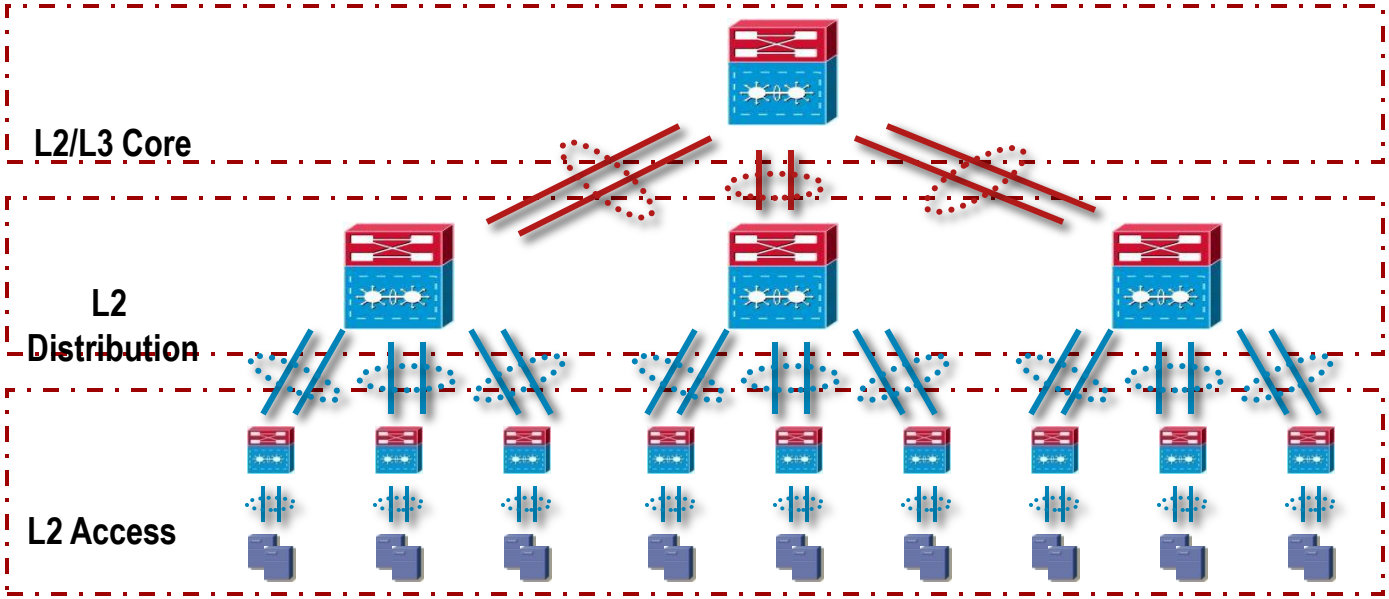
Data Centre

A Virtual Switching System-enabled Data Centre allows for maximum scalability so bandwidth can be added when required, but still providing a larger Layer 2 hierarchical architecture free of reliance on Spanning Tree…

Single router node, Fast L2 convergence, Scalable architecture

Dual Active Uplinks, Fast L2 convergence, minimised L2 Control Plane, Scalable

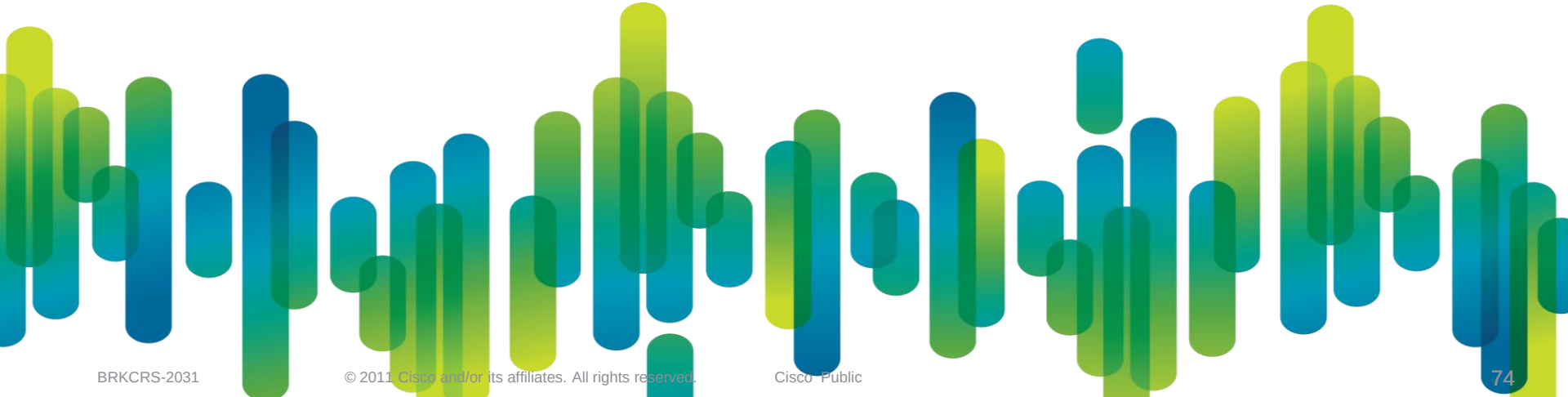
Dual-Homed Servers, Single active uplink per VLAN (PVST), Fast L2 convergence



VSS Simplifies the Configuration

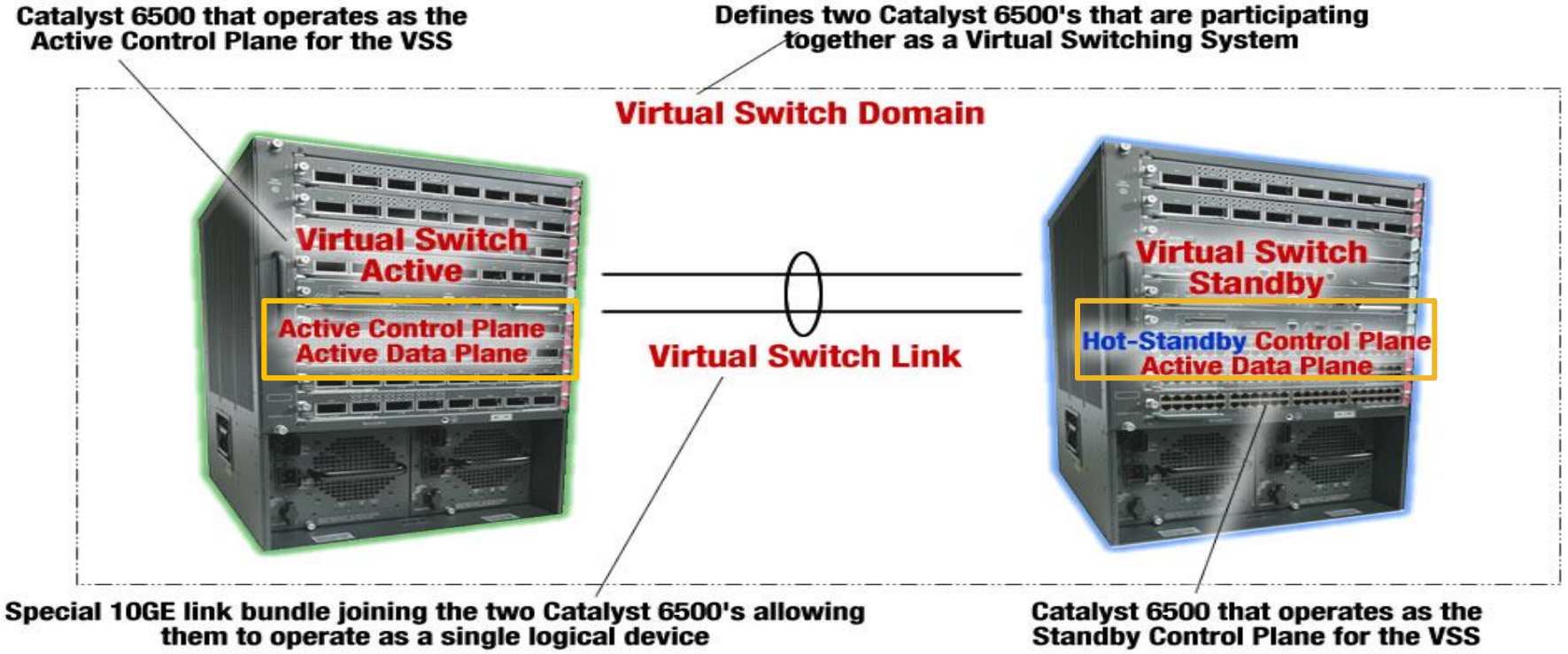
Standalone (two coordinated switch configurations)	VSS (single configuration)
Spanning Tree Configuration	
! Enable 802.1d per VLAN spanning tree enhancements. spanning-tree mode pvst **spanning-tree loopguard default** no spanning-tree optimize bpdu transmission spanning-tree extend system-id **spanning-tree uplinkfast** **spanning-tree backbonefast** **spanning-tree vlan 2-7,20-51,102-149,202-207,220-249 priority 24576**!	! Enable 802.1d per VLAN spanning tree enhancements spanning-tree mode rapid-pvst no spanning-tree optimize bpdu transmission spanning-tree extend system-id spanning-tree vlan 2-7,20-51,102-149,202-207,220-249 priority 24576
L3 SVI Configuration	
! Define the Layer 3 SVI for each voice and data VLAN interface Vlan4 description Data VLAN for 4507 SupII+ ip address 10.120.4.3 255.255.255.0 no ip redirects no ip unreachables **! Reduce PIM query interval to 250 msec** **ip pim query-interval 250 msec** **ip pim sparse-mode** load-interval 30 **! Define HSRP default gateway with 250/800 msec hello/hold** **standby 1 ip 10.120.4.1** **standby 1 timers msec 250 msec 800** **! Set preempt delay large enough to allow network to stabilize before HSRP** **! switches back on power on or link recovery** **standby 1 preempt delay minimum 180** **! Enable HSRP authentication** **standby 1 authentication cisco123**	! Define the Layer 3 SVI for each voice and data VLAN interface Vlan2 description Data VLAN for 4507 SupII+ ip address 10.120.2.1 255.255.255.0 no ip redirects no ip unreachables ip pim sparse-mode load-interval 30

VSS Architecture



Introduction to Virtual Switching System

Concepts



Virtual Switching System

Virtual Switching System Architecture

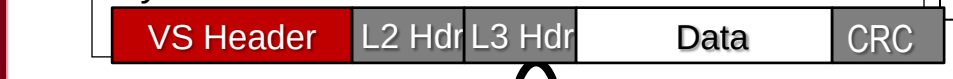
Virtual Switch Link (VSL)

The Virtual Switch Link joins the two physical switch together - it provides the mechanism to keep both the chassis in sync

A Virtual Switch Link bundle can consist of up to 8 x 10GE links

All traffic traversing the VSL link is encapsulated with a 32 byte "Virtual Switch Header" containing ingress and egress switchport indexes, class of service (COS), VLAN number, other important information from the layer 2 and layer 3 header

Control plane uses the VSL for CPU to CPU communications while the data plane uses the VSL to extend the internal chassis fabric to the remote chassis



Virtual Switch Link

Virtual Switch Active

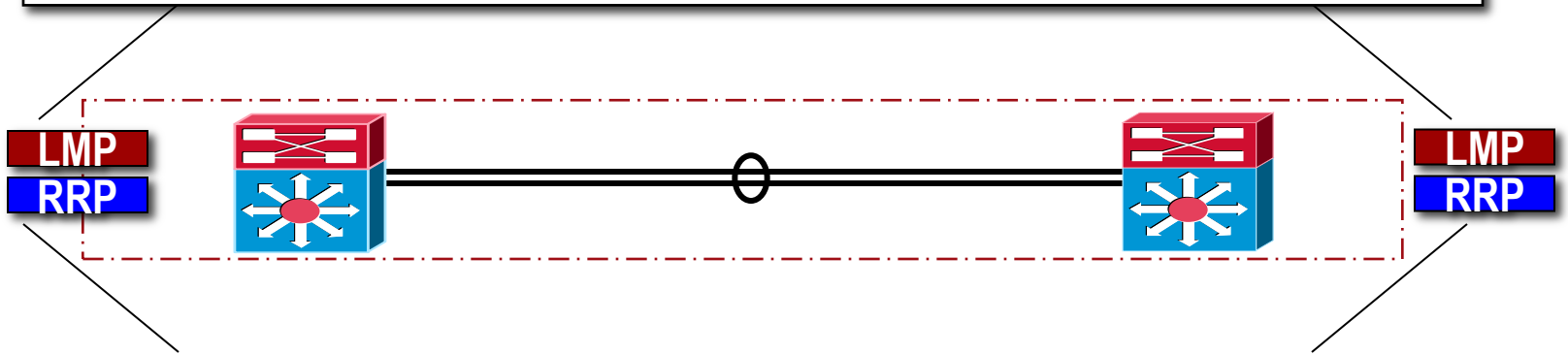
Virtual Switch Standby

Virtual Switching System Architecture

Initialisation

Before the Virtual Switching System domain can become active, the Virtual Switch Link must be brought online to determine Active and Standby roles. The initialisation process essentially consists of 3 steps:

1. **Link Bringup to determine which ports form the VSL**
2. **Link Management Protocol (LMP) used to track and reject Unidirectional Links, Exchange Chassis ID and other information between the 2 switches**

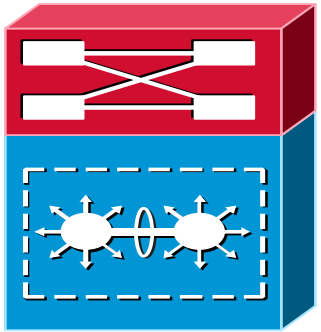


3. **Role Resolution Protocol (RRP) used to determine compatible Hardware and Software versions to form the VSL as well as determine which switch becomes Active and Hot Standby from a control plane perspective**

Virtual Switching System Architecture

VSL Configuration Consistency Check

After the roles have been resolved through RRP, a Configuration Consistency Check is performed across the VSL switches to ensure proper VSL operation. The following items are checked for consistency:



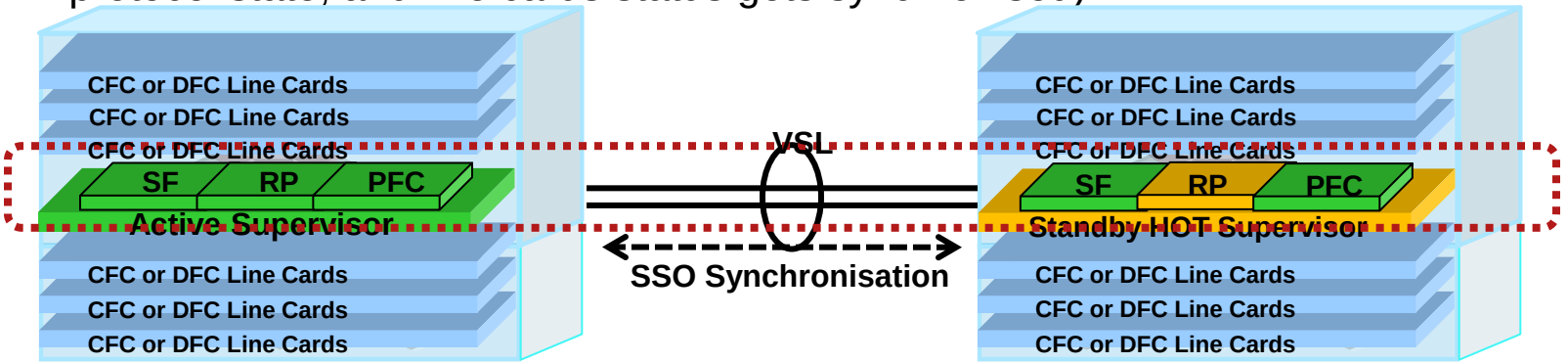
- Switch Virtual Domain ID
- Switch Virtual Switch ID
- Switch Priority
- Switch Preempt
- VSL Port Channel Link ID
- VSL Port state, interfaces…
- Power Redundancy mode
- Power Enable on VSL cards

Note that if configurations do not match, the Hot-Standby Supervisor will revert to RPR mode, disabling all non-VSL interfaces…

Virtual Switching System

Unified Control Plane

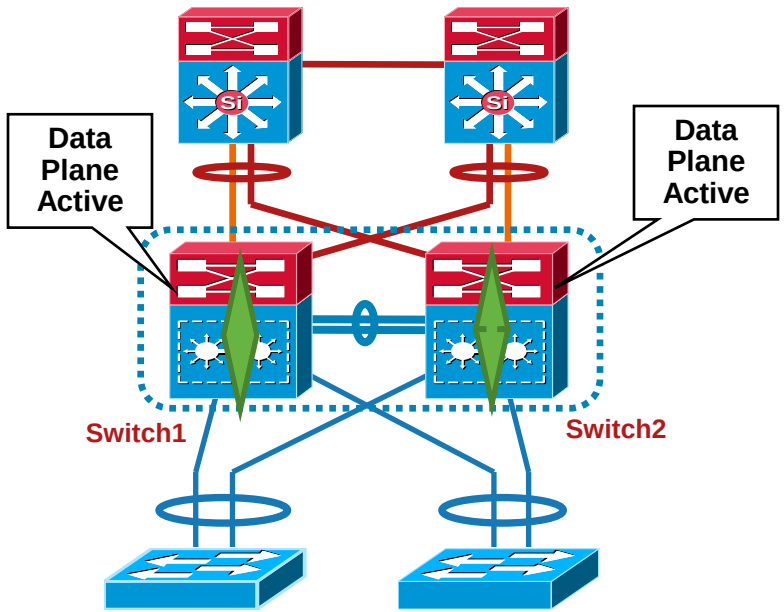
- One active supervisor in each chassis with inter-chassis Stateful Switchover (SSO)
- **Active** supervisor manages the **control plane functions** such as protocols (routing, EtherChannel, SNMP, telnet, etc.) and hardware control (Online Insertion Removal, port management)
- **Active/Standby** supervisors run in synchronised mode (boot-env, running-configuration, protocol state, and line cards status gets synchronised)



Virtual Switching System
Dual Active Forwarding Planes

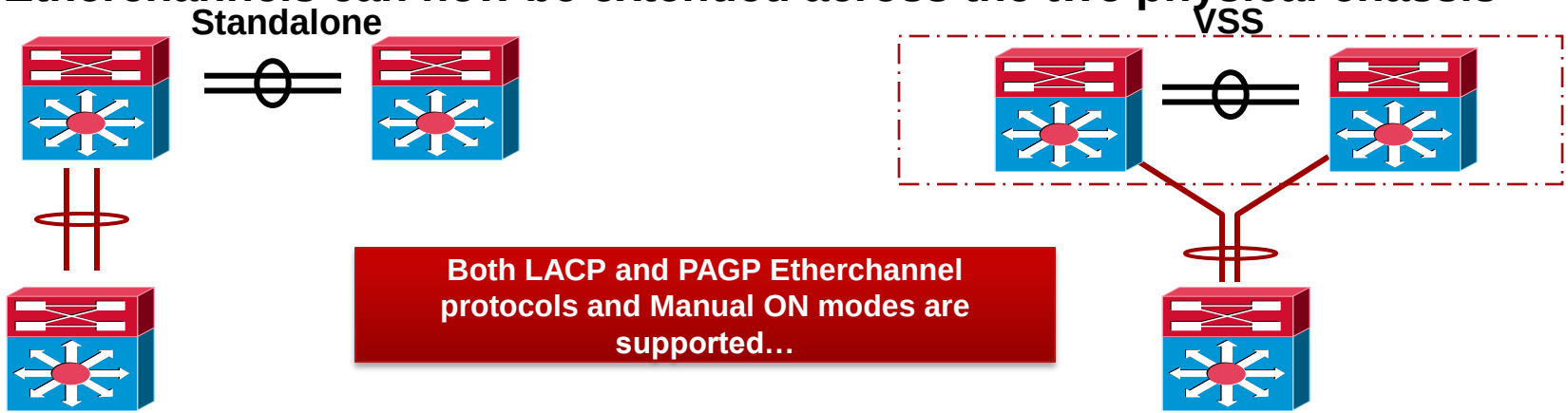
- Both forwarding planes are active
- Standby supervisor and all linecards including DFC's are actively forwarding

```
VSS# show switch virtual redundancy
My Switch Id = 1
Peer Switch Id = 2
<snip>
Switch 1 Slot 5 Processor Information :
-------------------------------------------------
  Current Software state = ACTIVE
<snip>
                Fabric State = ACTIVE
     Control Plane State = ACTIVE
Switch 2 Slot 5 Processor Information :
-------------------------------------------------
  Current Software state = STANDBY HOT
   (switchover target)
 <snip>
                Fabric State = ACTIVE
     Control Plane State = STANDBY
```



Virtual Switching System Architecture
Multichassis EtherChannel (MEC)

Prior to the Virtual Switching System, Etherchannels were restricted to reside within the same physical switch. In a Virtual Switching environment, the two physical switches form a single logical network entity - therefore Etherchannels can now be extended across the two physical chassis



Regular Etherchannel on single chassis

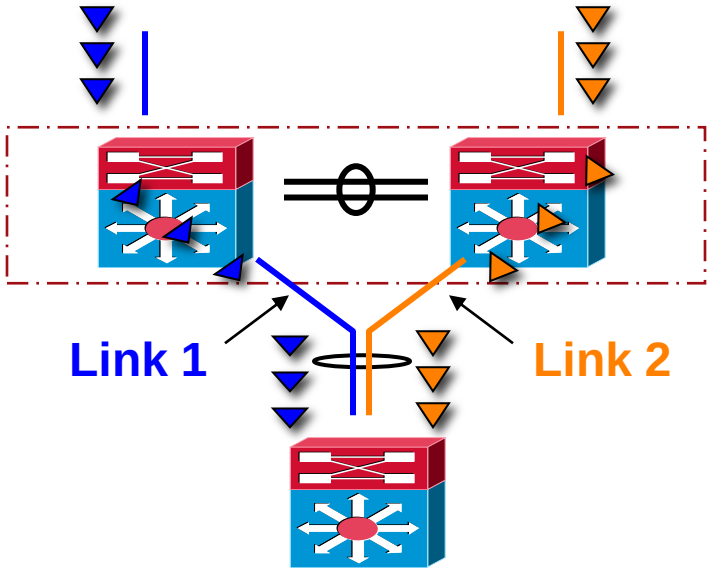
Multichassis EtherChannel across 2 VSS-enabled chassis

Virtual Switching System Architecture

EtherChannel Hash for MEC

Etherchannel hashing algorithms are modified in VSS to always favor locally attached interfaces

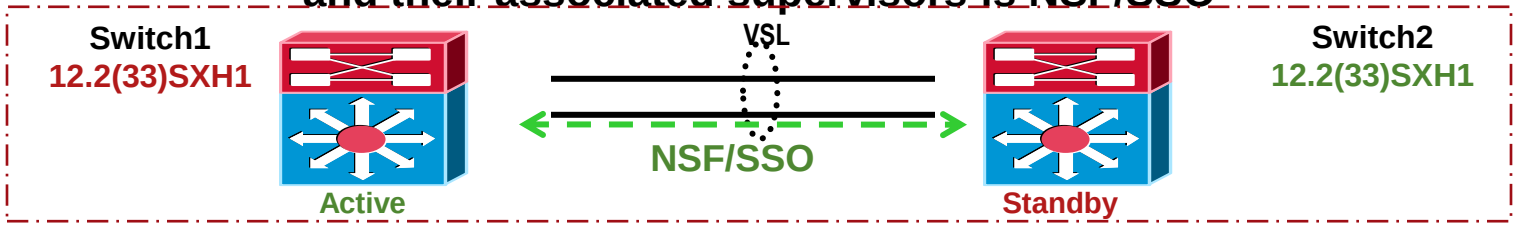
Blue Traffic destined for the Server will result in **Link 1** in the MEC link bundle being chosen as the destination path…



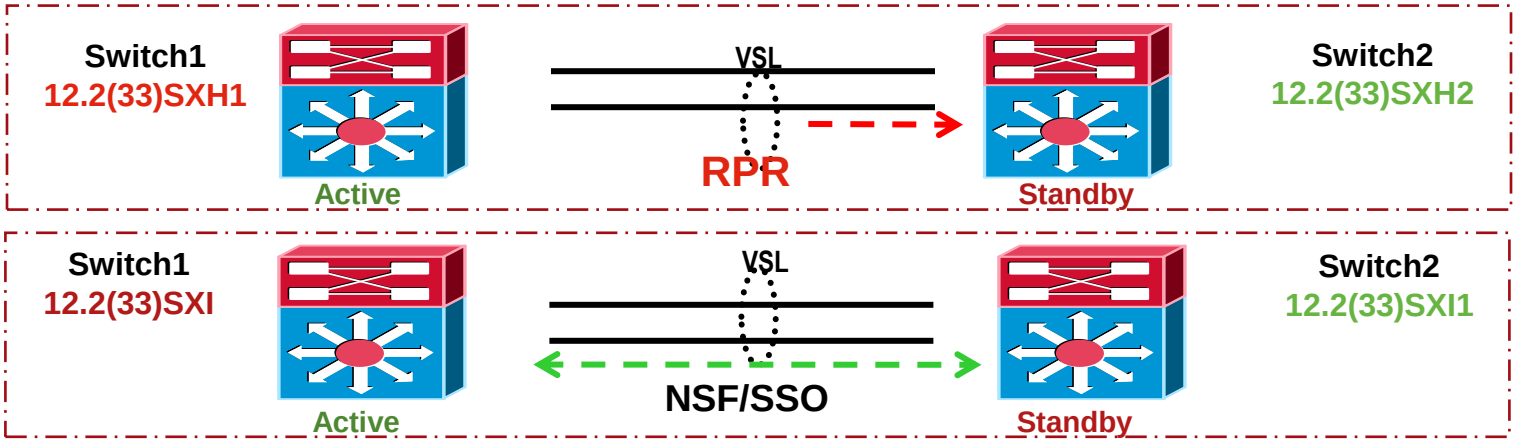
Orange Traffic destined for the Server will result in **Link 2** in the MEC link bundle being chosen as the destination path…

High Availability
Redundancy Schemes

Default redundancy mechanism between the two VSS chassis and their associated supervisors is NSF/SSO

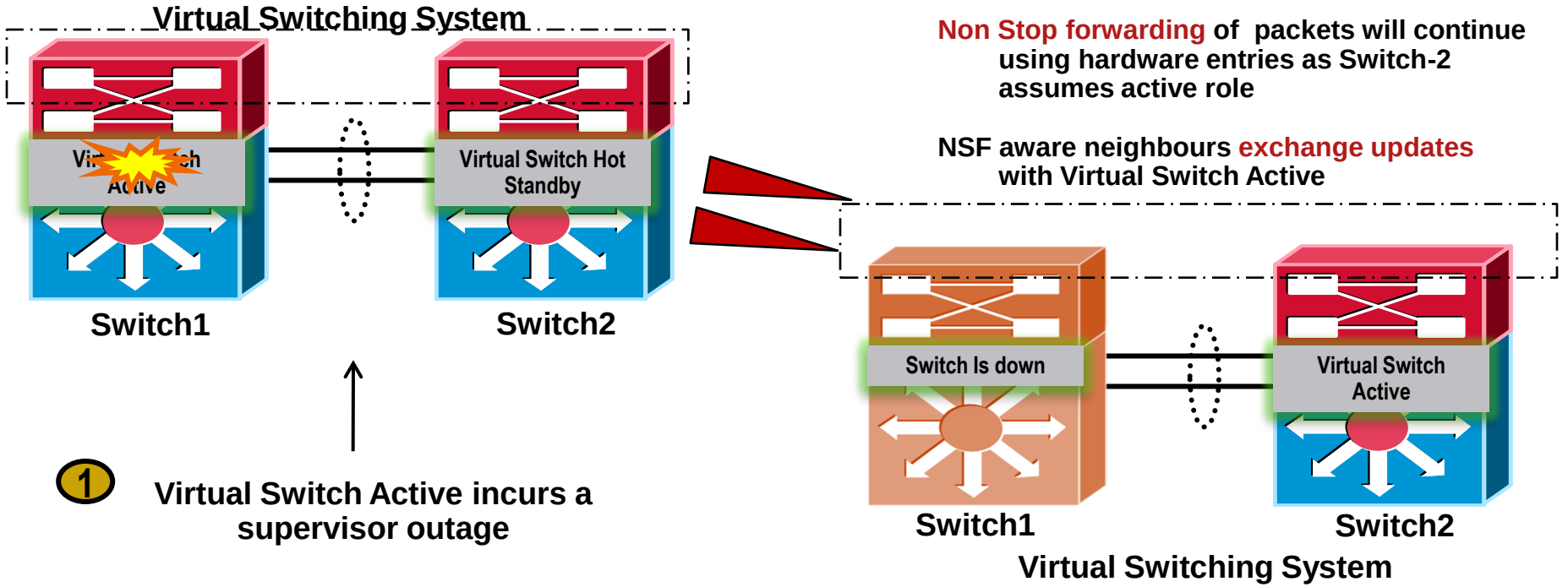


If a mismatch of information occur between the Active & Standby, the Standby will revert to RPR mode
Starting 12.2(33)SXI, minor mis-match in software will be still keep the switch in SSO mode



Virtual Switching System

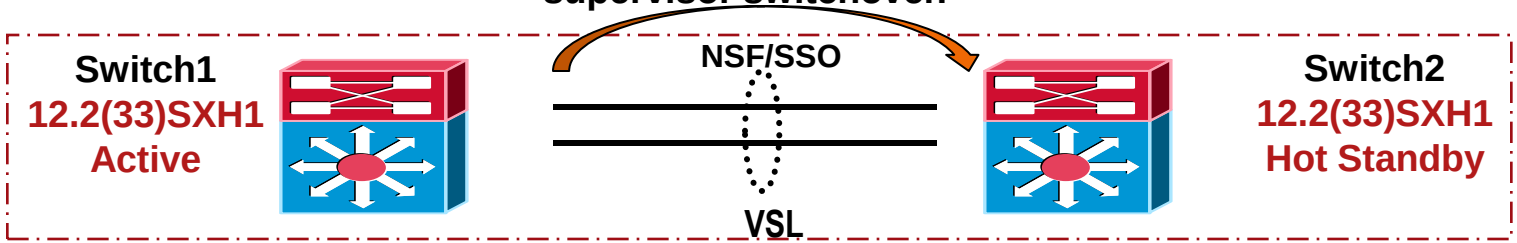
Inter Chassis NSF/SSO



High Availability

NSF/SSOz

NSF feature with SSO minimises the amount of traffic loss following supervisor switchover while continuing to forward traffic using hardware entries. In VSS environment this feature is required to minimise traffic disruption in the event such as supervisor failure that causes supervisor switchover.

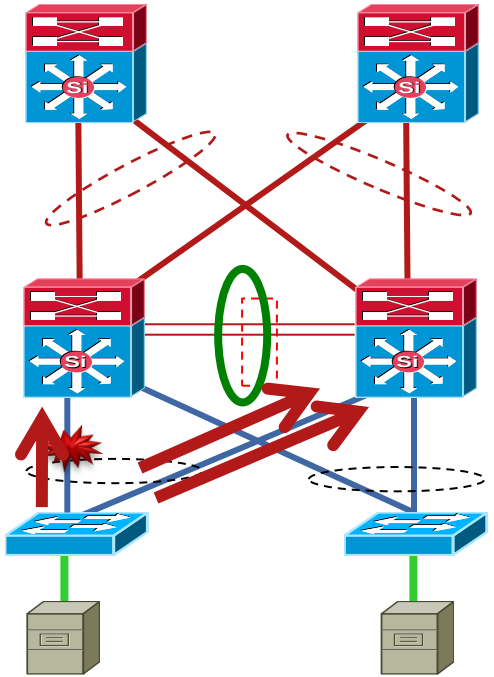



```
VSS#config t
VSS(config)#router ospf 1
VSS(config-router)#nsf

VSS#show ip ospf
 Routing Process "ospf 10" with ID 192.168.2.1
 Start time: 00:15:29.344, Time elapsed: 23:12:03.484
 Supports only single TOS(TOS0) routes
 External flood list length 0
 Non-Stop Forwarding enabled
 IETF NSF helper support enabled
 Cisco NSF helper support enabled
 Reference bandwidth unit is 100 mbps
```

NSF is supported by the BGP, EIGRP, OSPF & IS-IS

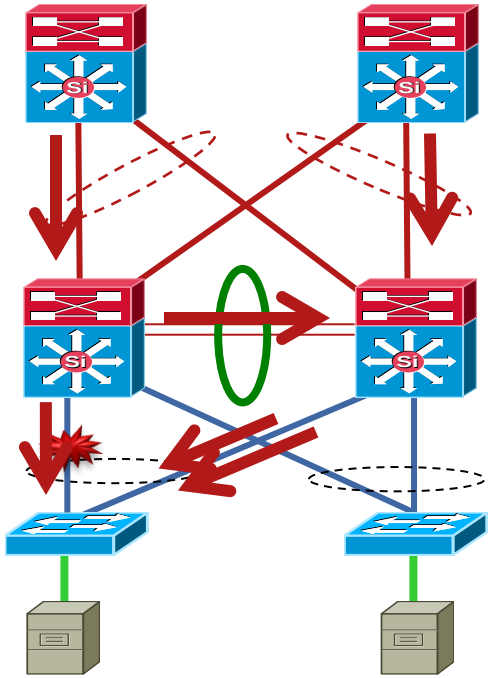
High Availability
Failure of MEC member – Upstream Traffic

- Convergence is determined by Access device
- Etherchannel convergence - typically 200ms
- Typically only the flows on the failed link are effected



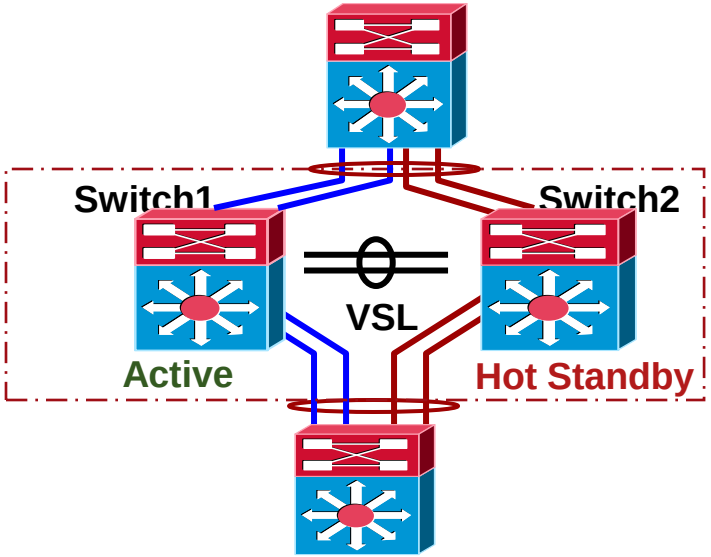
High Availability
Failure of MEC member – Downstream Traffic

- Convergence is determined by VSS
- VSS Etherchannel convergence
  - Typically Sub - 200ms
  - Only the flows on the failed link are effected



High Availability
Dual-Active Detection

In a Virtual Switching System Domain, one switch is elected as Active and the other is elected as Standby during boot up by VSLP. Since the VSL is always configured as a Port Channel, the possibility of the entire VSL bundle going down is remote, however it is a possibility…



Recommendation is to deploy the VSL with two or more links and distribute those interfaces across multiple modules to ensure the highest redundancy

High Availability
Dual-Active Detection

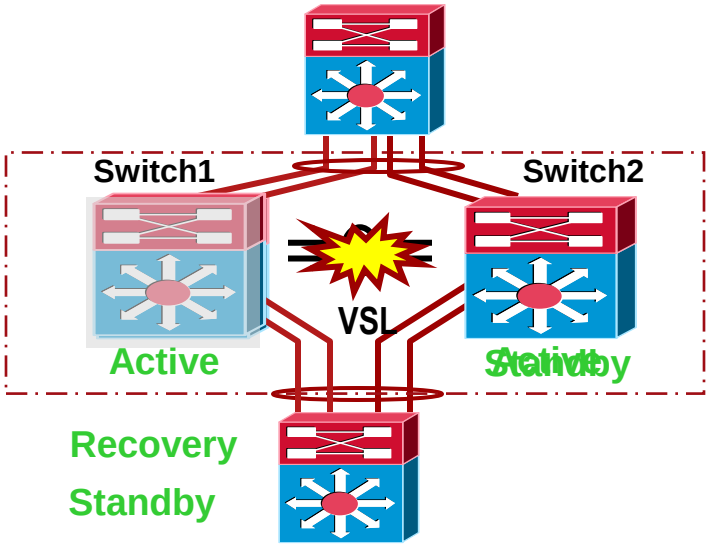
If the entire VSL bundle should happen to go down, the Virtual Switching System Domain will enter a Dual Active scenario where both switches transition to Active state and share the same network configuration (IP addresses, MAC address, Router IDs, etc…) potentially causing communication problems through the network…

3 Step Process

1. **Dual-Active detection (using one or more of three available methods)**

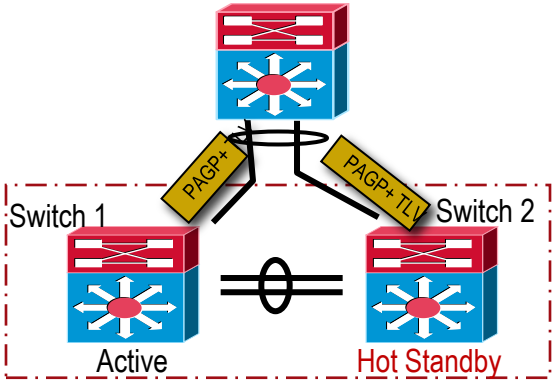
2. **Recovery Period- Further network disruption is avoided by disabling previous VSS active switch interfaces connected to neighbouring devices .**

3. **Dual-Active Restoration - when VSL is restored , the switch that has all it's interfaces brought down in the previous step will reload to boot in a preferred standby state**



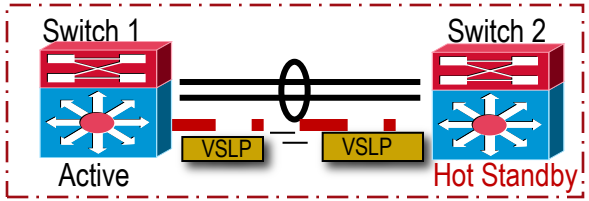
High Availability
Dual-Active Protocols

Enhanced PAgP



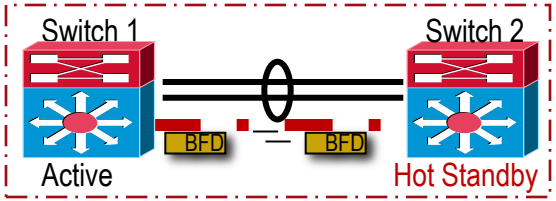
- Requires ePagP capable neighbour :
  - 3750: 12.2(46)SE
  - 4500: 12.2(44)SE
  - 6500: 12.2(33)SXH1
- Sub-second convergence

VSLP Fast Hello



- Direct L2 Connection
- Requires 12.2(33)SXI
- Sub-second convergence

IP-BFD

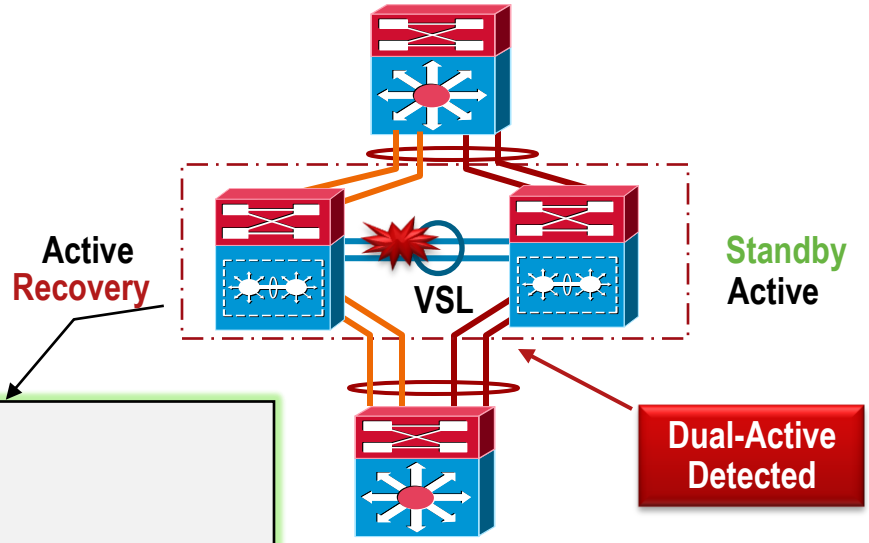


- Direct L3 Connection
- Requires 12.2(33)SXH1
- Seconds of convergence*

High Availability

Dual-Active: Recovery Mode

```
%DUAL_ACTIVE-SW1_SP-1-DETECTION: Dual-active condition detected: all non-VSL and non-
                                 excluded interfaces have been shut down
```



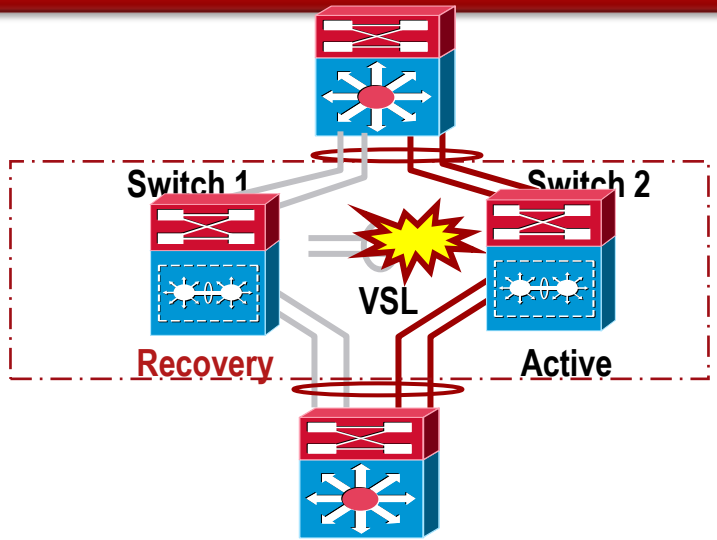

```
VSS#show switch virtual dual-active summary
Pagp dual-active detection enabled: Yes
Bfd dual-active detection enabled: Yes

No interfaces excluded from shutdown in recovery mode

In dual-active recovery mode: Yes
  Triggered by: Pagp detection
  Triggered on interface: Gi1/2/3
```

High Availability
Dual Active: Recovery Mode

Important ! Do not make any configuration changes while in the Dual Active Recovery mode.

If the config is changed the system will not automatically recover once the VSL becomes active again

One must issue the “write memory” command and then reload the switch in recovery mode using the “reload shelf” command



High Availability
Dual-Active Detection – Exclude Interfaces

Upon detection of a Dual Active scenario, all interfaces on the previous-Active switch will be brought down so as not to disrupt the functioning of the remainder of the network.

The “exclude interfaces” include VSL port members as well as any pre-configured ports which may be used for management purposes…

```
vs-vsl#conf t
Enter configuration commands, one per line.  End with CNTL/Z.
vs-vsl(config)#switch virtual domain 100
vs-vsl(config-vs-domain)#dual-active exclude interface Gig 1/5/1
vs-vsl(config-vs-domain)#dual-active exclude interface Gig 2/5/1
vs-vsl(config-vs-domain)# ^Z
vs-vsl#
```

VSS Deployment Best Practices

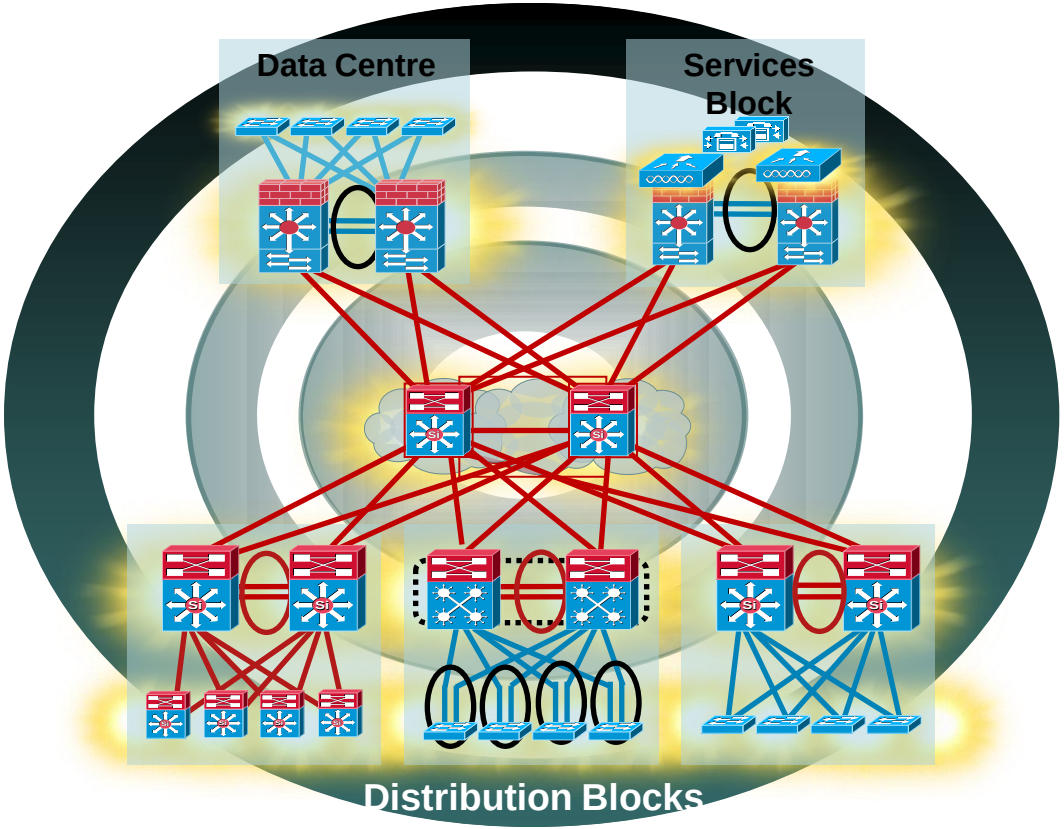
DO
✓ Configure “Switch accept-mode virtual”
✓ Use unique VSS domain-id within the same network
✓ Save backup configuration file in both active & hot-standby bootdisk:
✓ Use a minimum of one Supervisor uplink for the VSL, this provides for faster VSL bring up.
✓ Enable out-of-band MAC sync “mac-address-table synchronise”
✓ Dual-home connected devices whenever possible, use L2 or L3 Multi-Chassis Etherchannel, L3 ECMP
✓ Use ePAgP and VSLP Fast Hello Dual Active Protocol.
✓ Enable NSF under routing protocols

VSS Deployment Best Practices Con't

DO NOT ….
× Tune default VSLP timers unless recommended by cisco
× Use preemption
× Issue "shutdown" for VSL failure, it creates config mismatch. Disconnect cables to create a realistic failure scenario
× Change VSL hashing algorithm in production. It requires a shut/no shut on PO. Shutting down VSL will cause traffic disruption and dual-active scenario.
× "Write-erase" to reset the VSS configuration. "Write-erase" will erase startup-configuration and rommon variables. VSS bring-up process requires "switch-id" to be present in rommon variable to boot in VSS mode. Use "**erase-nvram**" instead.

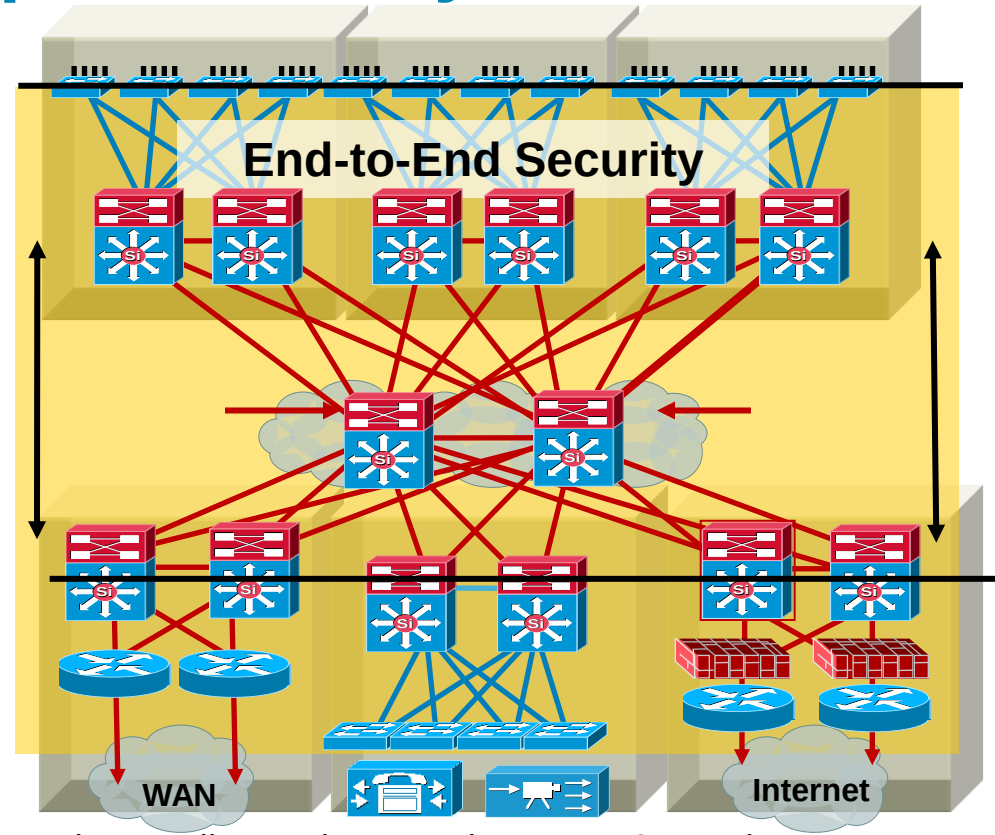
Agenda

- Multilayer Campus Design Principles
- Foundation Services
- Campus Design Best Practices
- VSS Distribution Block
- Security Considerations
- Putting It All Together
- Summary



Best Practices—Campus Security

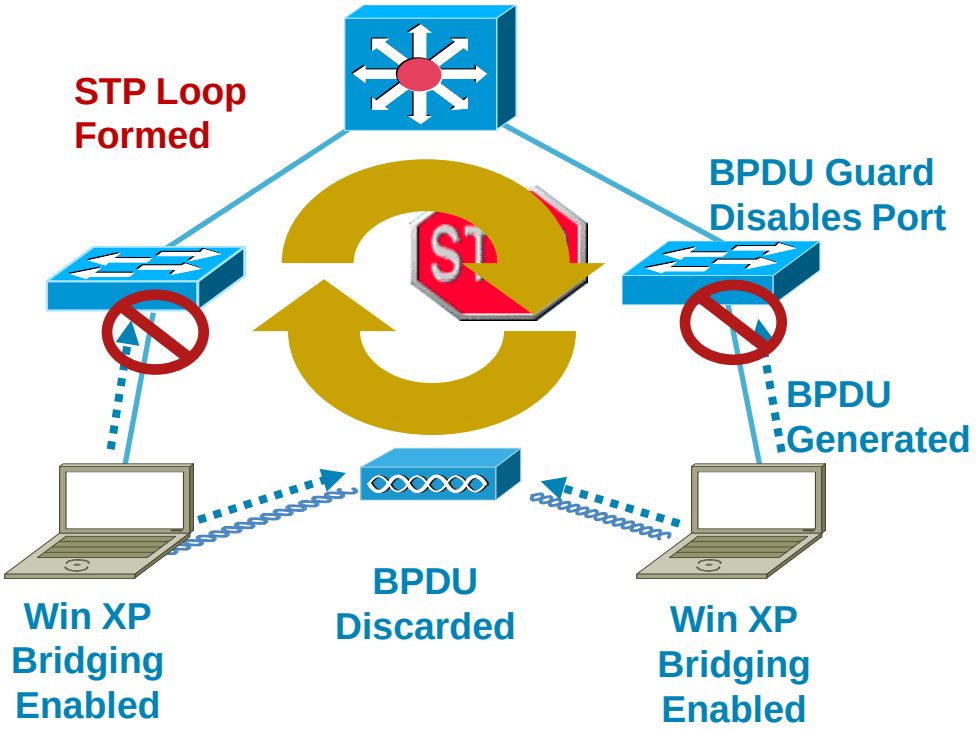
- **New stuff that we will cover!**
  - Catalyst integrated security feature set!
  - Dynamic port security, DHCP snooping, Dynamic ARP inspection, IP source guard
- Things you already know—we won't cover…
  - Use SSH to access devices instead of Telnet
  - Enable AAA and roles-based access control (RADIUS/TACACS+) for the CLI on all devices
  - Enable SYSLOG to a server. Collect and archive logs
  - When using SNMP use SNMPv3
  - Disable unused services:
  - No service tcp-small-servers
    No service udp-small-servers
  - Use FTP or SFTP (SSH FTP) to move images and configurations around—avoid TFTP when possible
  - Install VTY access-lists to limit which addresses can access management and CLI services
  - Enable control plane protocol authentication where it is available (EIGRP, OSPF, BGP, HSRP, VTP, etc.)
  - Apply basic protections offered by implementing RFC2827 filtering on external edge inbound interfaces



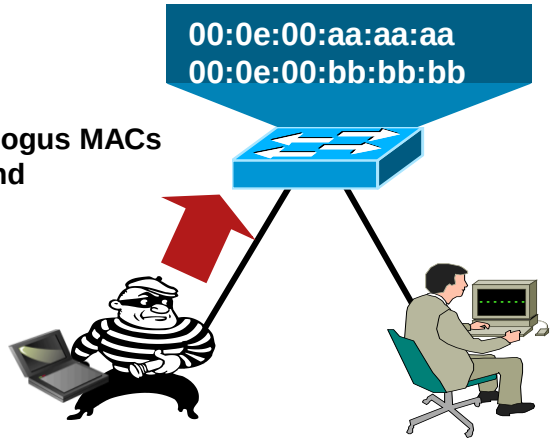
For More Details, See BRKSEC-2002 Session, Understanding and Preventing Layer 2 Attacks

BPDU Guard

- **Problem:**
  - –WLAN APs do not forward BPDUs
  - –Multiple Windows XP machines can create a loop in the wired VLAN via the WLAN
- **Solution:**
  - –BPDU Guard configured on all end-station switch ports will prevent loop from forming



Securing Layer 2 from Surveillance Attacks



Problem:

Script Kiddie Hacking Tools Enable Attackers Flood Switch CAM Tables with Bogus Macs; Turning the VLAN into a Hub and Eliminating Privacy

Switch CAM Table Limit Is Finite Number of Mac Addresses

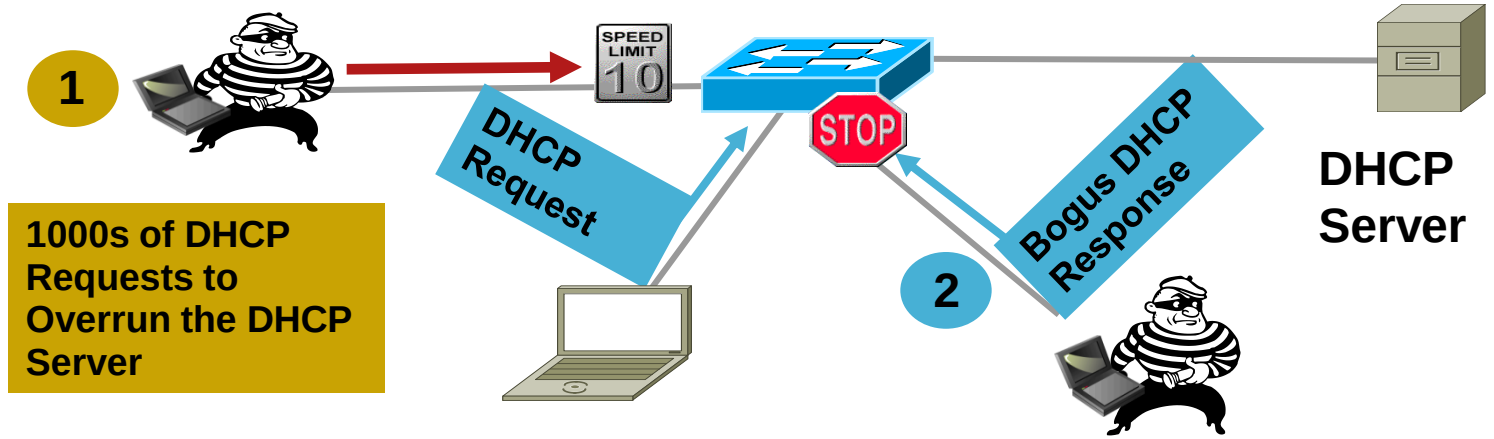
Solution:

Port Security Limits MAC Flooding Attack and Locks Down Port and Sends an SNMP Trap

```
switchport port-security
switchport port-security maximum 10
switchport port-security violation restrict
switchport port-security aging time 2
switchport port-security aging type inactivity
```

DHCP Snooping

Protection Against Rogue/Malicious DHCP Server

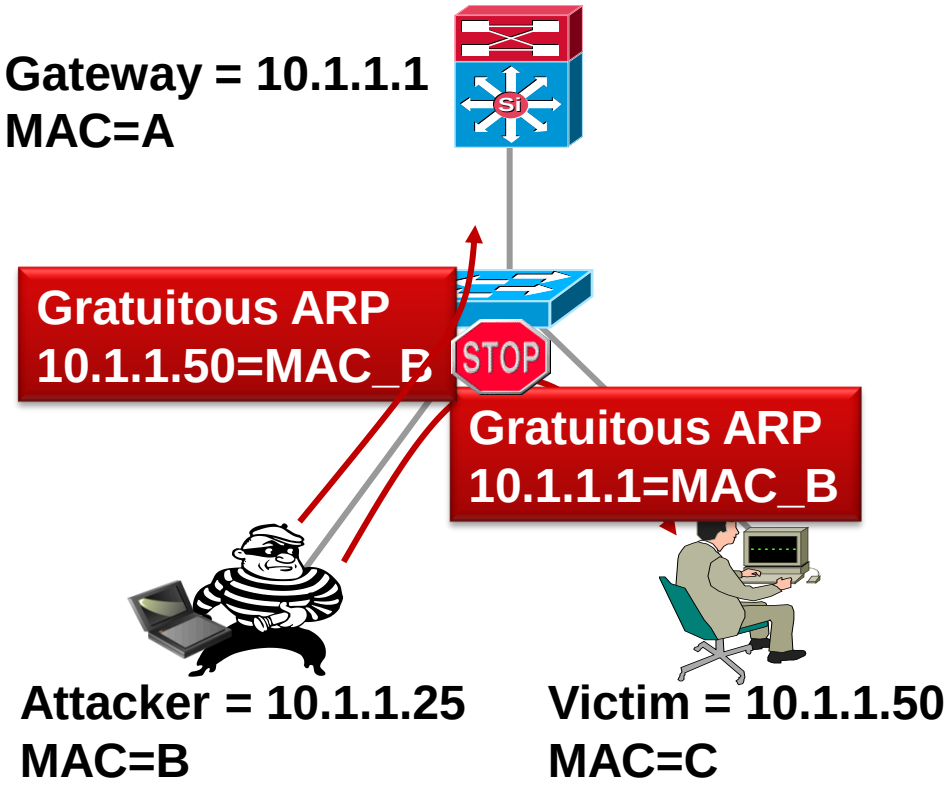


- DHCP requests (discover) and responses (offer) tracked
- Rate-limit requests on trusted interfaces; limits DoS attacks on DHCP server
- Deny responses (offers) on non trusted interfaces; stop malicious or errant DHCP server

Securing Layer 2 from Surveillance Attacks

Protection Against ARP Poisoning

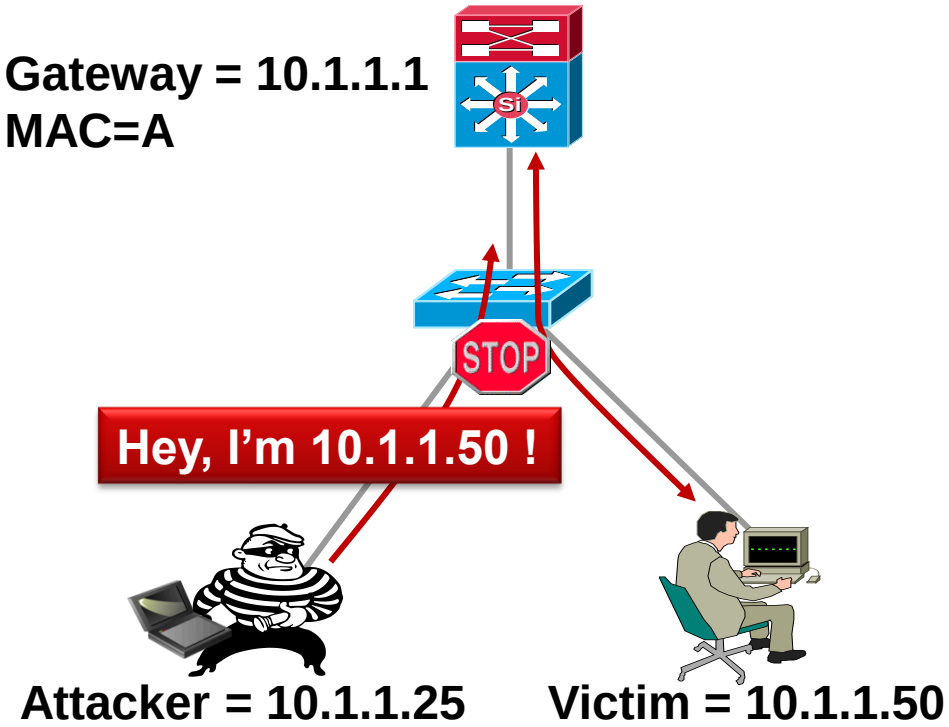
- Dynamic ARP inspection protects against ARP poisoning (ettercap, dsnif, arpspoof)
- Uses the DHCP snooping binding table
- Tracks MAC to IP from DHCP transactions
- Rate-limits ARP requests from client ports; stop port scanning
- Drop **bogus** gratuitous ARPs; stop ARP poisoning/MIM attacks



IP Source Guard

Protection Against Spoofed IP Addresses

- IP source guard protects against spoofed IP addresses
- Uses the DHCP snooping binding table
- Tracks IP address to port associations
- Dynamically programs port ACL to drop traffic not originating from IP address assigned via DHCP



Catalyst Integrated Security Features

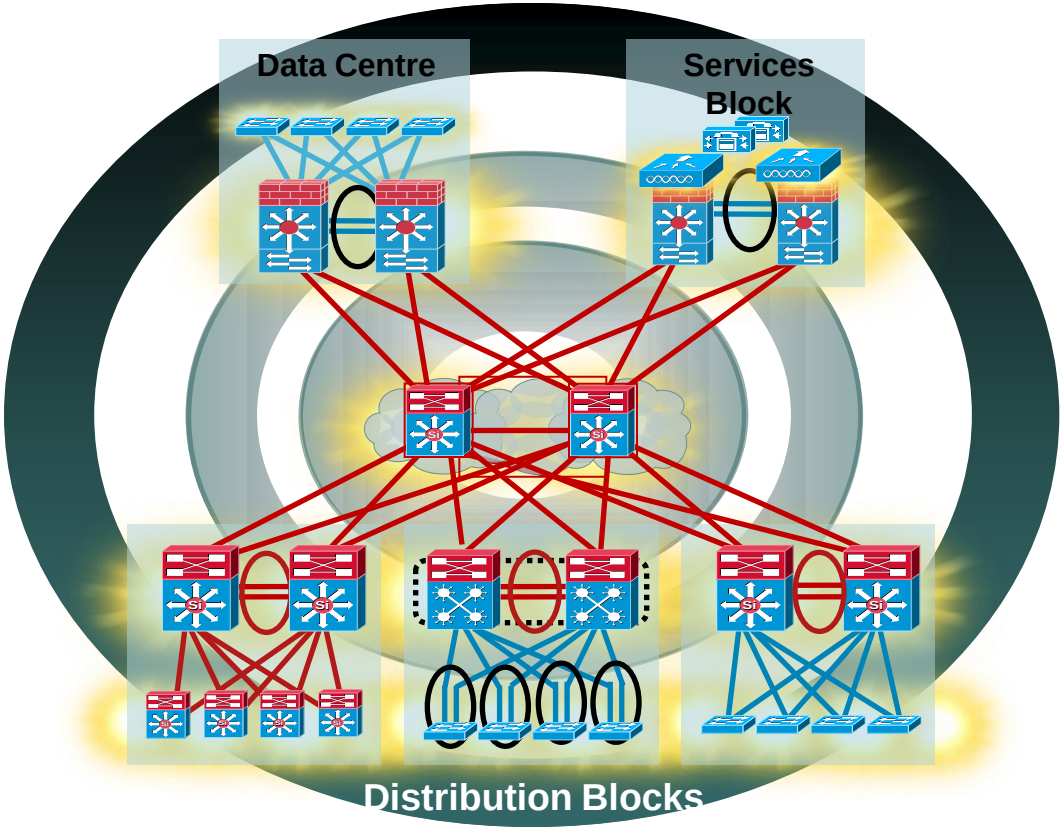
Summary Cisco IOS

- Port security prevents MAC flooding attacks
- DHCP snooping prevents client attack on the switch and server
- Dynamic ARP Inspection adds security to ARP using DHCP snooping table
- IP source guard adds security to IP source address using DHCP snooping table

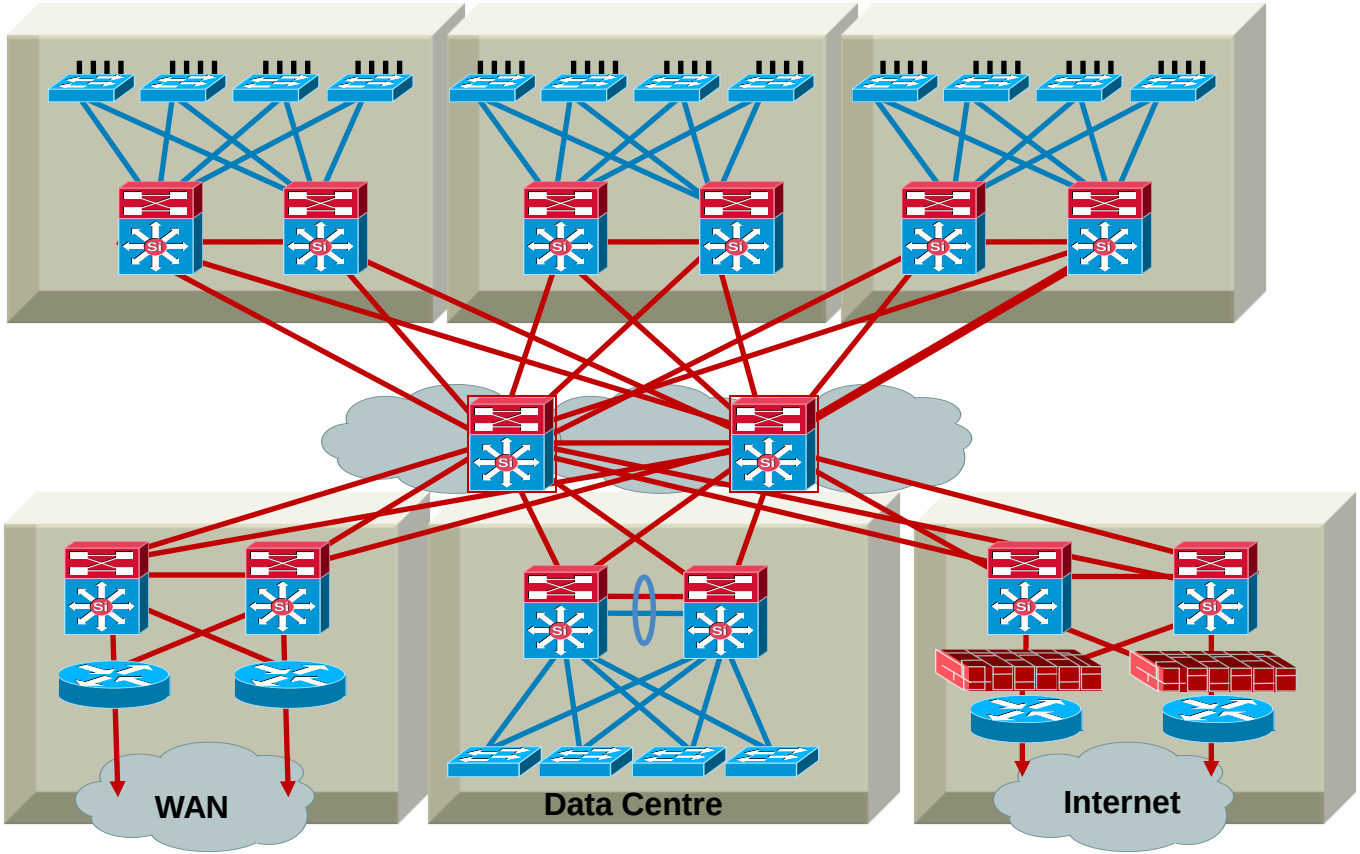
```
ipdhcp snooping
ipdhcp snooping vlan 2-10
iparp inspection vlan 2-10
!
interface fa3/1
switchport port-security
switchport port-security max 3
switchport port-security violation restrict
switchport port-security aging time 2
switchport port-security aging type inactivity
iparp inspection limit rate 100
ipdhcp snooping limit rate 100
ip verify source vlandhcp-snooping
!
Interface gigabit1/1
ipdhcp snooping trust
iparp inspection trust
```

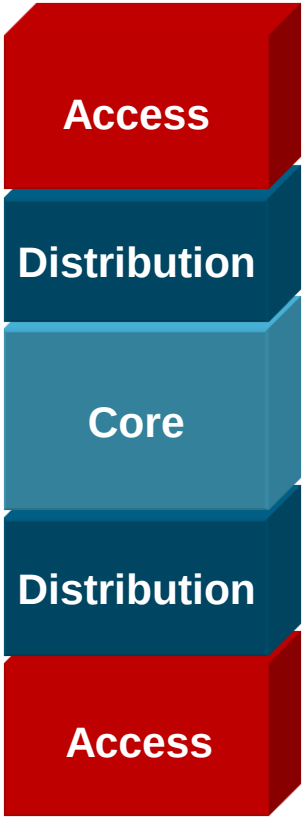
Agenda

- Multilayer Campus Design Principles
- Foundation Services
- Campus Design Best Practices
- VSS Distribution Block
- Security Considerations
- Putting It All Together
- Summary



Hierarchical Campus

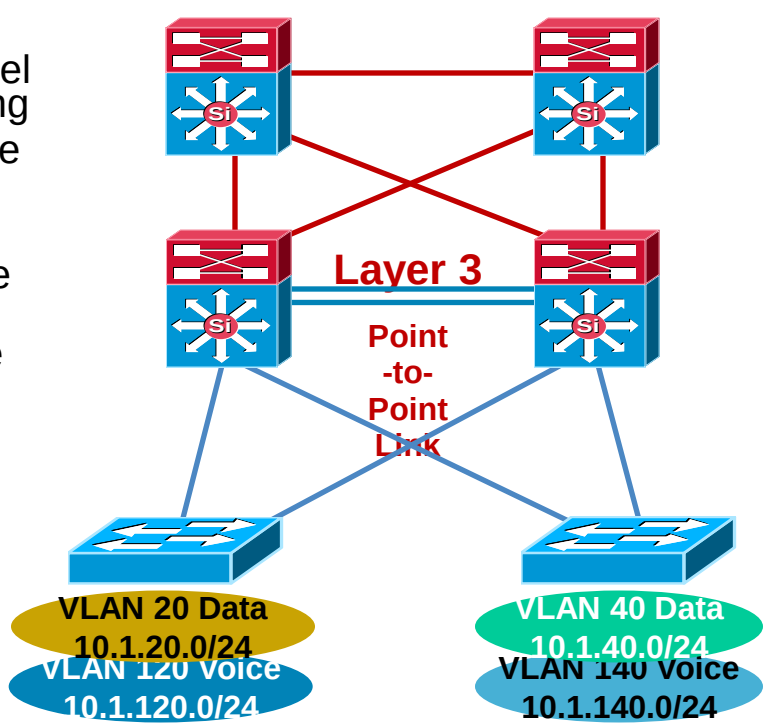




Layer 3 Distribution Interconnection

Layer 2 Access—No VLANs Span Access Layer

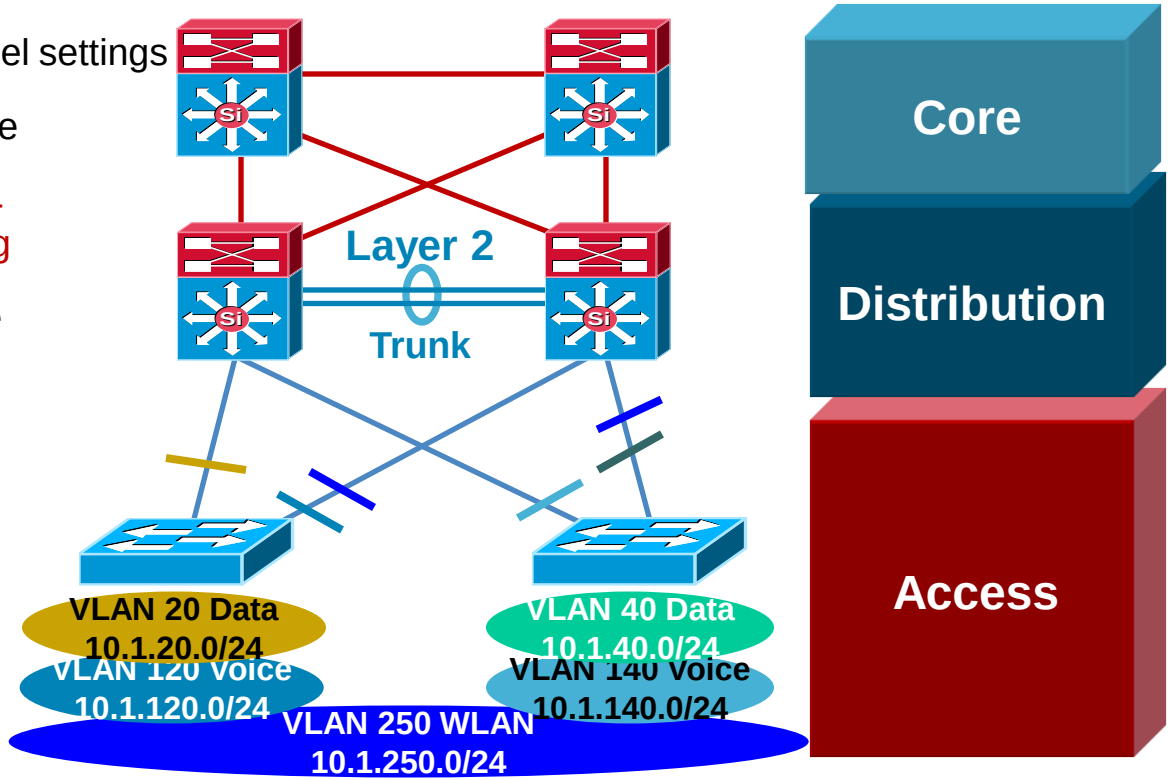
- Tune CEF load balancing
- Match CatOS/IOS EtherChannel settings and tune load balancing
- Summarise routes towards core
- Limit redundant IGP peering
- STP root and HSRP primary tuning or GLBP to load balance on uplinks
- Set trunk mode on/nonegotiate
- Disable EtherChannel unless needed
- Set port host on access layer ports:
  - Disable trunking
    Disable EtherChannel
    Enable PortFast
- RootGuard or BPDU-Guard
- Use security features



Layer 2 Distribution Interconnection

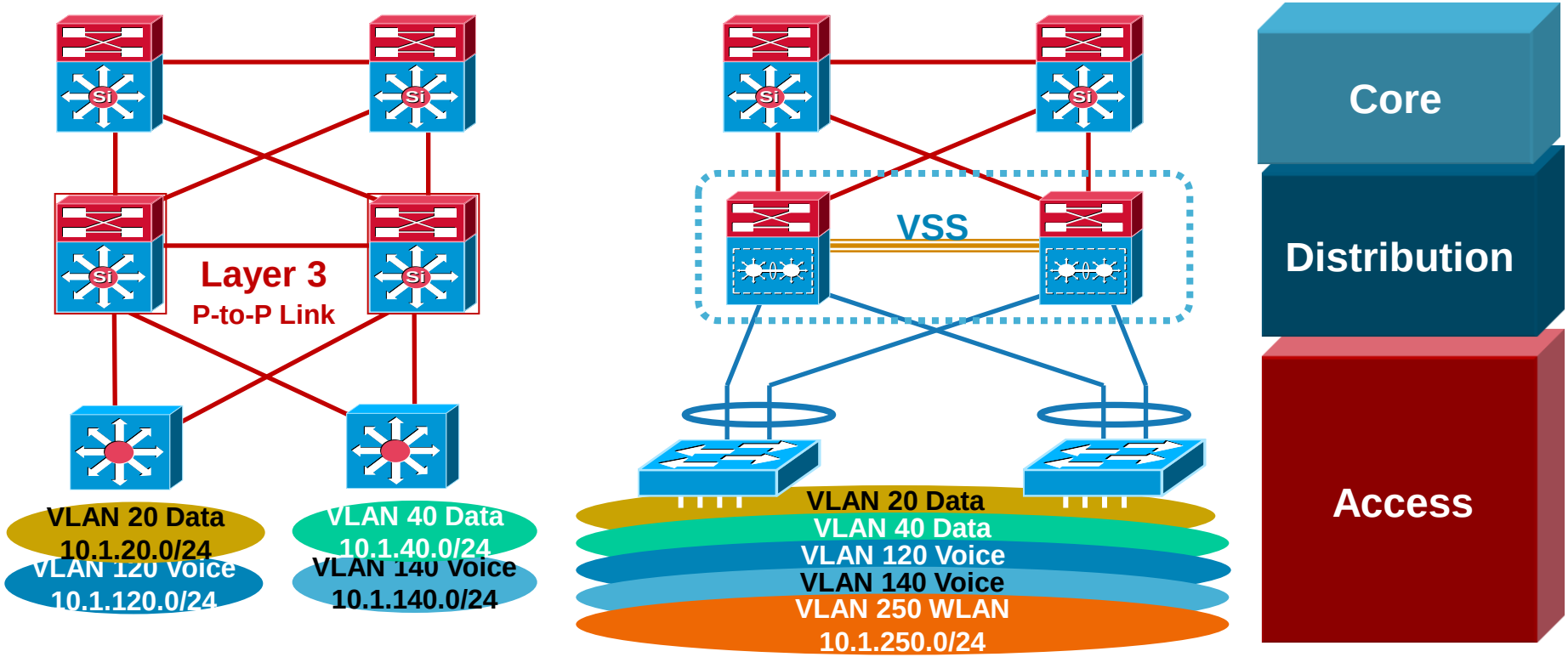
Layer 2 Access—Some VLANs Span Access Layer

- Tune CEF load balancing
- Match CatOS/IOS EtherChannel settings and tune load balancing
- Summarise routes towards core
- Limit redundant IGP peering
- STP root and HSRP primary or GLBP and STP port cost tuning to load balance on uplinks
- Set trunk mode on/nonegotiate
- Disable EtherChannel unless needed
- RootGuard on downlinks
- LoopGuard on uplinks
- Set port host on access Layer ports:
  - Disable trunking
    Disable EtherChannel
    Enable PortFast
- RootGuard or BPDU-Guard
- Use security features



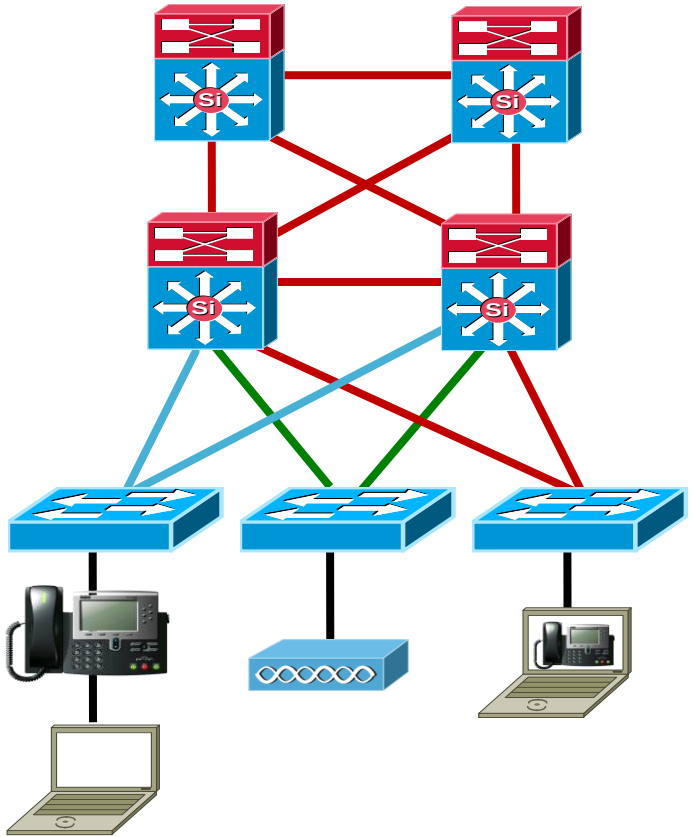
Routed Access and Virtual Switching System

Evolutions of and Improvements to Existing Designs



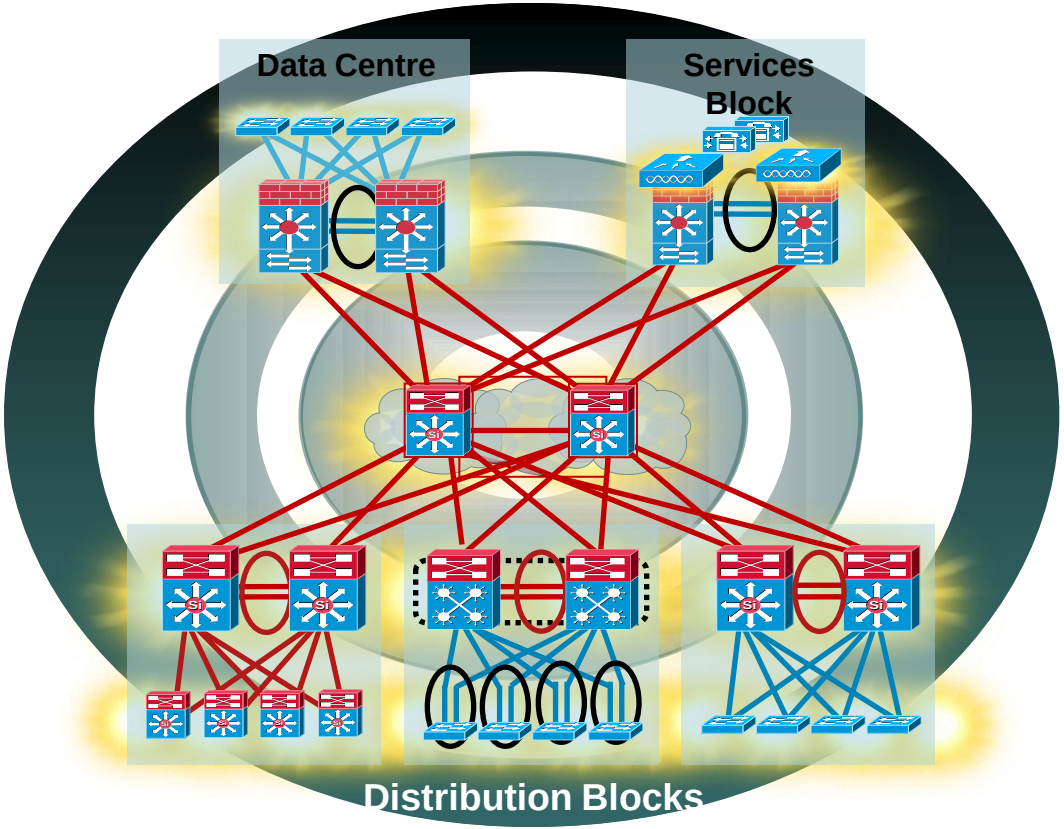
SmartPorts—Predefined Configurations

```
Access-Switch#show parser macro brief
   default global   : cisco-global
   default interface: cisco-desktop
   default interface: cisco-phone
   default interface: cisco-switch
   default interface: cisco-router
   default interface: cisco-wireless

Access-Switch(config-if)#$ macro apply cisco-phone $access_vlan 100 $voice_vlan 10

Access-Switch#show run int fa1/0/19
!
interface FastEthernet1/0/19
switchport access vlan 100
switchport mode access
switchport voice vlan 10
switchport port-security maximum 2
switchport port-security
switchport port-security aging time 2
switchport port-security violation restrict
switchport port-security aging type inactivity
srr-queue bandwidth share 10 10 60 20
srr-queue bandwidth shape  10  0  0  0
mls qos trust device cisco-phone
mls qos trust cos
 macro description cisco-phone
 auto qosvoipcisco-phone
 spanning-tree portfast
 spanning-tree bpduguard enable
end
```



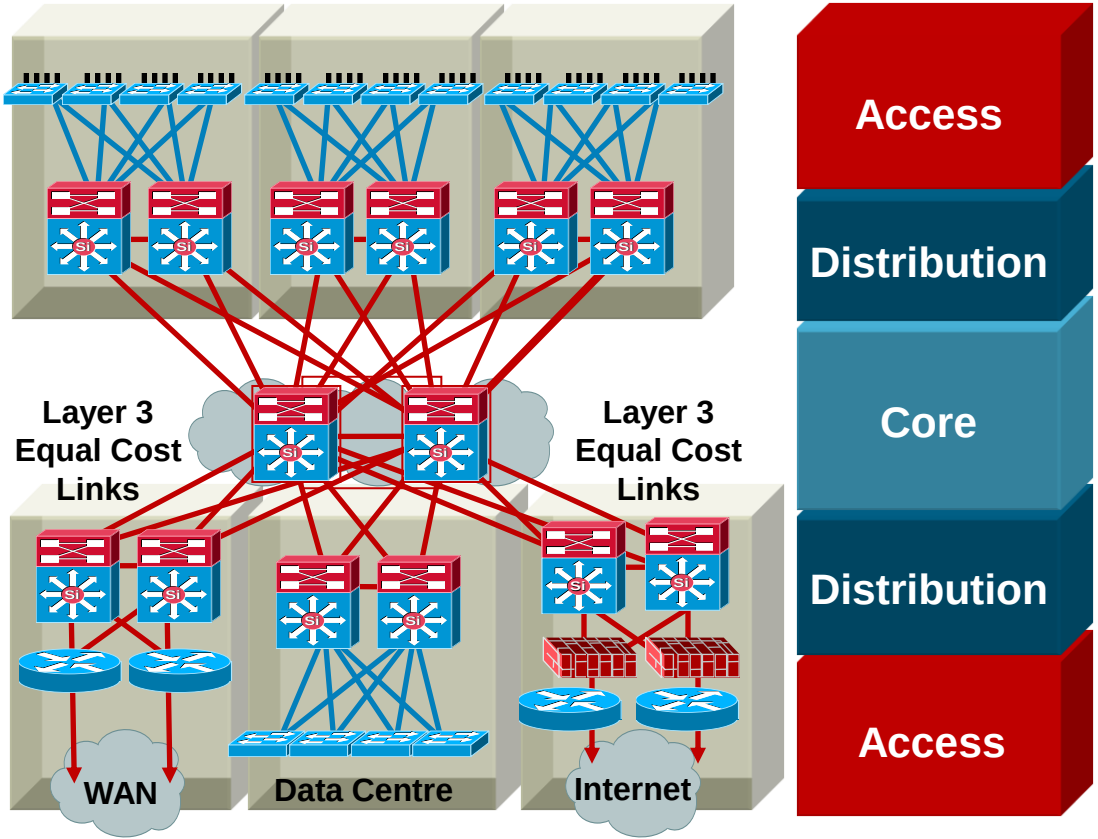
Agenda

- Multilayer Campus Design Principles
- Foundation Services
- Campus Design Best Practices
- IP Telephony Considerations
- QoS Considerations
- Security Considerations
- Putting It All Together
- Summary



Summary

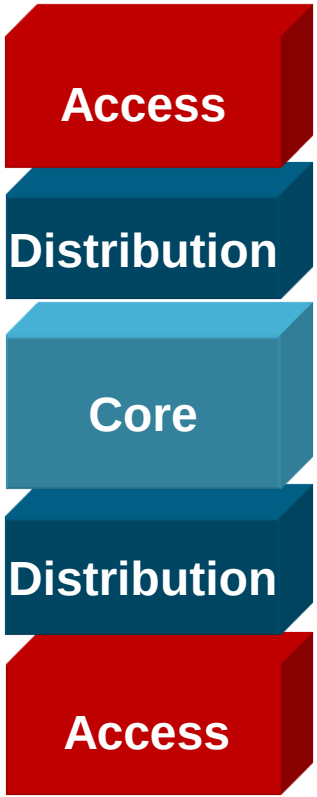
- Offers hierarchy—each layer has specific role
- Modular topology—building blocks
- Easy to grow, understand, and troubleshoot
- Creates small fault domains—clear demarcations and isolation
- Promotes load balancing and redundancy
- Promotes deterministic traffic patterns
- Incorporates balance of both Layer 2 and Layer 3 technology, leveraging the strength of both
- Utilises Layer 3 routing for load balancing, fast convergence, scalability, and control

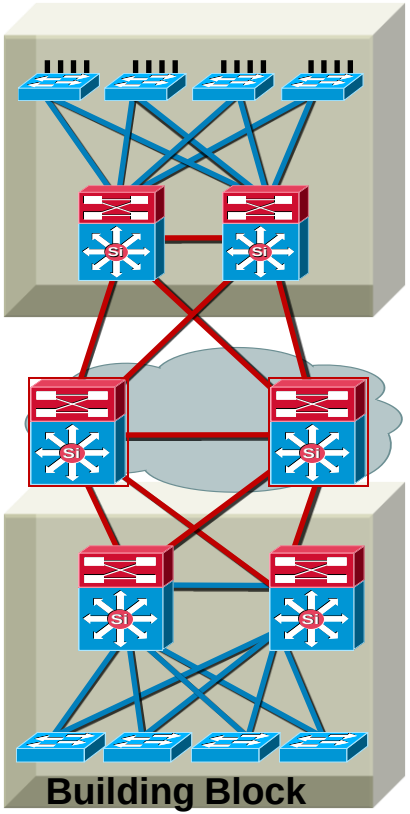


Q and A

Hierarchical Network Design

Without a Rock Solid Foundation the Rest Doesn't Matter





Reference Materials—Design Zone

- High Availability Campus Design Guide
- High Availability Campus Convergence Analysis
- High Availability Campus Design Guide—Routed Access EIGRP and OSPF
- http://www.cisco.com/go/srnd

Complete Your Online Session Evaluation

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