PI-Grau
(Internet Protocols)

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- **Topic 2: Corporate Networks: Switching Blocks**
  - Objectives
    - Introduce basic **switching** concepts
    - Understand **Corporate Network design** principles
    - Understand **L2/L3 reliability** concepts and protocols
    - Learn **CPD (Data Processing Center)** design techniques

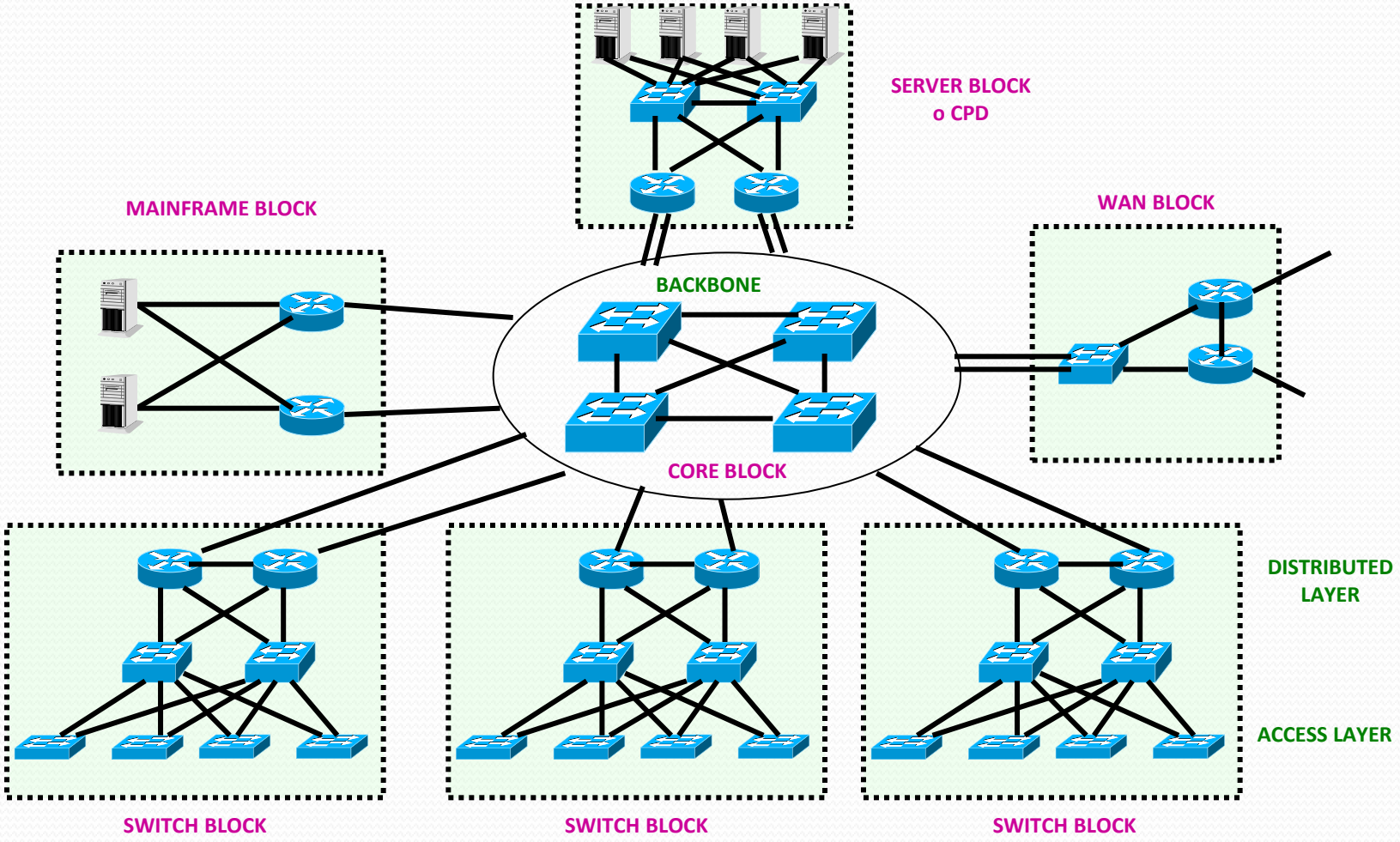
Corporative Networks

- Companies with ***end users*** and ***end services***
- As any end user, they are connected to other end users and other corporative networks via an ISP
- A corporative network can be something ranging between:
  - Small company with few users, to a large company with thousands of users
- A corporative network may:
  - Manage their services in a CPD (Centre Processing Data) located in the Main Site
  - Manage their services via others (e.g. either another corporative network or an ISP) that provides the service (e.g. hosting, housing, virtualization, …)

- **Switching Block Architectures:**
  - **Corporate Network Design:** use switching blocks interconnected by a fast switching backbone
    - **Switching blocks:** users connect to access switches. These ones are connected to aggregation switches that aggregate user traffic to the routers that get them out of the switching block.
    - **Data Processing Center (CPD):** specific switching block in which the access switches give service to servers instead of end users.
    - **Backbone block:** group of core switches that interconnect switching blocks
    - **WAN block:** block that give access to Internet and to VPN connectivity.

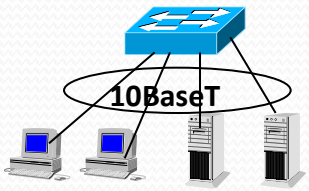
Topic 2: Corporate Networks: Switching Blocks

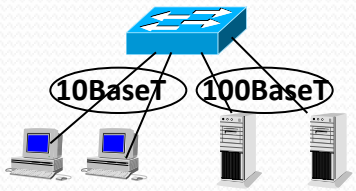
- **Switching Block Architectures:**

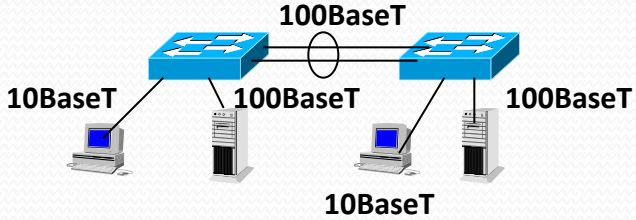


- **Ethernet Technologies:**
  - Symmetric ports: all with the same rate
  - Asymmetric ports: different rates
  - **Half Duplex** ports (typically 10BaseT) and **Full Duplex** (typically Fast Eth. and GigaBit Eth.)
    - FD ports deactivates the collision CSMA/CD mechanism
  - **MAC Tables:** static/dynamic entries. The MAC table allows switching frames from one port to other as a function of @MAC-dst

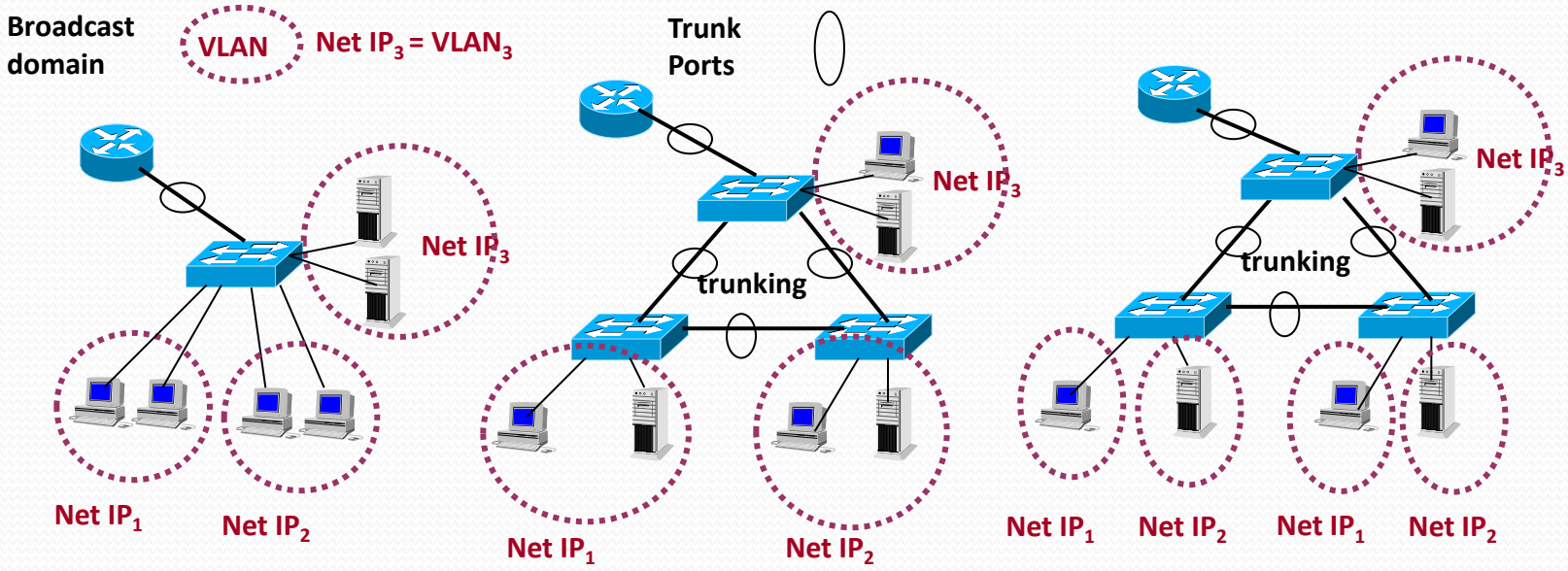
PORT (IFACE)	MAC	AGE
Eth0	01:01:01:ab:fe:f2	10'
Eth0	01:01:01:cb:5e:27	10'
Eth1	01:01:01:bb:a4:31	10'







- **VLANs**
  - Split broadcast domains in a switch instead than do it in the router (saves router ports) using dedicates software
    - **Static VLANs**: each switch port assigns the desired VLAN
    - **Dynamic VLAN:** data base that assign MACs to the VLAN
    - **Trunking:** links hat support multiple VLANs using "tagging" techniques: 802.1Q, CISCO ISL (Inter-switch Link), 3COM VLP (Virtual LAN trunk)



VLANs: CISCO IoS (Sw 2950)

Setting a static VLAN

!!! Setting vlan in the database with name vlan2

Sw# **vlan database**

Sw(vlan)# **vlan** 2 **name** vlan2

!!!! Assigning the port Ge0 to vlan 2

Sw(conf)# **interface** Ge0

Sw(config-if)# **switchport mode access**

Sw(config-if)# **switchport access vlan** vlan2

!!! Port Ge1 activated as port trunk

Sw(conf)# **interface** Ge1

Sw(config-if)# **switchport mode trunk**

VLANs: Setting dynamic VLANs

Las líneas que empiezan con el carácter '!' son comentarios. A continuación hay una breve descripción:

- Hay que definir un *VMPS domain* (línea 6), este dominio debe coincidir con el dominio VTP del switch. VTP (Virtual Trunking Protocol) es un protocolo propietario de CISCO que permite propagar la configuración de las VLANs a todos los switches de un mismo dominio. Por ejemplo, al crear una VLAN en un servidor VTP, la VLAN se propaga a todo el dominio.
- VMPS puede operar en modo *open* o *secure* (línea 7). En modo *open*: Si una MAC no está definida, se le asigna una VLAN por defecto (línea 8). En modo *secure*: Si una MAC no está definida se bloquea el puerto. Para desbloquear un puerto hay que ejecutar los comandos *shutdown / no shutdown*.
- En la sección *MAC Addresses* (línea 11) se asignan las VLANs a las que pertenecen las direcciones MAC. Puede usarse --NONE-- para denegar explícitamente el acceso a cualquier VLAN. Notar que para identificar las VLANs se usa el VLAN-name, no el VLAN-id. En el switch deben haberse creado las VLANs con el mismo nombre que el indicado en esta sección del fichero de configuración.
- Una VLAN se puede restringir a un switch específico, o a un grupo de puertos de un switch. Para ello hay que especificar:
  1. Los puertos permitidos (sección *Port Groups*, línea 24). Por ejemplo, la línea 31 especifica el puerto 2/4 del switch 10.0.0.1, y la línea 32 especifica todos los puertos del switch 10.0.0.2.
  2. Las VLANs a las que se les aplicará alguna restricción (sección *VLAN groups*, la línea 34).
  3. La asociación entre las definiciones anteriores (sección *VLAN port Policies*, línea 43).

VLANs: Setting dynamic VLANs

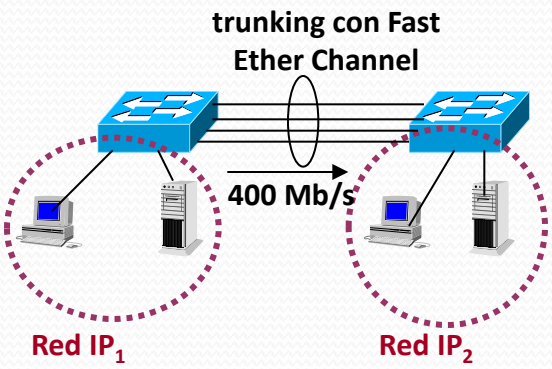
1. **!vmps domain <domain-name> - The VMPS domain must be defined.**
2. **!vmps mode { open | secure } - The default mode is open.**
3. **!vmps fallback <vlan-name>**
4. **!vmps no-domain-req { allow | deny } - The default value is allow.**
5. **!**
6. vmps domain mydomain
7. vmps mode open
8. vmps fallback --NONE--
9. vmps no-domain-req deny
10. **!!**
11. **!MAC Addresses**
12. **! address <addr> vlan-name <vlan_name>**
13. **!**
14. vmps-mac-addrs
15. **!**
16. address 0010.a49f.30e1 vlan-name --DEFAULT--
17. **! disabled - no access**
18. address 0010.a49f.30e2 vlan-name --NONE--
19. **! vlan TEST restricted**
20. address 0010.a49f.30e3 vlan-name TEST
21. **! vlan TEST1 unrestricted**
22. address 0010.a49f.30e4 vlan-name TEST1

VLANs: Setting dynamic VLANs

```
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!Port Groups
!vmps-port-group <group-name>
! default-vlan <vlan-name>
! fallback-vlan <vlan-name>
! device <device-id> { port <port-name> | all-ports }
!
vmps-port-group myswitch
device 10.0.0.1 port 2/4
device 10.0.0.2 all-ports
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!VLAN groups
!vmps-vlan-group <group-name>
! vlan-name <vlan-name>
!
vmps-vlan-group myvlans
vlan-name TEST
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!VLAN port Policies
!vmps-port-policies {vlan-name <vlan_name> | vlan-group <group-name> }
! { port-group <group-name> | device <device-id> port <port-name> }
!
vmps-port-policies vlan-group myvlans
port-group myswitch
```

Link Aggregation in L2

- **Link aggregation**: technique consisting in using several (around n=2-4) Ethernet links in order to increase the capacity to nxC Mb/s (for each Full Duplex direction)
  - Load balancing policies: based in L2 (MACs), L3 (IPs) or L4 (ports) or flows
  - Port redundancy (if a link fails, the rest of links still work)
- i.e. **IEEE 802.3ad** for link aggregation
- i.e. CISCO Fast Ether Channel or Giga Ether Channel **(port trunking)**
- i.e. others call it **NIC-team(ing)**



Aggregation implies a reduction in the number of physical ports in the switch that normally are used for other purposes (e.g. hosts).

Options:

- **add switches**
- **put a switch with more ports (normally if more than 50% of the switch ports are used in aggregation.**

- **Port aggregation: CISCO IoS (Sw 2950)**

Setting an aggregated port

!!!! Create the port-channel and assign ports

!!!! The ports have to be in the same VLAN or to be trunk

Sw(conf)# **interface port-channel** 1

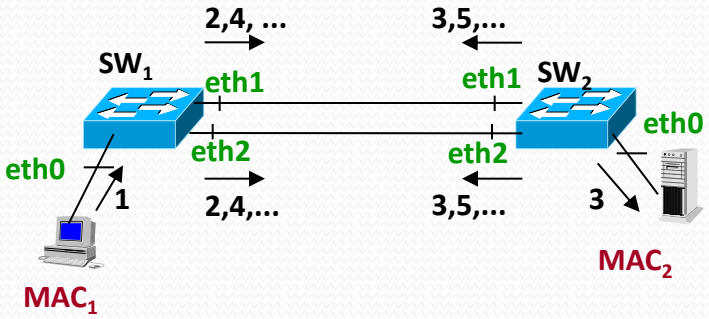
Sw(conf)# **interface** Ge1

Sw(config-if)# **channel-group** 1 **mode on**

Sw(conf)# **interface** Ge2

Sw(config-if)# **channel-group** 1 **mode on**

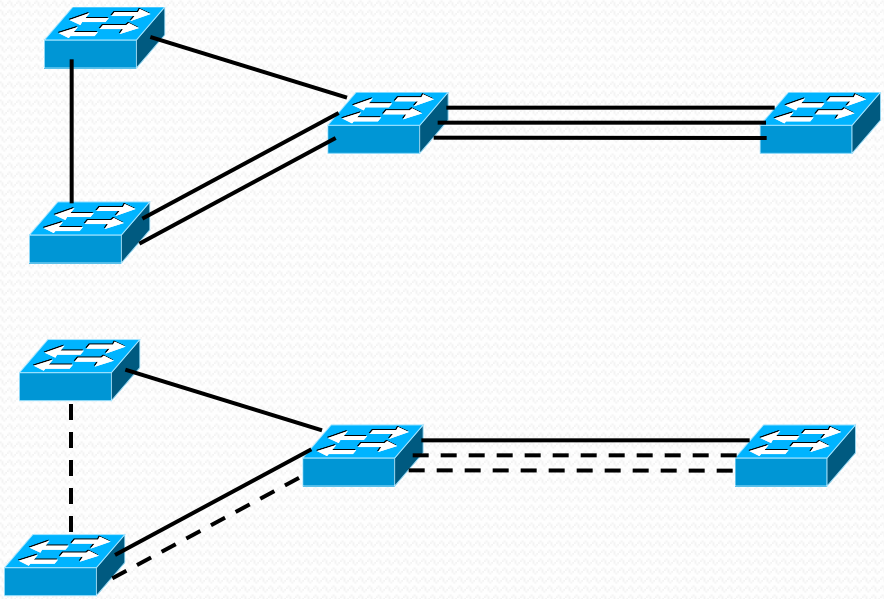
- **Broadcast Storms:**



(1) Station 1 sends a frame in broadcast (e.g. an ARP frame)
(2) Sw1 forwards in eth1 and eth2
(3) Sw2 forwards again (e.g. eth1 to eth2 and eth0)
(4) Sw1 forwards again → infinite loop

If the broadcast produces a loop (i.e. un ARP) the growth in number of frames is exponential → the loop will produce a Sw failure (load causes around 80% of the CPU of the Sw but routers also will process these broadcasts) → the whole network fails

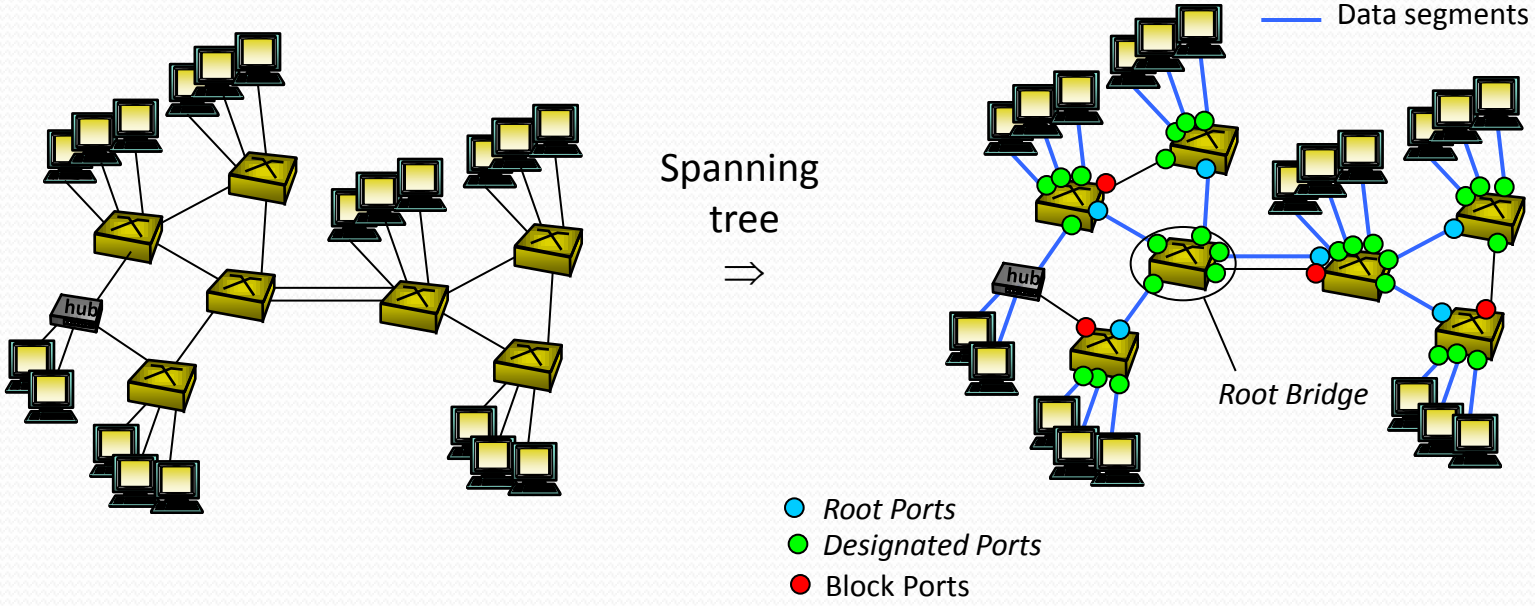
- **Spanning Tree Protocol (STP, IEEE 802.1D):**
  - Main objective:
    - Avoid and eliminate *loops and redundant links* organizing the network in a tree topology (*blocking* those switch ports that would produce a loop)
    - Use costs based on link rates as metrics



Link capacity	Cost
10 Gb/s	2
1 Gb/s	4
100 Mb/s	19
10 Mb/s	100

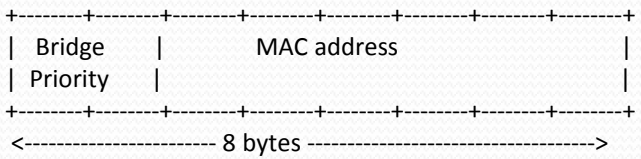
- **In order to build a Spanning Tree, the protocol has to choose:**

1. A ***Root Bridge*** **(RB)** for the whole broadcast domain. Note: s*witch and bridge* has the same meaning.
2. A ***Root Port*** for each switch that is not the RB, this allows sending traffic towards the RB. Guarantees a tree topology.
3. A ***Designated Port*** at each collision domain. Guarantees that all collision domains are reachable. those port not elected as *Root Ports* or *Designated Ports*, will be blocked.



For the election of *Root Bridge, Root Port, Designated Port*:

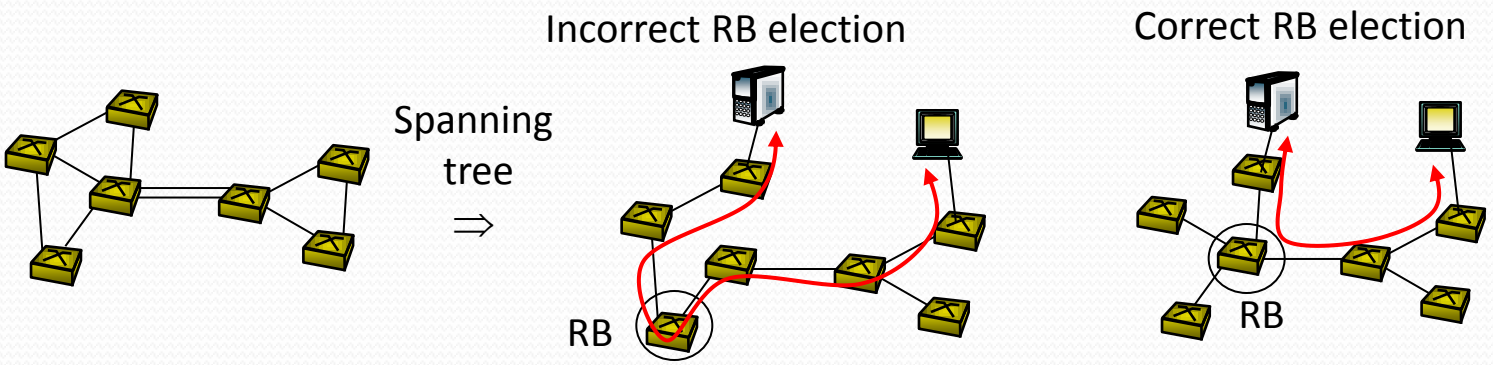
- Switches are identified with a *Bridge ID* formed with a priority field (manually configurable) and one of the MACs addresses of the switch:



  - Signaling messages are sent: *Bridge Protocol Data Unit* (BPDU).
- Initially the BPDUs are sent every 2 seconds to the multicast address 01-80-C2-00-00-00 The BPDUs fields used in the tree calculation are:
  - *Root BID* (8 bytes)
  - *Root Path Cost* (4 bytes): Is incremented with the cost of the port where is received.
  - *Sender BID* (8 bytes): BID of the switch that sends the BPDU.
  - *Port ID* (2 bytes): ID of the port that transmits the BPDU (all the ports of the same switch have different IDs and have a port-priority). Thus, **PORT-ID = Priority (1B) + port# (1B)**. Initially: **Priority=128**.

Root Bridge (RB) election:

- Initially all switches generate BPDUs with *Root BID* = *Sender BID*.
- If a switch receive a BPDU with a lower *Root BID*, stops sending BPDUs and assumes that BID as *Root BID*. In small amount of time only the RB generates BPDUs. The other switches modify the *Root Path Cost, Sender BID* y *Port ID* before sending the BPDU. The RB sends BPDUs for all its ports. The other switches only send BPDUs received from the *Root Port*.
- The **Switch priority** may be manually configurable. Initially values **0x8000 (32768).** Lower have more priority:
  - Switch#spanning-tree vlan *vlan-id* priority *priority*
- The election of the RB may impact performance: should be the more centric switch (star topology is better than tree topology).

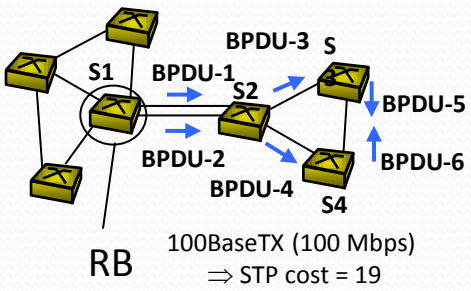


• *Root Port election*:

- Each switch that is not the RB selects a port as *Root Port*.
- For the election the information contained in the received BPDUs is compared at each port. The selected port is the one that has received a BPDU that fulfils the following sequence of conditions :
  1. Lowest *Root BID* (towards the *Root Bridge*).
  2. Lowest *Root Path Cost* (optimal path towards the *Root Bridge*).
  3. Lowest *Sender BID*
  4. Lowest *Port ID*

} In order the selection is unique.

Root BID = BID-S1 = 00:00:00:00:00:11:11:11
BID-S2 = 80:00:00:00:00:22:22:22
BID-S3 = 80:00:00:00:00:33:33:33
BID-S4 = 80:00:00:00:00:44:44:44



⇒

BPDU-1: Root BID = Sender BID = BID-S1
Root Path Cost = 0, Port ID = 1

BPDU-2: Root BID = BID-S1, Sender BID = BID-S1
Root Path Cost = 0, Port ID = 2

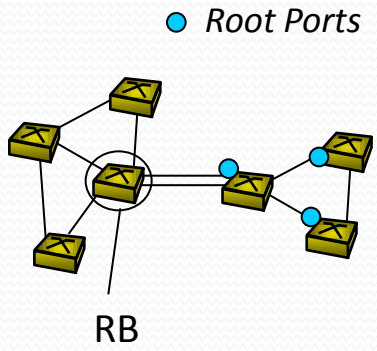
BPDU-3: Root BID = BID-S1, Sender BID = BID-S2
Root Path Cost = 19, Port ID = 1

BPDU-4: Root BID = BID-S1, Sender BID = BID-S2
Root Path Cost = 19, Port ID = 2

BPDU-5: Root BID = BID-S1, Sender BID = BID-S3
Root Path Cost = 38, Port ID = 1

BPDU-6: Root BID = BID-S1, Sender BID = BID-S4
Root Path Cost = 38, Port ID = 1

⇒

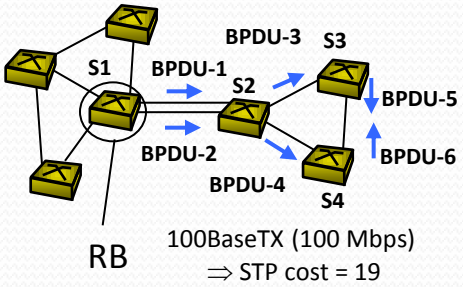


Designated Port Election (collision domain access):

- All RB ports are *Designated Ports*, except those ones that may form a loop at level 1 (two ports connected to a hub or a crossover cable between two ports).
- For the other switches:
- The ports that do not receive BPDUs are *Designated Ports (*Host ports*)*
- The ports that receive BPDUs and are not *Root Ports*: Compare the information contained by BPDUs received and sent in that port. The port is *Designated Port* if fulfils the following sequence of conditions:
  - Lowest *Root BID* (towards the *Root Bridge*).
  - Lowest *Root Path Cost* (optimal path towards the *Root Bridge*).
  - Lowest *Sender BID*
  - Lowest *Port ID*

} In order the selection is unique.

Root BID = BID-S1 = 00:00:00:00:00:11:11:11
BID-S2 = 80:00:00:00:00:22:22:22
BID-S3 = 80:00:00:00:00:33:33:33
BID-S4 = 80:00:00:00:00:44:44:44



⇒

BPDU-1: Root BID = Sender BID = BID-S1
Root Path Cost = 0, Port ID = 1

BPDU-2: Root BID = BID-S1, Sender BID = BID-S1
Root Path Cost = 0, Port ID = 2

BPDU-3: Root BID = BID-S1, Sender BID = BID-S2
Root Path Cost = 19, Port ID = 1

BPDU-4: Root BID = BID-S1, Sender BID = BID-S2
Root Path Cost = 19, Port ID = 2

BPDU-5: Root BID = BID-S1, Sender BID = BID-S3
Root Path Cost = 38, Port ID = 1

BPDU-6: Root BID = BID-S1, Sender BID = BID-S4
Root Path Cost = 38, Port ID = 1

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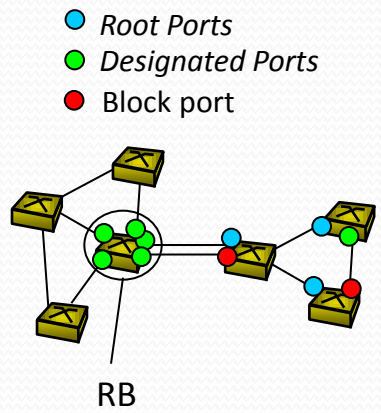


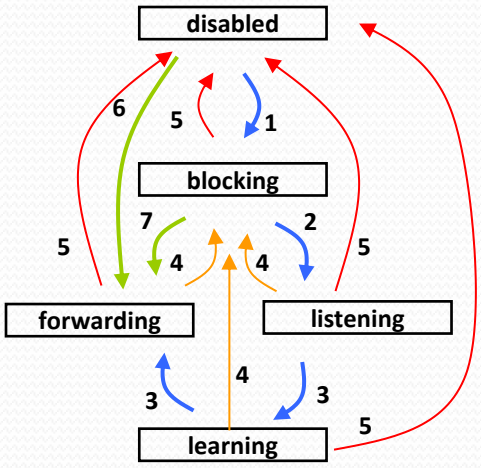
Topic 2: Corporate Networks: Switching Blocks

Port State:

- **Blocking** – No frame Forwarding. BPDUs are listened.
- **Listening** - No frame Forwarding. BPDUs are listened/transmitted (build the tree).
- **Learning** – No frame Forwarding. Learning addresses. BPDUs are listened/transmitted
- **Forwarding** - Forwarding of frames and Learning addresses. BPDUs are listened/transmitted
- **Disabled** - No frame Forwarding and BPDUs are not listened/transmitted

STP Timers:

- *Hello*: time between BPDUs sent by a switch *Root Bridge* (2 seconds).
- *Forward:* time spent in the *listening/learning states* (15 seconds).
- *Max Age*.: maximum time that a BPDU is stored (20 seconds). If no more BPDUs are received, go to the next STP state (*listening*).



State transitions:

1. Initiate or *no shutdown.*
2. *Root* or *Designated* port selected, or *timer Max. Age* expires
3. *Timer forwarding* expires (15 seconds).
4. The ports is no more *Root* or *Designated*. Initially all switches assume they are *Root Bridge* and all their ports are *Designated Ports*.
5. *Shutdown*

CISCO:

6. Port Fast: thought in case a host is connected directly to the switch. If the switch detects a loop, go to *blocking*.
7. UplinkFast: thought for *edge routers*. The switch take into account the redundant links for substituting them rapidly for a *Root Port i*n case fails.

Spanning Tree Protocol and VLANs

- STP (802.1D) initially design for **one** VLAN
- VLAN (802.1Q)
  - CISCO also uses ISL
  - CISCO defines PVST (Per VLAN Spanning Tree) that defines *one STP instance per VLAN* → works with ISL and is not compatible with 802.1Q
  - CISCO defines PVST+ that is compatible with 802.1Q
- IEEE adopts (2003) the concept of one STP instance per VLAN
  - Initially proposes 802.1s or *Multiple Spanning Tree Protocol* (MSTP)
    - MSTP allows regions of MST that may run multiple MST instances. These regions are interconnected using a unique common spanning tree (CST).
  - Finally MSTP is included in the 802.1Q

STP+VLAN: CISCO IoS (Sw 2950)

Setting STP in VLANs

!!!! Assign a STP instance to a VLAN

Sw(conf)# **spanning-tree vlan** vlan2

!!!! Select this Switch as Root Bridge for VLAN2

Switch# **spanning-tree vlan** vlan2 **root primary**

!!!! Other way: change the switch priority to some lower value

Switch# **spanning-tree vlan** vlan2 **priority** 0x7000

!!!! Modify cost and priority to a port

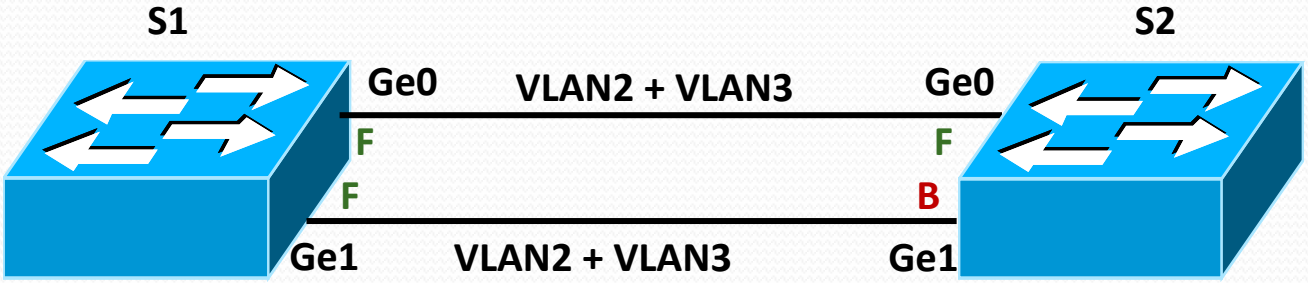
Sw(conf)# **interface** Ge0

Sw(config-if)# **spanning-tree vlan** vlan2 **cost** 5

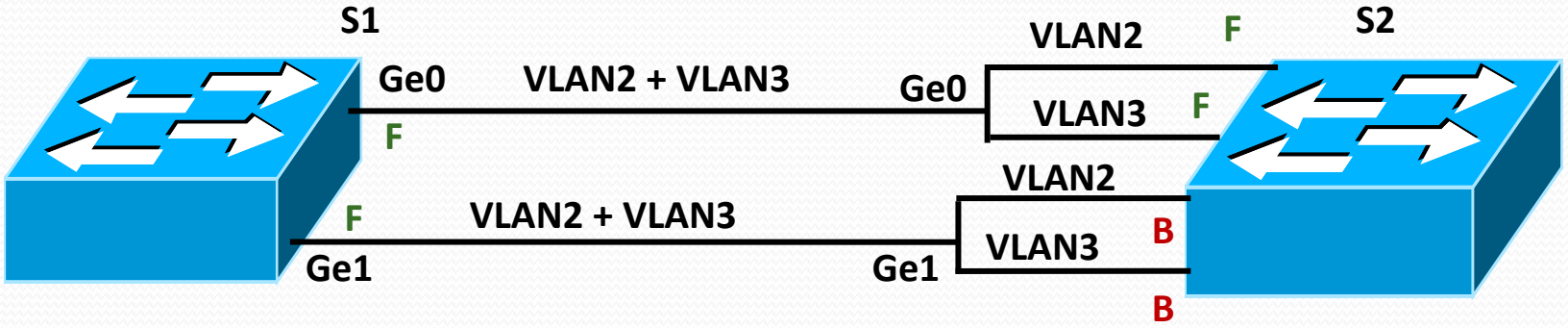
Sw(config-if)# **spanning-tree vlan** vlan2 **port-priority** 120

- **Spanning Tree Protocol and VLANs**

CASO 1: STP: VLAN2 + VLAN3



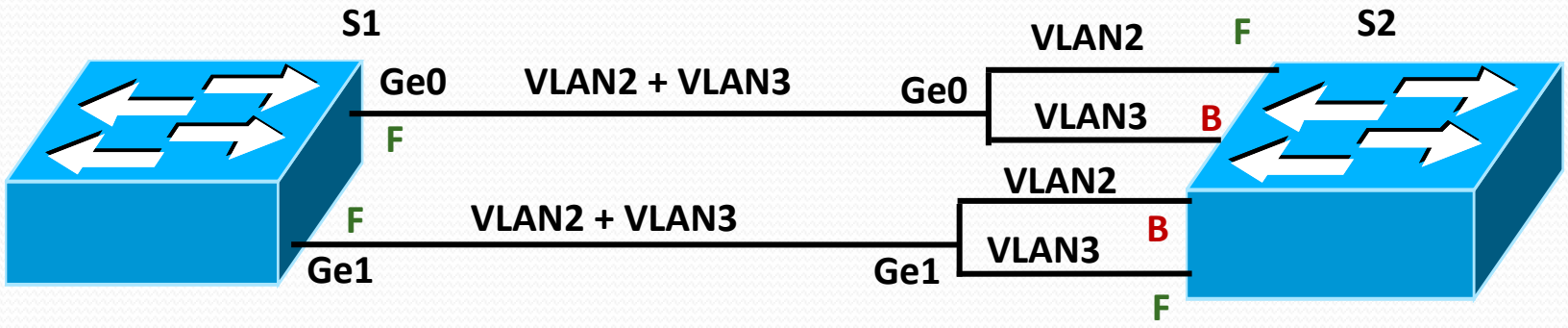
CASO 2: STP2: VLAN2 and STP3: VLAN3



No hay control de prioridades en los puertos (port-priority), el STP no logra balancear la carga de las VLANs ya que STP2 y STP3 bloquean los mismos puertos

- **Spanning Tree Protocol and VLANs**

CASO 3: STP2: VLAN2 and STP3: VLAN3



Hay control de prioridades en los puertos (port-priority, value from 0-255, default 128), el STP logra balancear la carga de las VLANs. Cuidado, el port-priority que hay que manipular es el de S1 (el transmisor para que S2 decida)

Para ello hay que poner en la fe0 una prioridad menor en el STP2 (VLAN2) que en la fe1 del mismo STP2. De manera simétrica, hay que poner en la fe0 una prioridad mayor en el STP3 (VLAN3) que en la fe1 del mismo STP3.

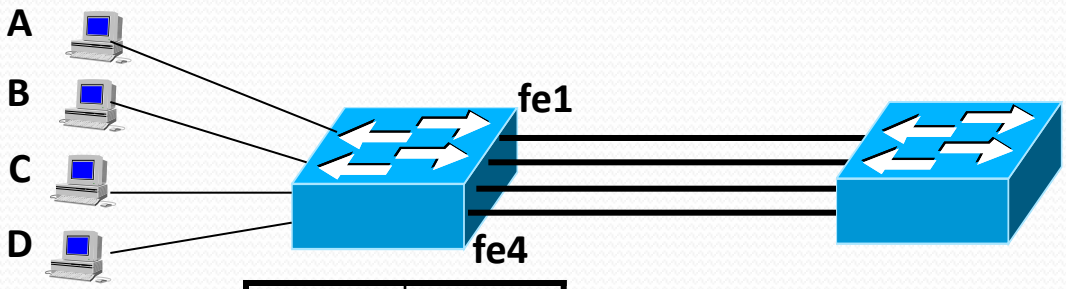
Ahora, los STP2 y STP3 bloquean puertos distintos.

- **STP+VLAN: CISCO IoS (Sw 2950)**

Splitting ports per VLAN and STP instance

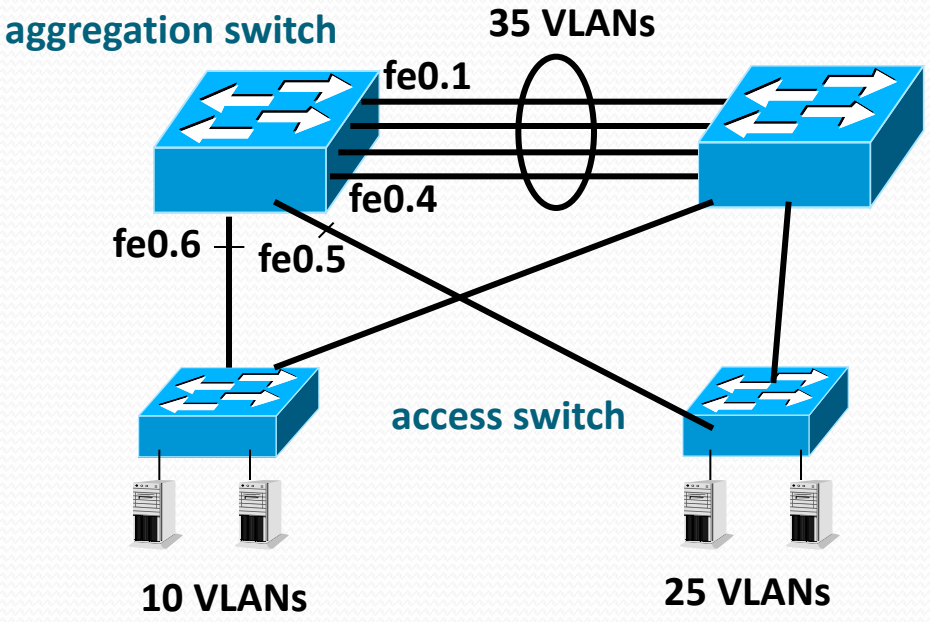
```
!!!! The port has to be trunk
Sw1(conf)# interface Ge0
Sw1(config-if)# switchport mode trunk
!!!! Play with the port priority at each VLAN and each STP instance. For
!!!! Example, Ge0, highest priority for VLAN2 than in Ge1
Sw1(config)# interface Ge0
Sw1(config-if)# spanning-tree vlan vlan2 port-priority 64
Sw1(config-if)# spanning-tree vlan vlan3 port-priority 128
Sw1(config)# interface Ge1
Sw1(config-if)# spanning-tree vlan vlan2 port-priority 128
Sw1(config-if)# spanning-tree vlan vlan3 port-priority 64
```

- **Spanning Tree Protocol and Link Aggregation**
  - i.e how does STP works with Fast Etherchannel:
    - Fast EtherChannel with 4 parallel ports usually works with flow load balancing
    - The parallel links are treated by STP as a unique link



Flow	Port
A	fe1
B	fe2
C	fe3
etc	...

- **Number of virtual ports per Line Card**
  - Virtual ports are a per-line card value that reflects the total number of spanning tree processing instances used on a particular line card.
    - Each Line Card may have several interfaces: e.g. Line Card FE0 → FE0.0, FE0.1, ..., FE0.N



#Virtual_ports = Sum of trunks * #VLANS

sh vlan virtual-port slot 0

Port	Virtual-ports
fe0.1	35
fe0.2	35
fe0.3	35
fe0.4	35
fe0.5	10
fe0.6	25
Total	175

Fast EtherChannel

Virtual ports: number of VLAN's supported by trunks in a Line Card and then a limit in the number of Spanning tree instances in the Line Card.

- **Number of virtual ports per Line Card**
  - Example: let's imagine a Line Card that supports 1500 Virtual Ports.
    - If we have a 48 switch port with 42 aggregated trunk ports and 6 access ports with a VLAN at each access, how many VLANs can be created ?

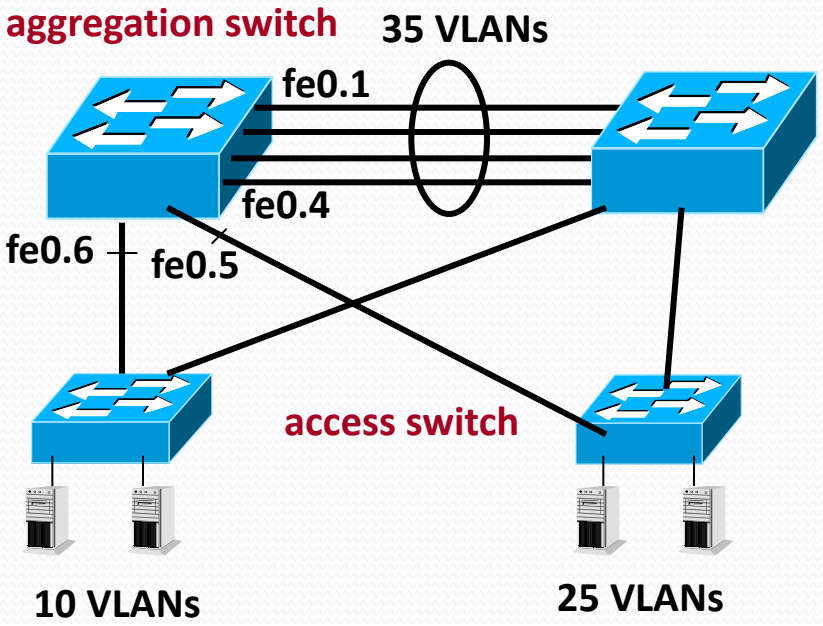
If x is the number of VLAN's that we may allocate. Since, the 6 access ports may upload in total x VLANs and each trunk may aggregate x VLANs each:

$$42*x + x \leq 1500 \rightarrow \qquad 43*x \leq 1500 \rightarrow$$

$$x \leq 34.88 \rightarrow \text{then 34 VLANs}$$

Virtual ports: number of VLAN's supported by trunks in a Line Card and then a limit in the number of Spanning tree instances in the Line Card.

- **Total number of STP logical ports STP active**
  - System-wide value that reflects the total number of spanning tree processing instances used in the whole system
    - Calculated for the whole switching module (broadcast network).
  - For an aggregated module:



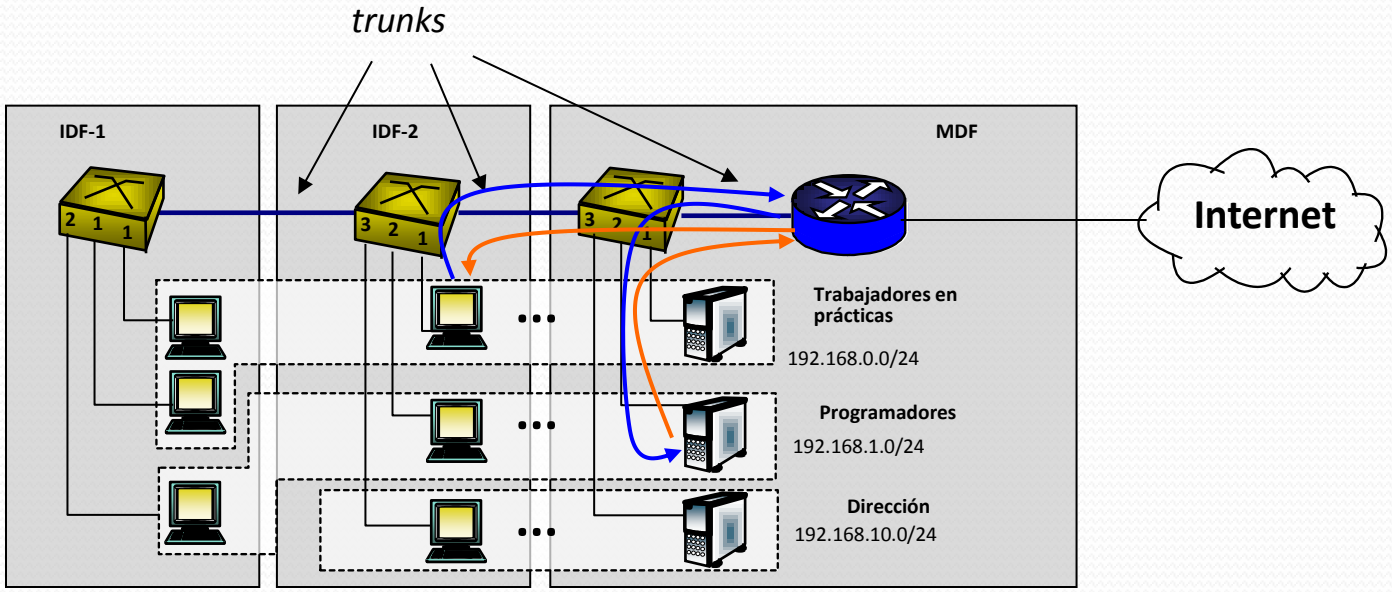
#logical ports = trunks * #VLANS + nontrunks

fe0.1-fe0.4 → 35 VLANS
fe0.5 → 25 VLANS
fe0.6 → 10 VLANS

Total → 70 VLANs

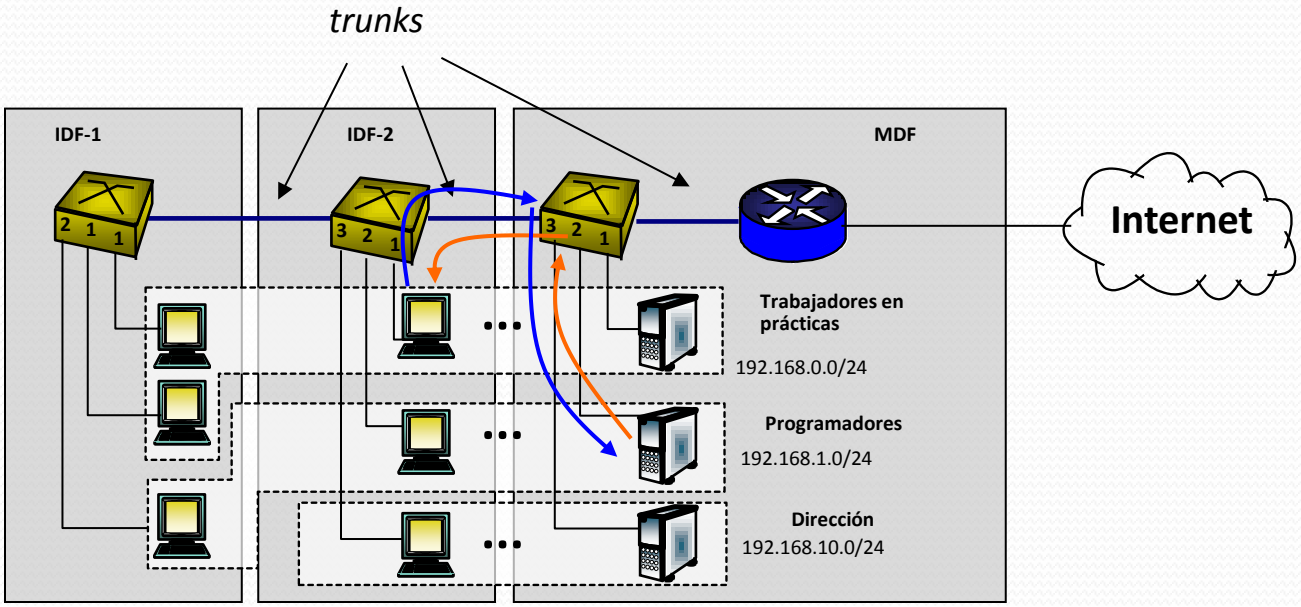
STP Logical Port active: number of STP instances in the whole switching system

- ***MultiLayer Switching* (MLS) or L3 Switches**
  - **Objective:**
    - Assume the following scenario: a VLAN-1 host access a VLAN-2 server.
    - Problem: frames has to cross the *trunk* link between the switch and router! ⇒ this *trunk* link will be the bottleneck



MLS working:

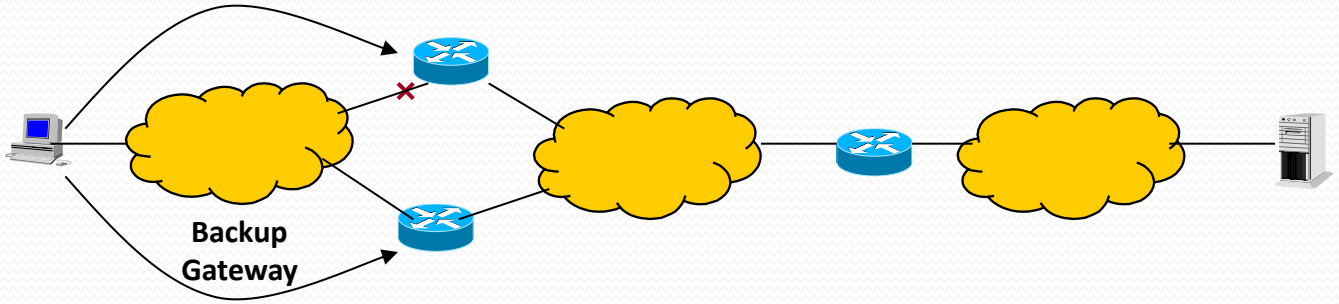
- When the first IP datagram from a *flow* directed to the router crosses the MLS-switch, this one registers the flow in one of the following ways (i) IP destination address, (ii) IP source and destination address, (iii) IP addresses and ports
- When the first IP packet of a flow crosses the switch, activates MLS for that flow using a cache (first time is necessary to look-up the routing table in order to fill the cache)
- Any IP packets from that flow arriving to the switch are fast routed towards destination (the switch works as a router!):



Fail Tolerance in L3:

Main Host Objective: obtain a default route to leave the network. Solution:

- Dynamic routing allows dynamic default routing configuration → so, the routing protocol is fail tolerant by definition
  - If a network point fails, the routing protocol is in charge of reconfiguring any routing table
- However, most Hosts and Servers use a default route statically configured or obtained via DHCP
  - If a point of failure appears → hosts loss connectivity



- **Virtual Router Redundancy Protocol (VRRP)**
  - Design to eliminate points of failure related to default routes
  - Terminology:
    - VRRP router: a router running VRRP
    - Virtual router: abstract object used by VRRP that acts as default router for hosts in a LAN
      - identification of virtual router + set of common @IP in a LAN
      - A router VRRP may be bound to several virtual routers
    - @IP owner: the VRRP router that has the physical @IP of the virtual router
    - Primary @IP: @IP selected from the set of physical @IP
    - Virtual router master: VRRP router responsible of the IP packet forwarding (e.g. the one that answers ARPs frames)
    - Virtual router backup: backup router that takes master responsibilities if this one fails

- **Gratuitous ARP (Request/Reply)**
  - **Gratuitous ARP-request:** ARP request packet where the $@IP_{source}$ and $@IP_{destination}$ are both set to the IP of the host sending the packet and the $@MAC_{destination}$=ff:ff:ff:ff:ff:ff (broadcast address).
  - **Gratuitous ARP reply:** a reply to which no request has been made

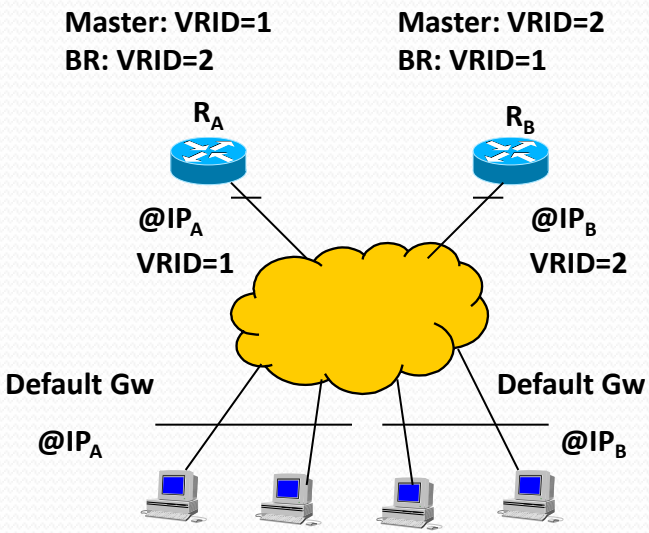
- **Gratuitous ARP objectives:**
  - Detect IP conflicts (@IP duplications)
  - Clear ARP caches
  - Update ARP caches in other hosts (e.g. because we have changed the NIC IP address)
  - Fill MAC Tables in switches
  - …

Gratuitous ARPs are useful for four reasons:

- They can help detect IP conflicts. When a machine receives an ARP request containing a source IP that matches its own, then it knows there is an IP conflict.
- They assist in the updating of other machines' ARP tables. Clustering solutions utilize this when they move an IP from one NIC to another, or from one machine to another. Other machines maintain an ARP table that contains the MAC associated with an IP. When the cluster needs to move the IP to a different NIC, be it on the same machine or a different one, it reconfigures the NICs appropriately then broadcasts a gratuitous ARP reply to inform the neighboring machines about the change in MAC for the IP. Machines receiving the ARP packet then update their ARP tables with the new MAC.
- They inform switches of the MAC address of the machine on a given switch port, so that the switch knows that it should transmit packets sent to that MAC address on that switch port.
- Every time an IP interface or link goes up, the driver for that interface will typically send a gratuitous ARP to preload the ARP tables of all other local hosts. Thus, a gratuitous ARP will tell us that that host just has had a link up event, such as a link bounce, a machine just being rebooted or the user/sysadmin on that host just configuring the interface up. If we see multiple gratuitous ARPs from the same host frequently, it can be an indication of bad Ethernet hardware/cabling resulting in frequent link bounces.

Virtual Router Redundancy Protocol

- E.g. with two Virtual Routers in the network



R_A: has @IP$_A$ as owner @IP
R_B: has @IP$_B$ as owner @IP
2 Hosts has @IP$_A$ as @IP$_{Gw}$
2 Hosts has @IP$_B$ as @IP$_{Gw}$

VRID=1 identifies a Virtual Router and is associated to the @IP$_A$ and VRID=2 identifies a Virtual Router and is associated to the @IP$_B$

When R_A activates VRRP is announced as master of VRID=1 with priority 255 (is owner of @IP$_A$) and backup of VRID=2

When R_B activates VRRP is announced as master of VRID=2 with priority 255 (is owner of @IP$_B$) and backup of VRID=1

While both routers work well there is load balancing

If R_A fails, R_B will take responsibility of routing packets as default Gw for that host that have Gw @IP$_A$ as address, and viceversa if R_B fails

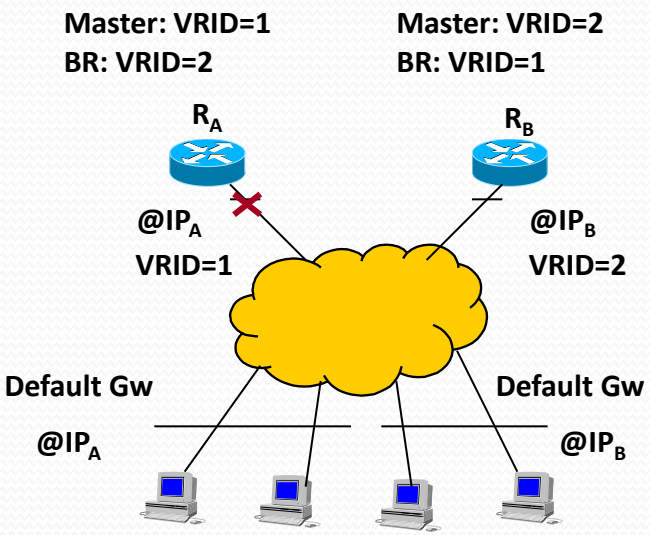
Virtual Router Redundancy Protocol

- While a router works as Master, it has an @IP associated to the Virtual Router.
- In Master state a router:
  - SHOULD answer to ARP requests directed to the @IP associated to the virtual router
    - uses the **virtual @MAC:** is not the physical MAC address of the interface, but a MAC address with ID **00-00-5E-00-01-{VRID}**
  - SHOULD forward packets with @MACdst =@MAC of the virtual router
  - SHOULD NOT accept packets addressed to the @IP associated to the virtual router to which is not @IP owner
  - SHOULD accept packets addressed to the @IP associated to the virtual router

- **Virtual Router Redundancy Protocol**
  - While a router is in Backup state monitors the availability of the Master router
  - In backup state, a router:
    - SHOULD NOT answer to ARP requests directed to @IP associated to the virtual router
    - SHOULD discard packets with @MACdst =@MAC del router virtual
    - SHOULD NOT accept packets addressed to the @IP associated to the virtual router

Virtual Router Redundancy Protocol

- The Master fails



R_A: has @IP_A as owner @IP
R_B: has @IP_B as owner @IP
2 Hosts has @IP_A as @IP_{Gw}
2 Hosts has @IP_B as @IP_{Gw}

R_A fails: R_B detects the master failure (VRRP messages are not listened) and detects that there is n other backup with higher priority than himself

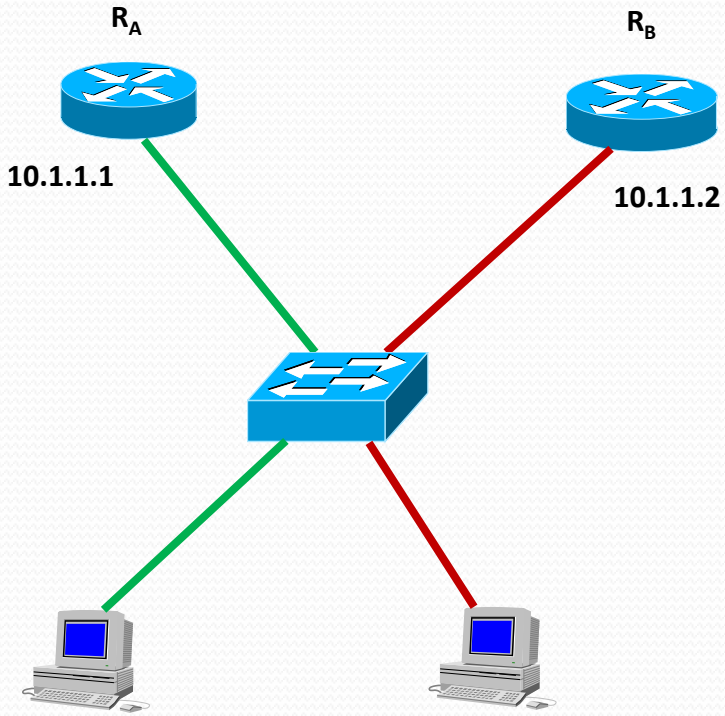
R_B sends ARP gratuitous in order that all Hosts "clean" their ARP cache and will update switching tables creating new L2 routing towards R_B

ARP gratuitous → If A fails and B sends a ARP request with @IP_{dst}= @IP_{src}=@IP_A and @MAC_{dst}= broadcast and @MAC_{src}= @$MAC_{virtual\text{-}ID=1}$ → all hosts will refresh their ARP table with the MAC that B wants to associate to the @IP_A

VRRP does that with the virtual MAC

- **VRRP: CISCO IoS**

Master: VRID=1, IP@= 10.1.1.10
BR: VRID=2, IP@= 10.1.1.11

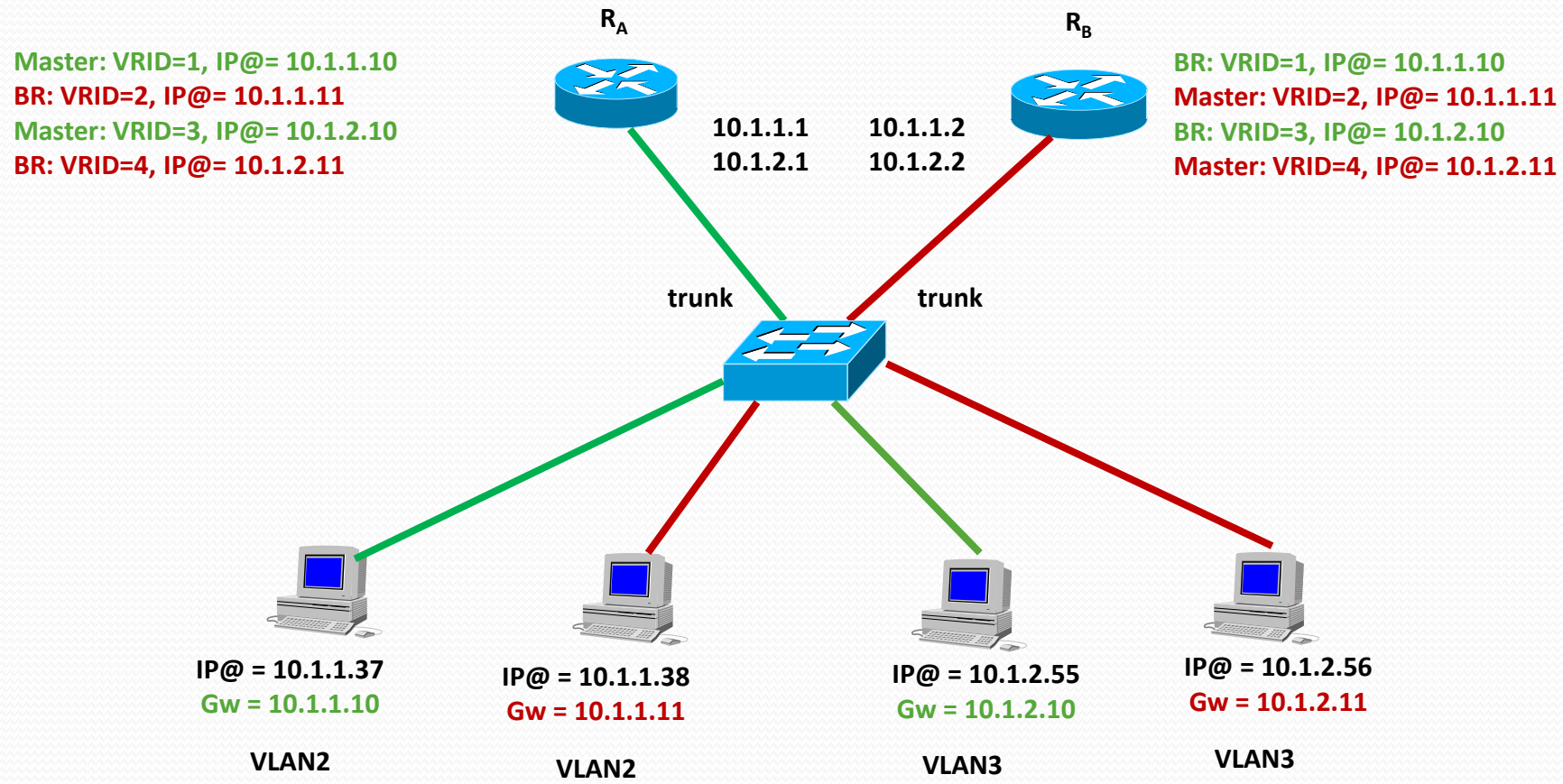


BR: VRID=1, IP@= 10.1.1.10
Master: VRID=2, IP@= 10.1.1.11

- **VRRP: CISCO IoS**

```
!!!! Router RA
RA(conf)# interface Ge0
RA(config-if)# ip address   10.1.1.1   255.255.255.0
RA(config-if)# vrrp 1 priority 200
RA(config-if)# vrrp 1 ip 10.1.1.10
RA(config-if)# vrrp 2 priority 100
RA(config-if)# vrrp 2 ip 10.1.1.11
RA(config-if)# no shutdown
!!!! Router RB
RB(conf)# interface Ge0
RB(config-if)# ip address   10.1.1.2   255.255.255.0
RB(config-if)# vrrp 1 priority 100
RB(config-if)# vrrp 1 ip 10.1.1.10
RB(config-if)# vrrp 2 priority 200
RB(config-if)# vrrp 2 ip 10.1.1.11
RB(config-if)# no shutdown
```

- **VRRP+STP+VLAN: CISCO IoS**



- ## VRRP+STP+VLAN: CISCO IoS

!!!! Router RA, is a trunk port

RA(conf)# **interface** Ge0

RA(config-if)# **no shutdown**

!!!! Subinterface (Virtual) of Ge0 → Ge0.1

RA(conf)# **interface** Ge0.1

RA(config-if)# **ip address** 10.1.1.1 255.255.255.0

RA(config-if)# **encapsulation** dot1q VLAN2

RA(config-if)# **vrrp** 1 **priority** 200

RA(config-if)# **vrrp** 1 **ip** 10.1.1.10

RA(config-if)# **vrrp** 2 **priority** 100

RA(config-if)# **vrrp** 2 **ip** 10.1.1.11

!!!! Subinterface (Virtual) of Ge0 → Ge0.2

RA(conf)# **interface** Ge0.2

RA(config-if)# **ip address** 10.1.2.1 255.255.255.0

RA(config-if)# **encapsulation** dot1q VLAN3

RA(config-if)# **vrrp** 3 **priority** 200

RA(config-if)# **vrrp** 3 **ip** 10.1.2.10

RA(config-if)# **vrrp** 4 **priority** 100

RA(config-if)# **vrrp** 4 **ip** 10.1.2.11

- ## VRRP+STP+VLAN: CISCO IoS

!!!! Router RB, is a trunk port

RB(conf)# **interface** Ge0

RB(config-if)# **no shutdown**

!!!! Subinterface (Virtual) of Ge0 → Ge0.1

RB(conf)# **interface** Ge0.1

RB(config-if)# **ip address** 10.1.1.2 255.255.255.0

RB(config-if)# **encapsulation** dot1q VLAN2

RB(config-if)# **vrrp** 1 **priority** 100

RB(config-if)# **vrrp** 1 **ip** 10.1.1.10

RB(config-if)# **vrrp** 2 **priority** 200

RB(config-if)# **vrrp** 2 **ip** 10.1.1.11

!!!! Subinterface (Virtual) of Ge0 → Ge0.2

RB(conf)# **interface** Ge0.2

RB(config-if)# **ip address** 10.1.2.2 255.255.255.0

RB(config-if)# **encapsulation** dot1q VLAN3

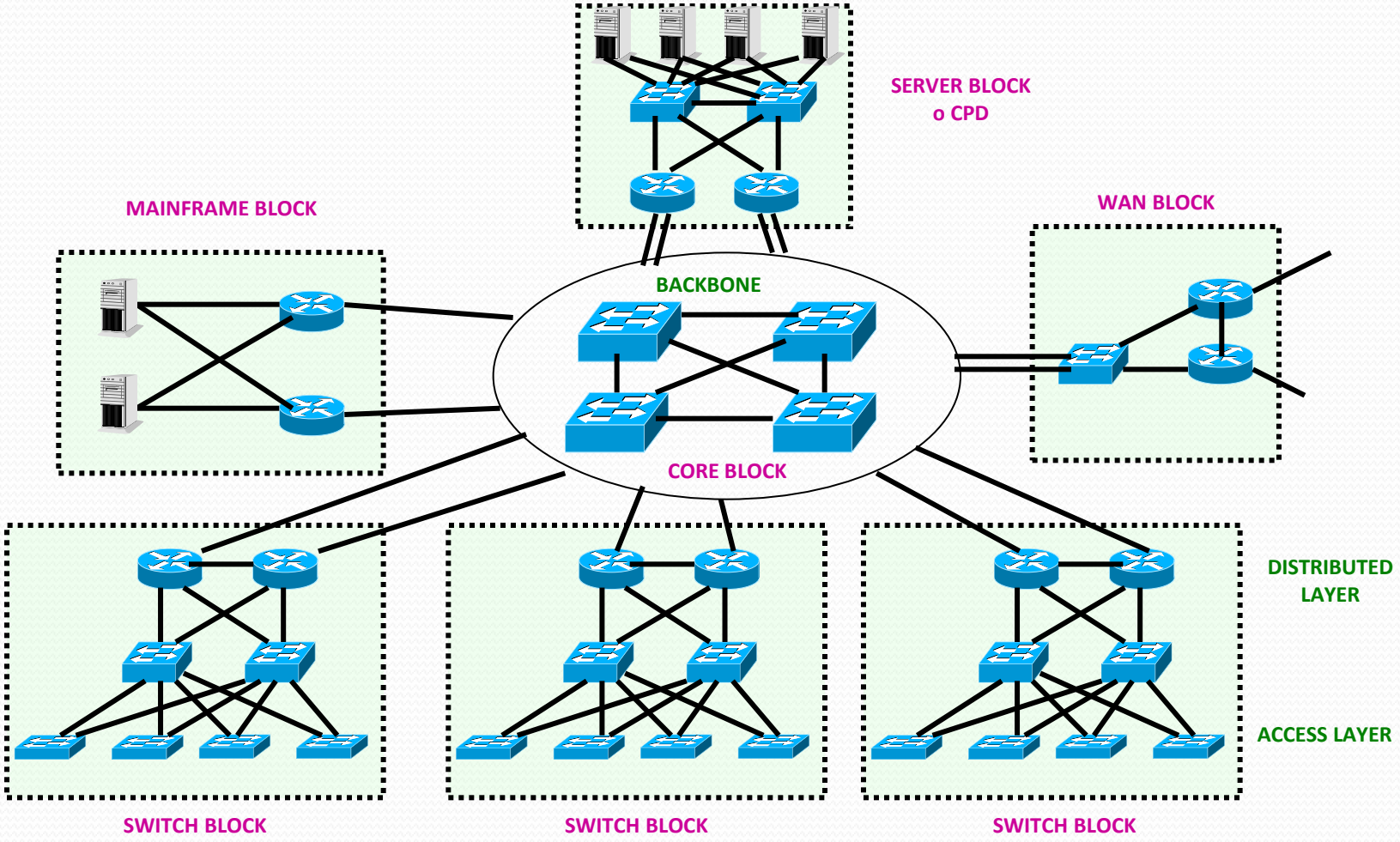
RB(config-if)# **vrrp** 3 **priority** 100

RB(config-if)# **vrrp** 3 **ip** 10.1.2.10

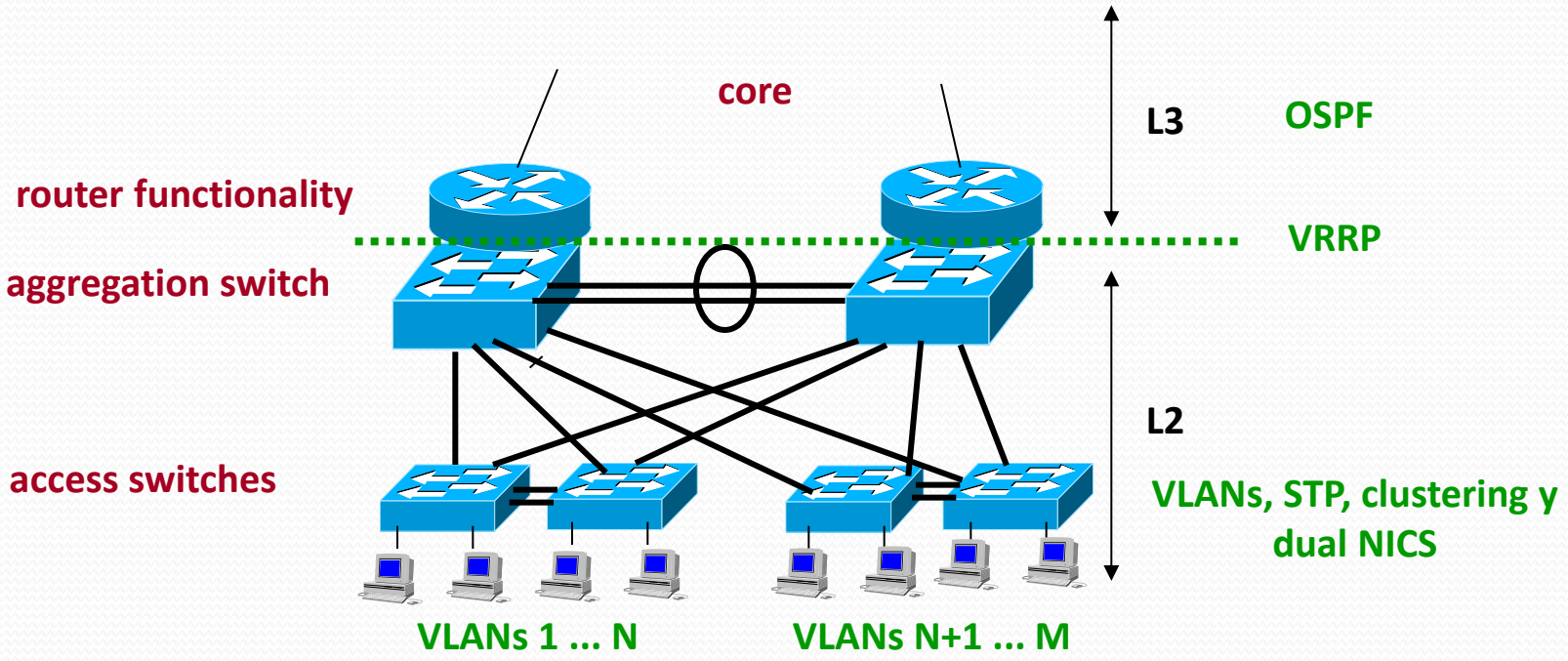
RB(config-if)# **vrrp** 4 **priority** 200

RB(config-if)# **vrrp** 4 **ip** 10.1.2.11

- Corporate Network architecture: the switching blocks

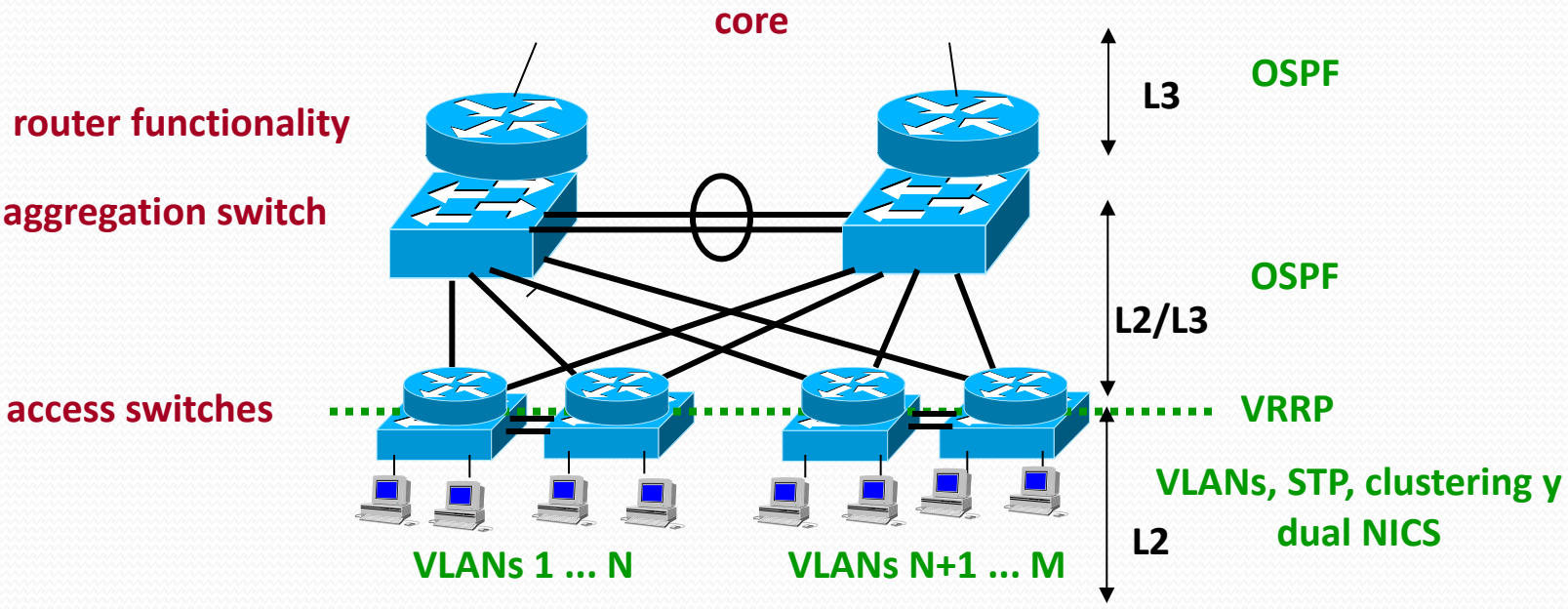


- **Switched block and Data Center**
  - Aggregation switch→ can be Multilayer Switch with routing functionalities (firewalling, load balancing, fail tolerance, ...)
  - L2 server adjacency → needed to exchange session information, synchronization, ...



Access Switches→ e.g., Multilayer Switch

- Avoid STP blocking when the aggregation modules are reached since there is a router that isolates the access to aggregation
- Limit broadcasts and improves convergence latencies
- clustering and NIC teaming restricted to groups of switches (need L2 adjacency for synchronization purposes)

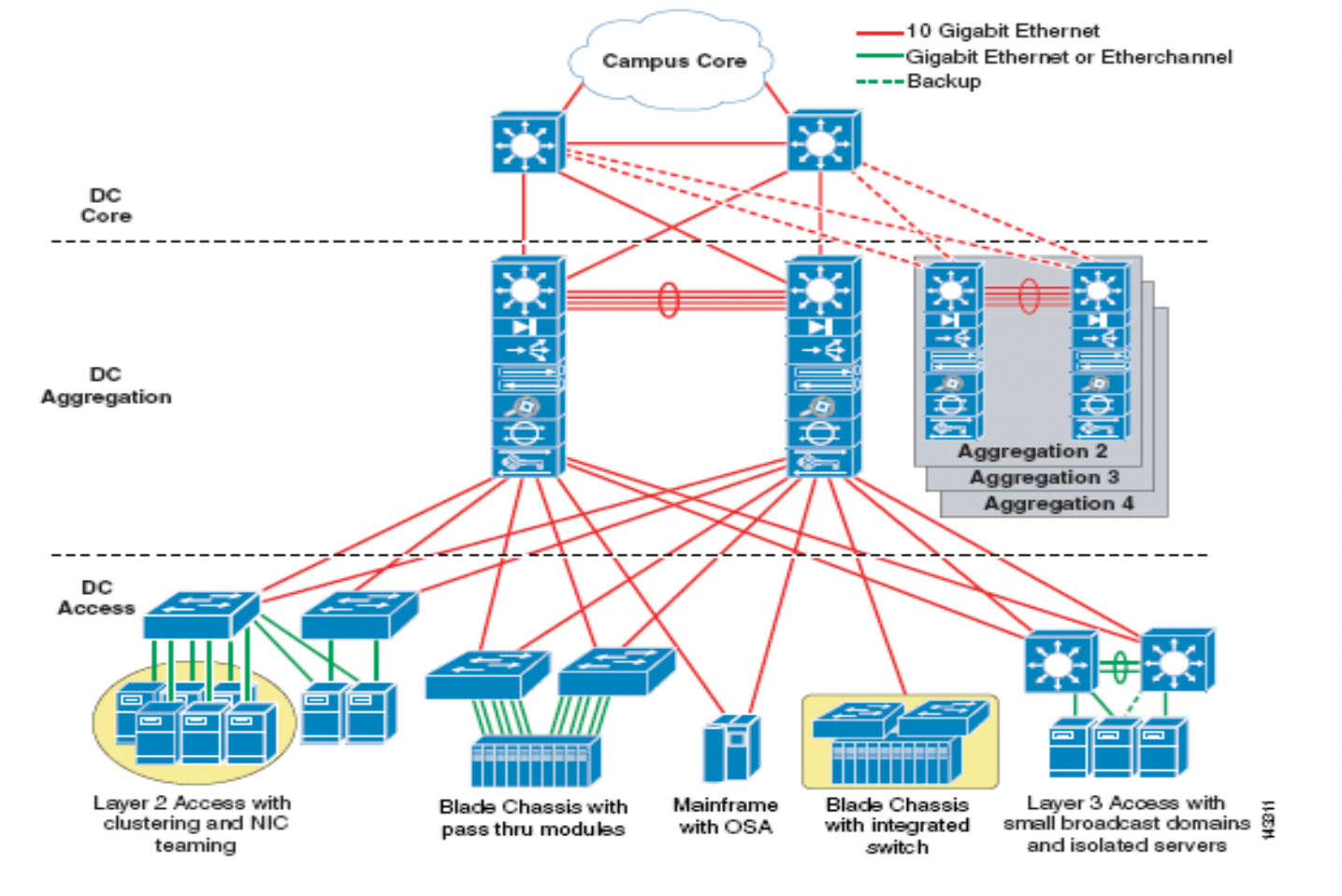


- **Data Processing Centers (CPD)**
  - A **data center** is a facility used to house computer systems and associated components, such as telecommunications and storage systems.
  - It generally includes redundant or backup power supplies, redundant data communications connections, environmental controls (e.g., air conditioning, fire suppression) and security devices.
    - Operate and manage a carrier's telecommunication network
    - Provide data center based applications directly to the carrier's customers
    - Provide hosted applications for a third party to provide services to their customers
    - Provide a combination of these and similar data center applications

Data Processing Centers (CPD)

Tier Level	Requirements
1	•Single non-redundant distribution path serving the IT equipment •Non-redundant capacity components •Basic site infrastructure with expected availability of 99.671% (fail less than 4’44s per day)
2	•Meets or exceeds all Tier 1 requirements •Redundant site infrastructure capacity components with expected availability of 99.741% (fail less than 3’43s per day)
3	•Meets or exceeds all Tier 1 and Tier 2 requirements •Multiple independent distribution paths serving the IT equipment •All IT equipment must be dual-powered and fully compatible with the topology of a site's architecture •Concurrently maintainable site infrastructure with expected availability of 99.982% (fail less than 15s per day)
4	•Meets or exceeds all Tier 1, Tier 2 and Tier 3 requirements •All cooling equipment is independently dual-powered, including chillers and heating, ventilating and air-conditioning (HVAC) systems •Fault-tolerant site infrastructure with electrical power storage and distribution facilities with expected availability of 99.995% (fail less than 4s per day)

- Data Processing Centers (CPD)



- **High Availability (HA)**
  - Applications, network equipment (servers, routers, switches, ...) and network interfaces can fail→ there is a need to improve fail tolerance
    - Applications: automatically (script) to re-initiate processes (SO)
    - L2: Spannning Tree Protocol handle fail tolerance at L2
    - L3: VRRP and OSPF handle fail tolerance at L3
    - Equipment: improve server performance (e.g. using clustering)
      - Clustering for High Availability: group of computers that support server applications that can be reliably utilized in a minimum of down-time.
      - Dual connections: use of more than one network interface card (NIC) in Servers.

- **Scalability**
  - React to company growth → implies a growth in the following points:
    - Growth in the number of network connections
    - Growth in the capacity of the network

Both impact the network infrastructure in terms of equipment (switches, routers, …)

  - Growth in the computation capabilities: use of **clusters** in order to increase
    - the server capacity (e.g. clustering for Load Balancing)
    - the computational capacity (e.g. clustering for Computational power),
    - And the reliability

- **Data Processing Centers (CPD): cluster servers**
  - Main objective: execute multiple application in multiple machines
    - Clustering techniques allow dispatch queries to those servers that are more reliable or unloaded (fail tolerance)

Server 1	**Application 1**	**Application 2**
Server 2	**Application 1**	**Application 2**
Server N	**Application 1**	**Application 2**

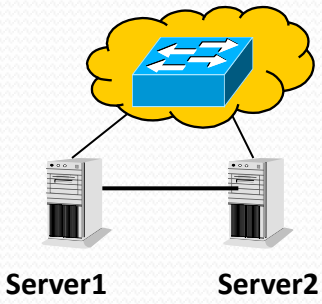
VIPA (Virtual IP address) → allows redirect a query to a set of servers (in fact it is the IP address of the "dispatcher" that receives the client query)

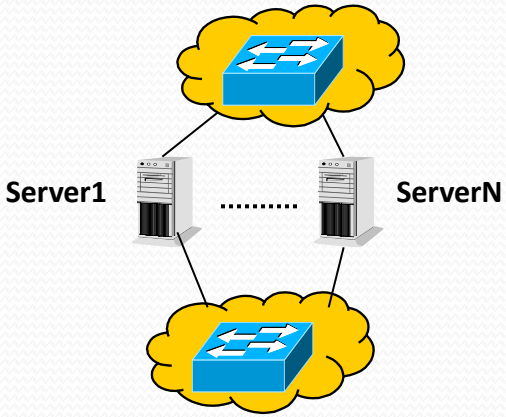
Distribute client queries to servers → linked to load balance techniques

Backup of the dispatcher !!! It can also fail

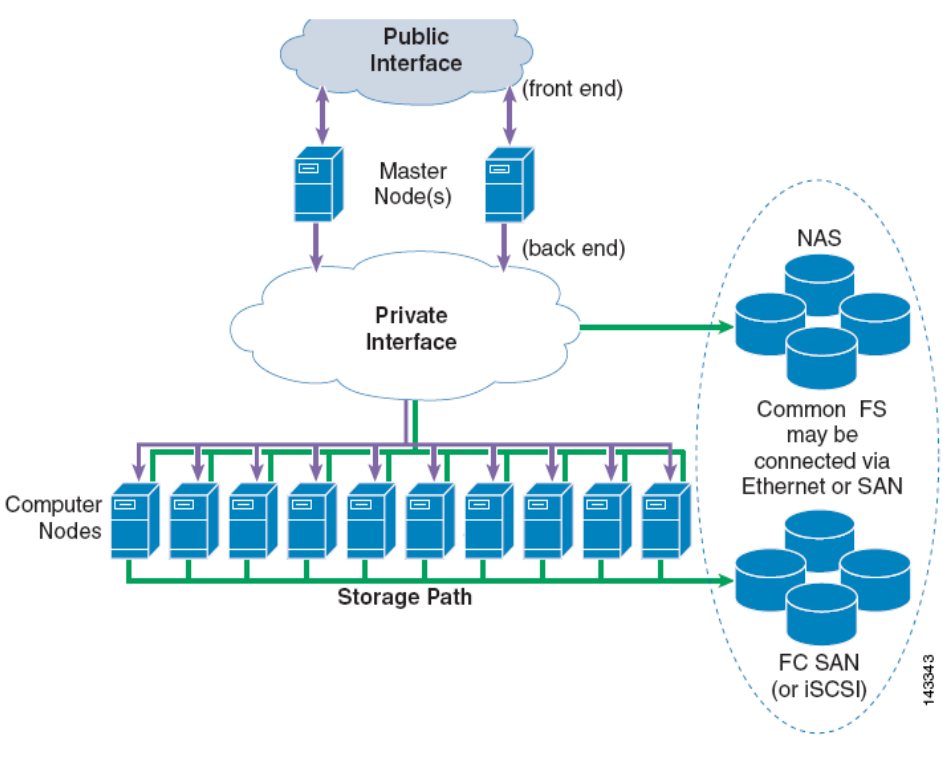
- **Data Processing Centers (CPD): cluster servers**
  - If two servers:
    - They can be interconnected (e.g. via a crossover wire) in order to exchange information (e.g. exchange of data, session state or monitoring states).
  - If more than two servers
    - Interconnected via LAN

Require adjacency at L2





Data Processing Centers (CPD): cluster servers



Front end: interfaces with external access to the cluster (e.g. Application servers or users that send jobs to be executed in the cluster)

Master Nodes: responsible of managing switched nodes in the cluster and to optimize the computing capacity

Back-end high speed fabric: the media that uses the master to communicate with the computation nodes (low-latency and high bandwidth). Typically 10GigaE or Infiniband

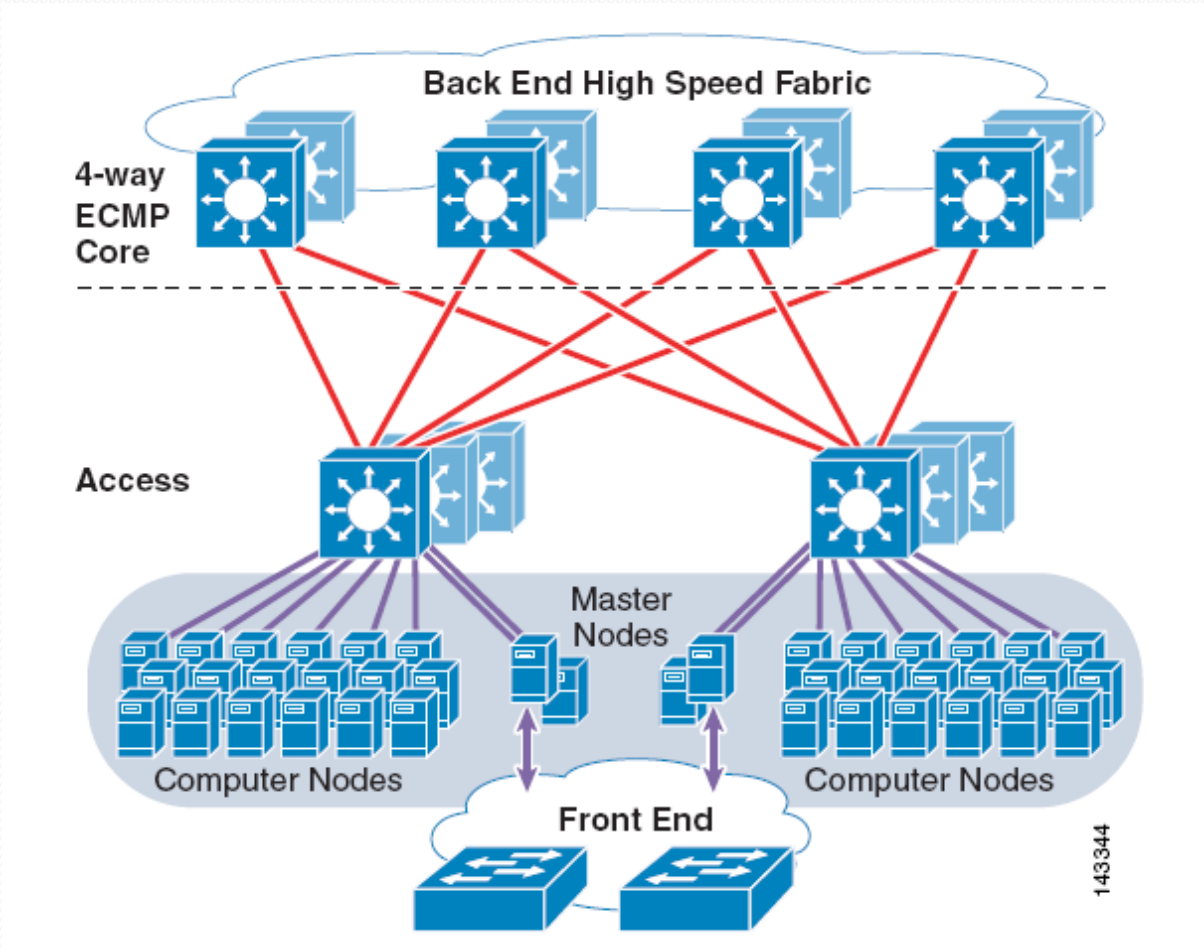
Computer Nodes: Computation nodes with an OS responsible of intensive operations

Storage Path: Ethernet or Fibre Channel for connecting with the storage capabilities (SAN: Storage Area Network)

Common parallel FS (File System) to access all computation nodes

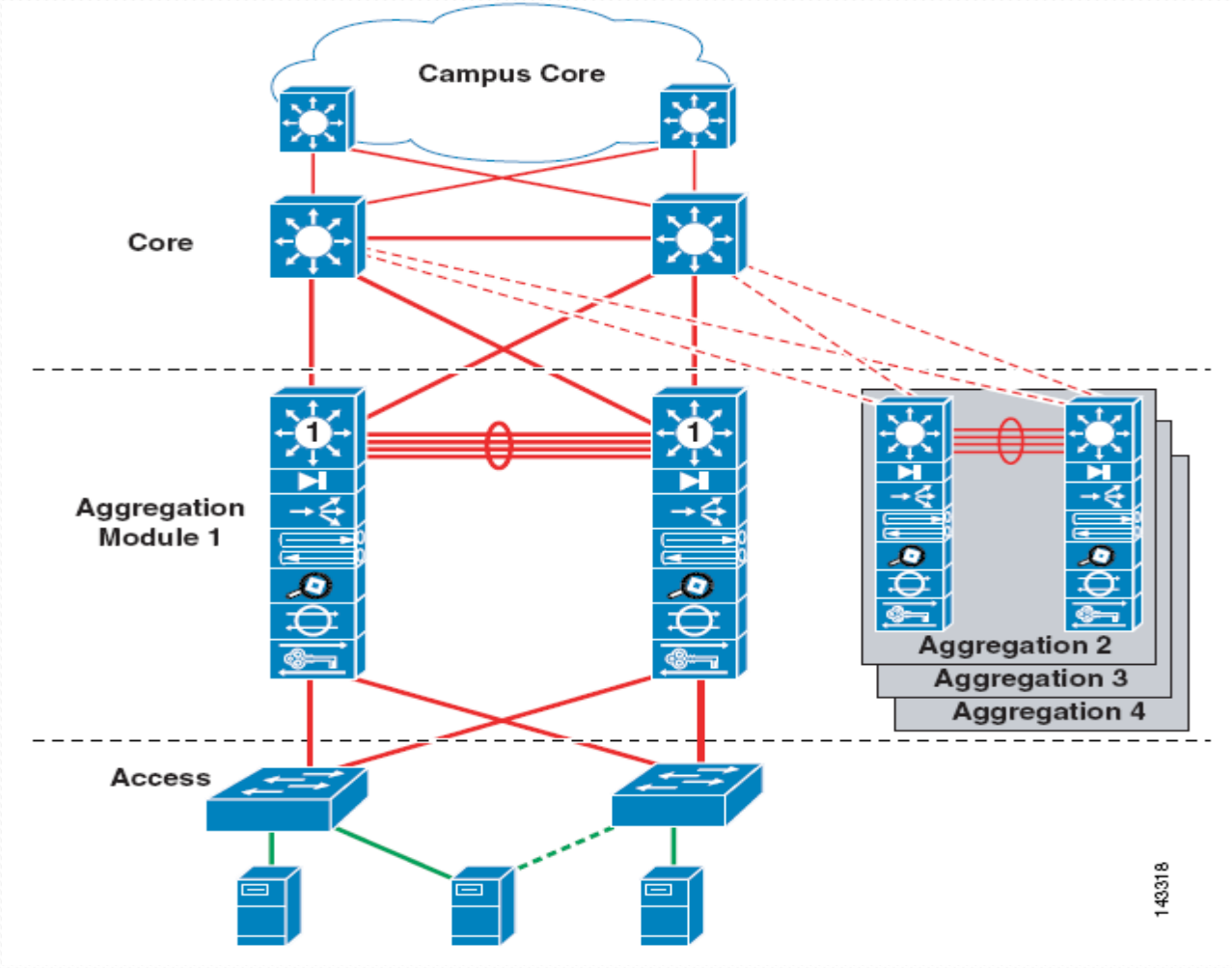
- **Data Processing Centers (CPD): cluster servers**
  - **Load Balancing**
    - If there are several lines that interconnect the servers, we can distribute the **load** is such a way that this tends to be more **symmetric** (have equivalent loads in all servers)
    - Load Distribution
      - As a function of the knowledge that the dispatcher has on the work-load of the systems
      - If the dispatchers have no information related to the servers
        - Distribute via round-robin
        - Distribute as a function of the number of on-going queries

- **Data Processing Centers (CPD): cluster servers**



Multi-tier Data Centers:

- Most common DC design technique in many companies



- **Data Center Core Layer**
  - Connects the Core Distribution (backbone) Campus layer with the Data Center Aggregation layer
  - Gives high speed connection towards the aggregation modules
  - Not always required
  - If the core is independent of the Core Campus (backbone) layer, is allowed to implement independent policies (e.g. QoS, Access list, maintenance, ...) in the DC and in the Campus backbone
  - 10 GEth ports
  - Usually L3 switches

- **Data Center Aggregation Layer**
  - Aggregate thousands of connections that want to access the Data Center
  - The aggregation switches must be capable of supporting many 10 GigE and GigE interconnects while providing a high-speed switching fabric with a high forwarding rate.
    - Support of 10 GEth ports (towards the core) and 1GEth ports (towards access)
  - The aggregation layer switches carry the workload of spanning tree processing and default gateway redundancy protocol processing.

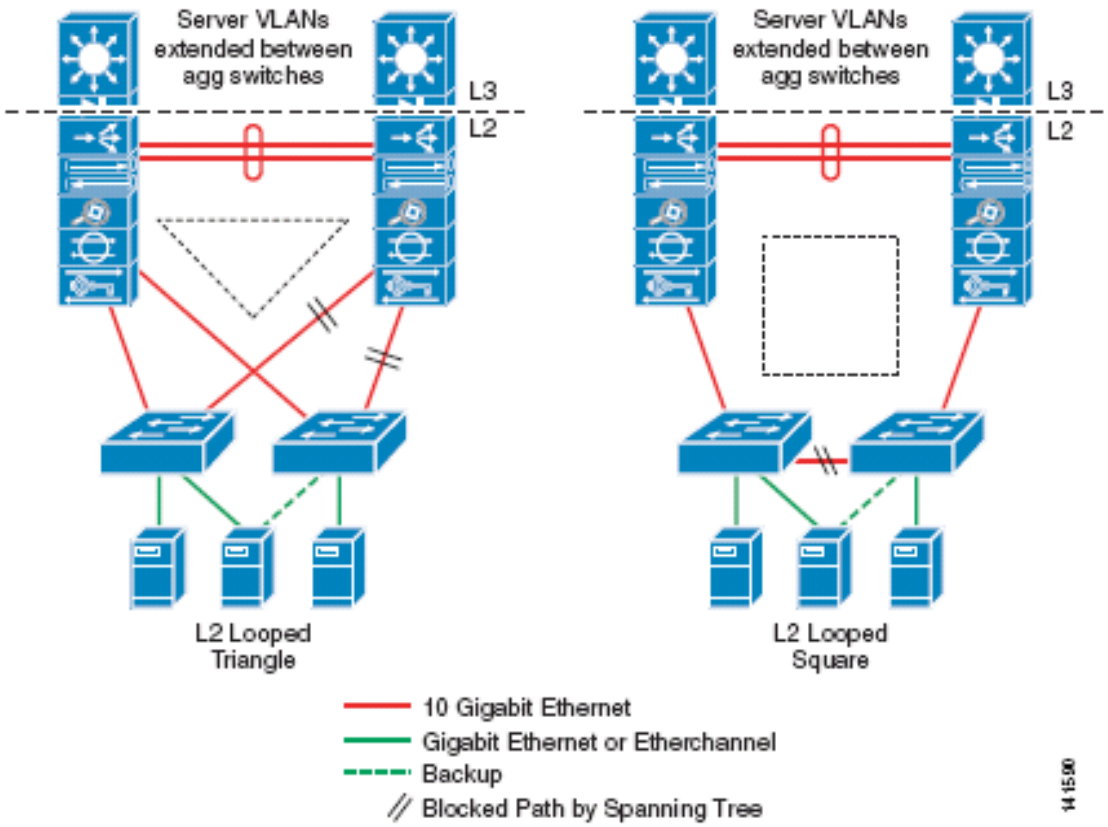
- **Data Center Aggregation Layer**
  - Support high value services such as Load balancing, Firewalling and Intrusion Detection, SSL (Secure Socket Layer) to the servers, caches, network monitoring, etc,
    - High port densities
    - 10Gbps ports
    - VLAN
    - 802.1s (MSTP), 802.1w (rapid STP)
    - MPLS-VPN
    - Hardware-based NAT
    - QoS
    - Load Balancing and security modules

- **Data Center Access Layer**
  - Gives a connection point to the servers and operates at L2 and L3
  - The mode plays a critical role in meeting particular server requirements such as NIC teaming, clustering, and broadcast containment.
  - The access layer is the first oversubscription point in the data center because it aggregates the server traffic onto Gigabit EtherChannel or 10 GigE/10 Gigabit EtherChannel uplinks to the aggregation layer.

- **Data Center Access Layer**
  - Always Redundancy: at least a couple of switches inter-connected with STP
    - see following slides for examples
    - **Looped** configurations such as triangle and square or **looped-free** such as U or U-down
      - Triangle configurations usually the best one but needs a lot of experience,
      - U's configurations are simple and used when low STP experience or because STP is undesired (e.g. all uplink links active) → in general use STP

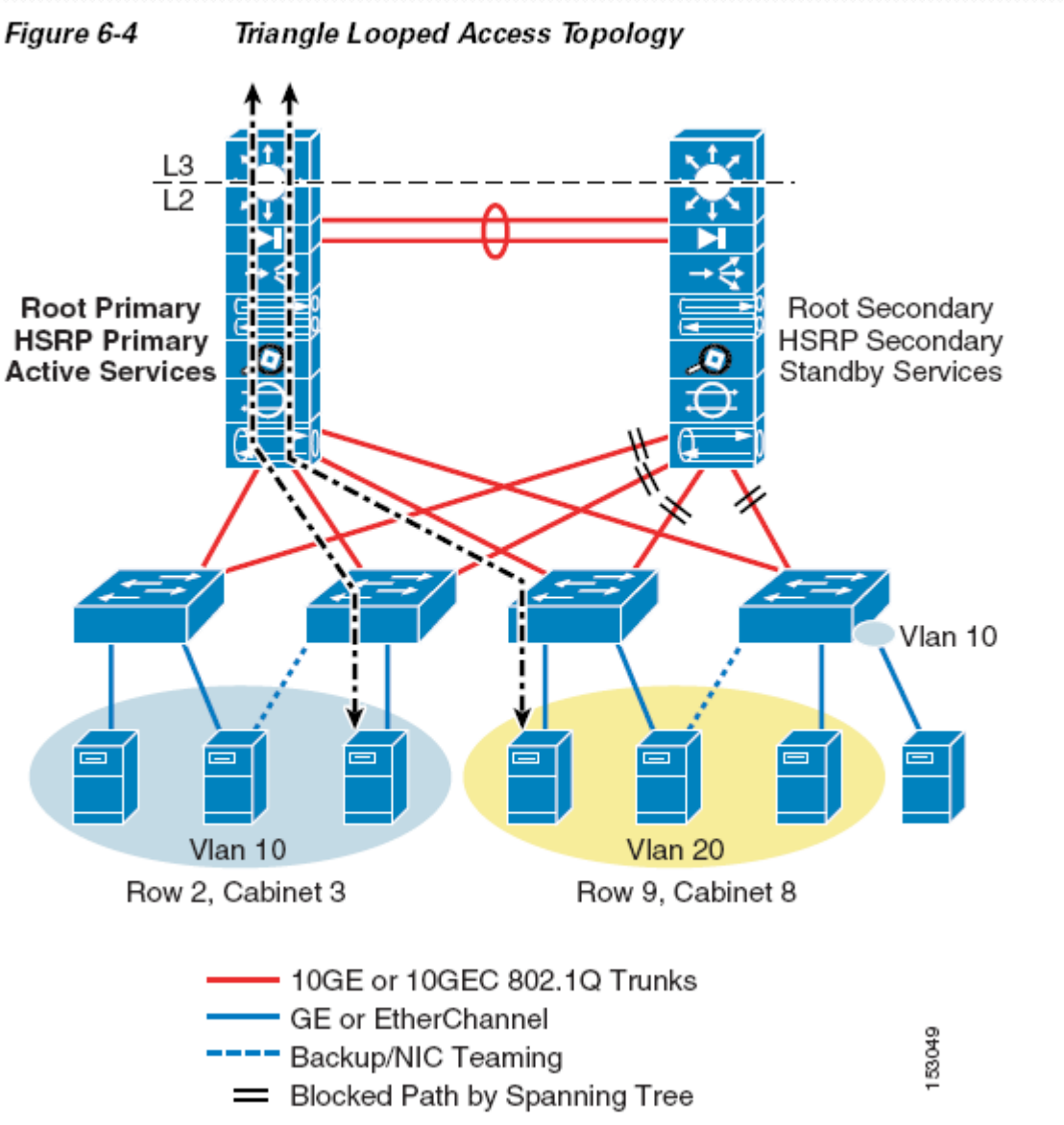
- **Data Center Access Layer**
  - **Looped** configurations are desirable because:
    - **VLAN extension**: The ability to add servers into a specific VLAN across the entire access layer is a key requirement in most data centers.
    - **Resiliency:** Looped topologies are inherently redundant.
    - **Service module interoperability**: Service modules operating in active-standby modes require Layer 2 adjacency between their interfaces.
    - Server requirements for Layer 2 adjacency in support of NIC teaming and high availability clustering.

- **Data Center Access Layer**



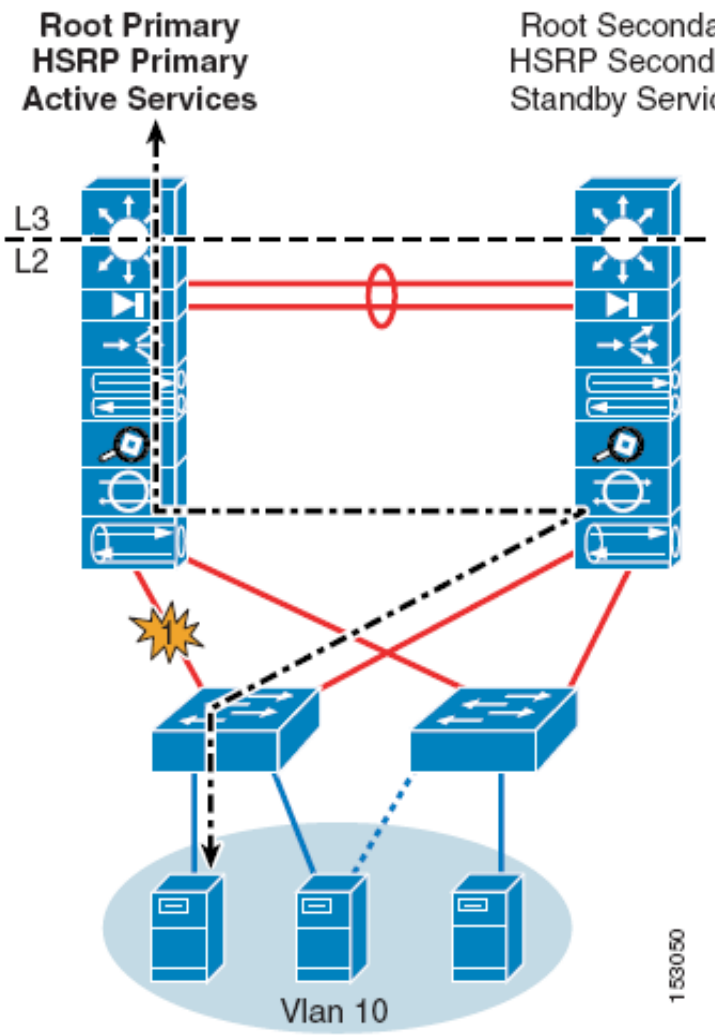
Access Topologies (Looped) using L2 technologies

- **Data Center Access Layer:**
  - Triangle looped topology + VRRP (or HSRP)



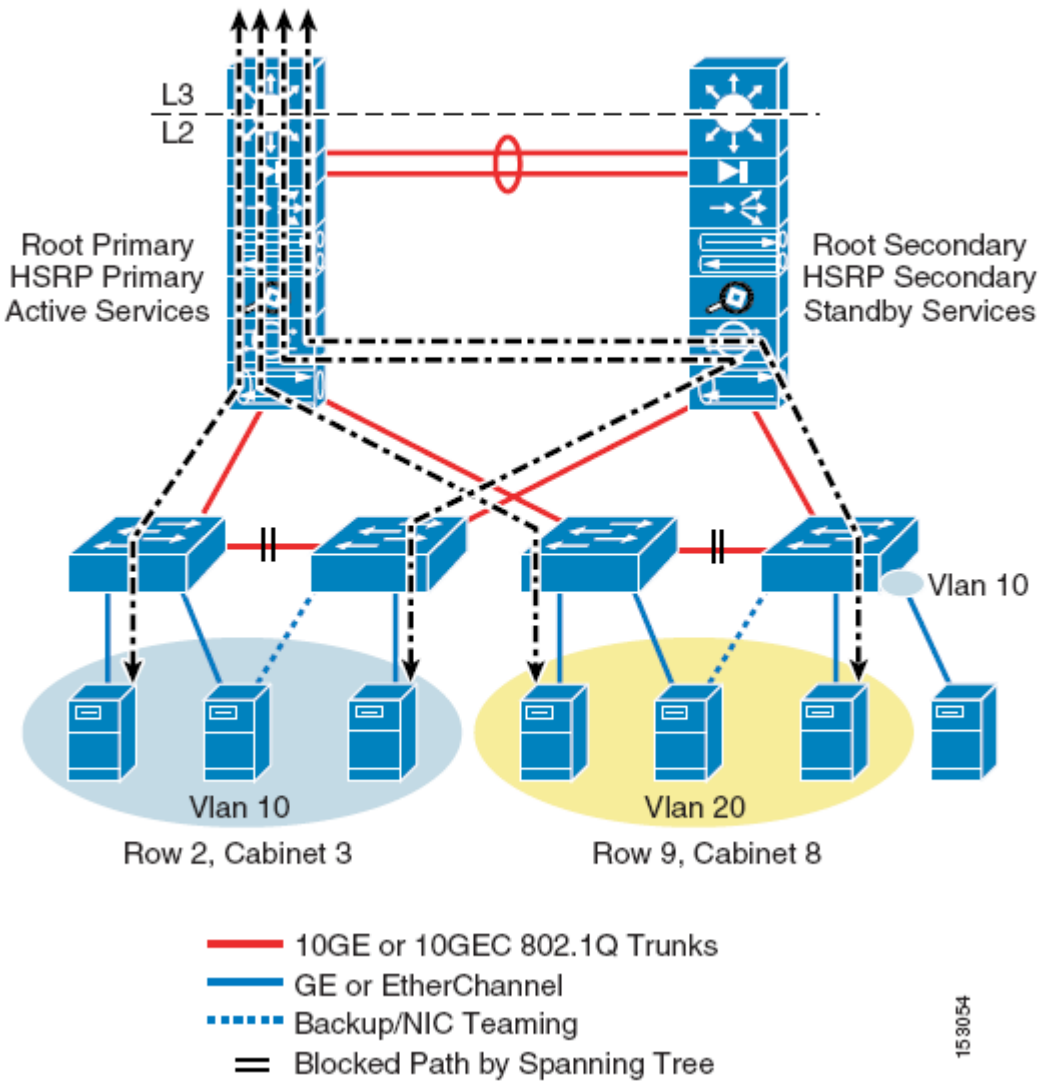
- **Data Center Access Layer:**
  - Triangle looped topology + VRRP (or HSRP)

Figure 6-5 Triangle Looped Failure Scenario 1—Uplink Down



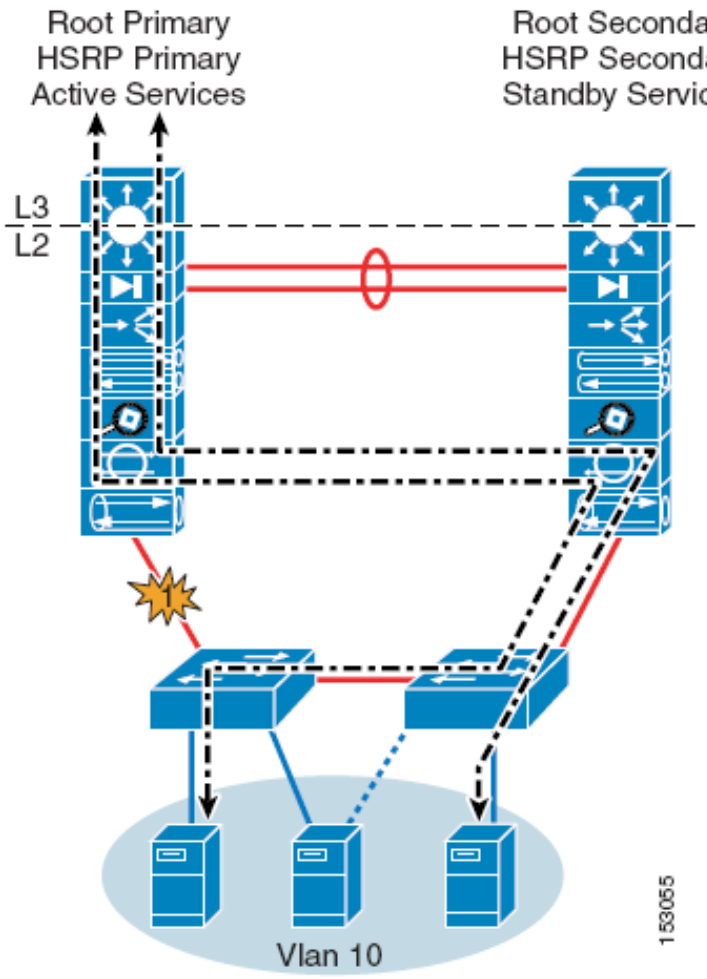
- **Data Center Access Layer:**
  - Square looped topology + VRRP (or HSRP)

Figure 6-9 Square Looped Access Topology

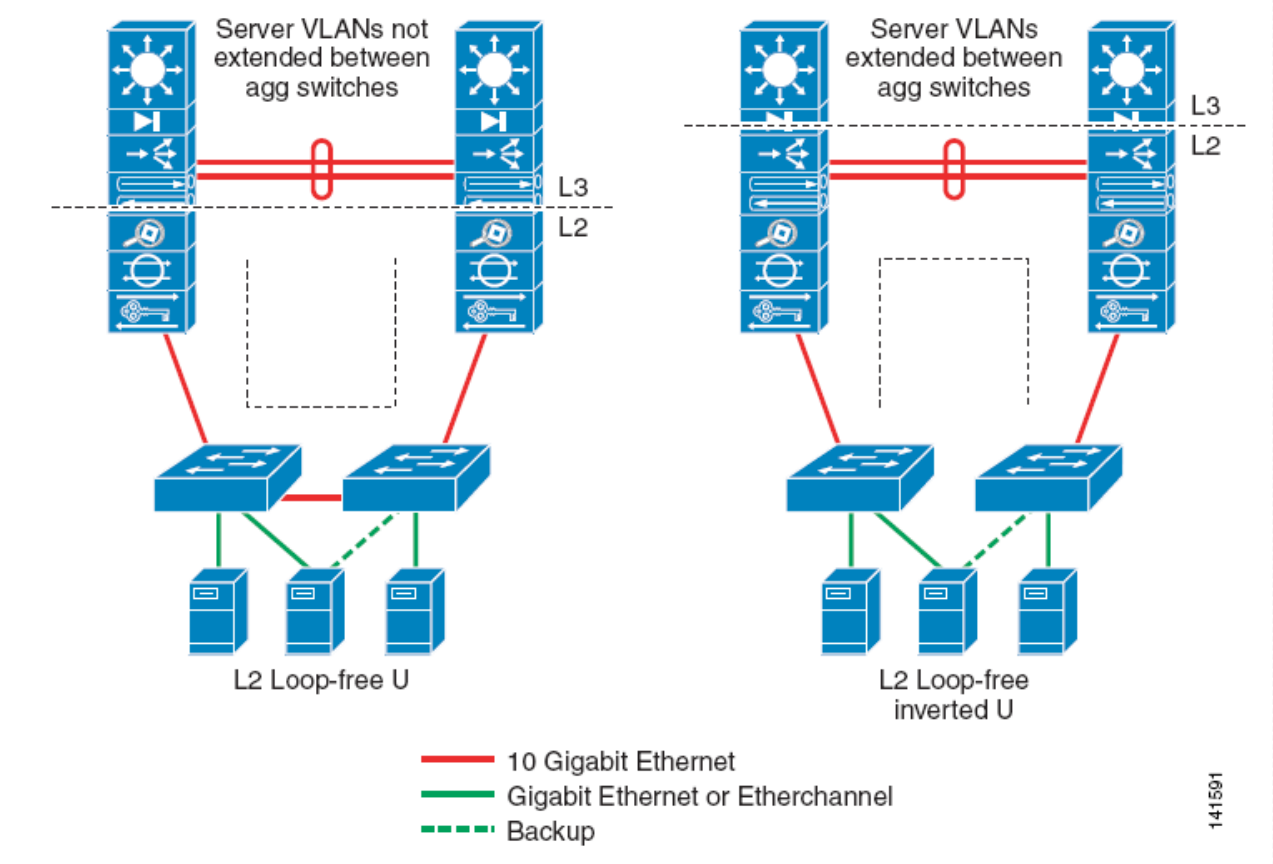


- **Data Center Access Layer:**
  - Square looped topology + VRRP (or HSRP)

Figure 6-10 Square Looped Failure Scenario 1—Uplink Down



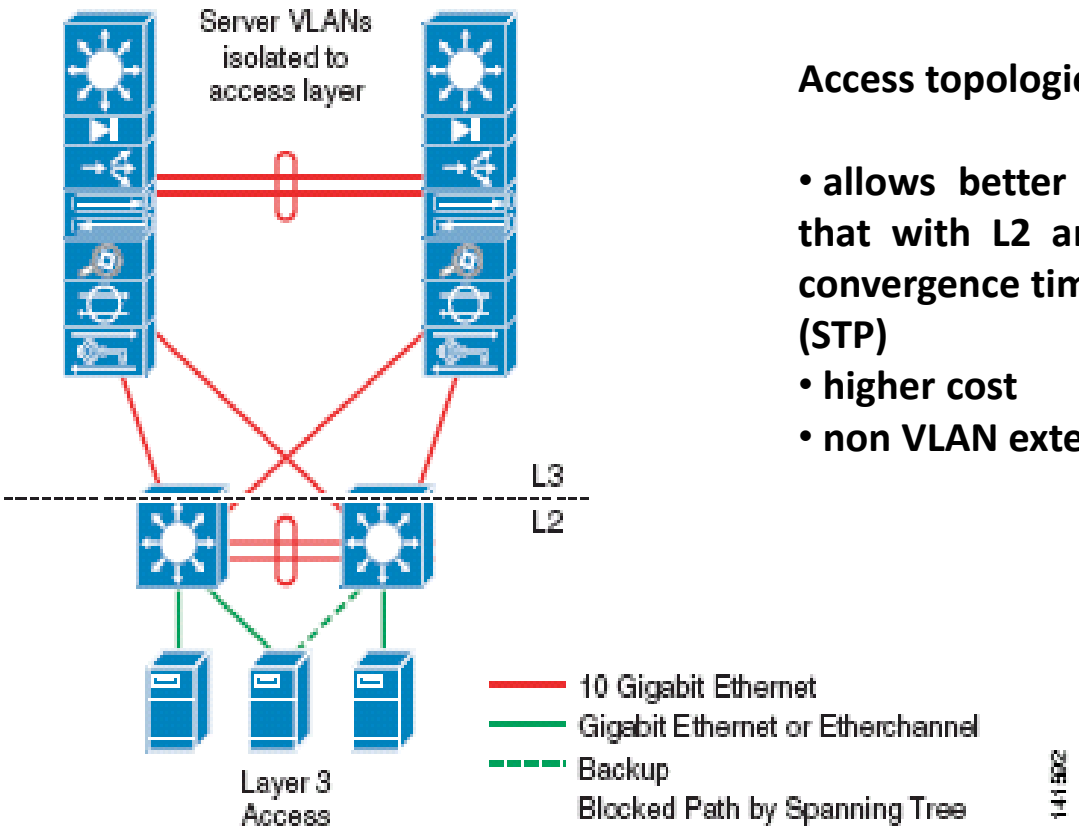
- **Data Center Access Layer**



Access Topologies Looped-free using L2 technologies

- **Data Center Access Layer**
  - Main differences between a **Looped** and a **looped-free** configuration:
    - No blocking on uplinks, all links are active in a loop-free topology
    - Layer 2 adjacency for servers is limited to a single pair of access switches in a loop-free topology
    - VLAN extension across the data center is not supported in a loop-free U topology but is supported in the inverted U topology.
  - In any case, even in loop-free topologies, activate STP to prevent loops

- **Data Center Access Layer**



Access topologies using L3 technology:

- **allows better control (isolate the servers) that with L2 and L3 access and has better convergence times (e.g. OSPF) with respect L2 (STP)**
- **higher cost**
- **non VLAN extensions across the data center**

Data Center Access Layer

- Scalability: number of servers versus switches
  - Average bandwidth (or Throughput) per server: the OS (operator system) and NIC (Network Interface Card) is able to produce traffic that occupies a % of the link capacity. E.g a server occupies a 60% of the 1 Gb/s link → occupies 600 Mb/s
  - Oversupscription ratio per server: average number of servers to occupy a link capacity. E.g. if a sever occupies 60% of the link, then 1/0.6= 1.666 → oversubscription ratio is of **1.66:1**
  - Oversupscription ratio of a switch: average number of servers to occupy the uplink capacity of a switch.

    We have to take into account all the access links connected to the servers and all the uplink aggregated links towards the aggregation switch.

- **Data Center Access Layer**
  - Scalability: number of servers versus switches
    - Maxim number of 1GEth server connections: scale with switches. Increase servers and switches in such a way that a minimum bandwidth and maximum latency is guaranteed
    - Approximate bandwidth per server: if N 10 GEth ports towards aggregation and M server ports → Nx10 GEth/M = C Mbps per server (e.g. 4x10Gbps/336 servers = 120 Mbps
    - Oversupscription ratio per server: divide the number of server connections by the access aggregate. E.g. 336 server connections with 4x10GEth → 8.4:1 (1Gbps/120Mbps=8.4)

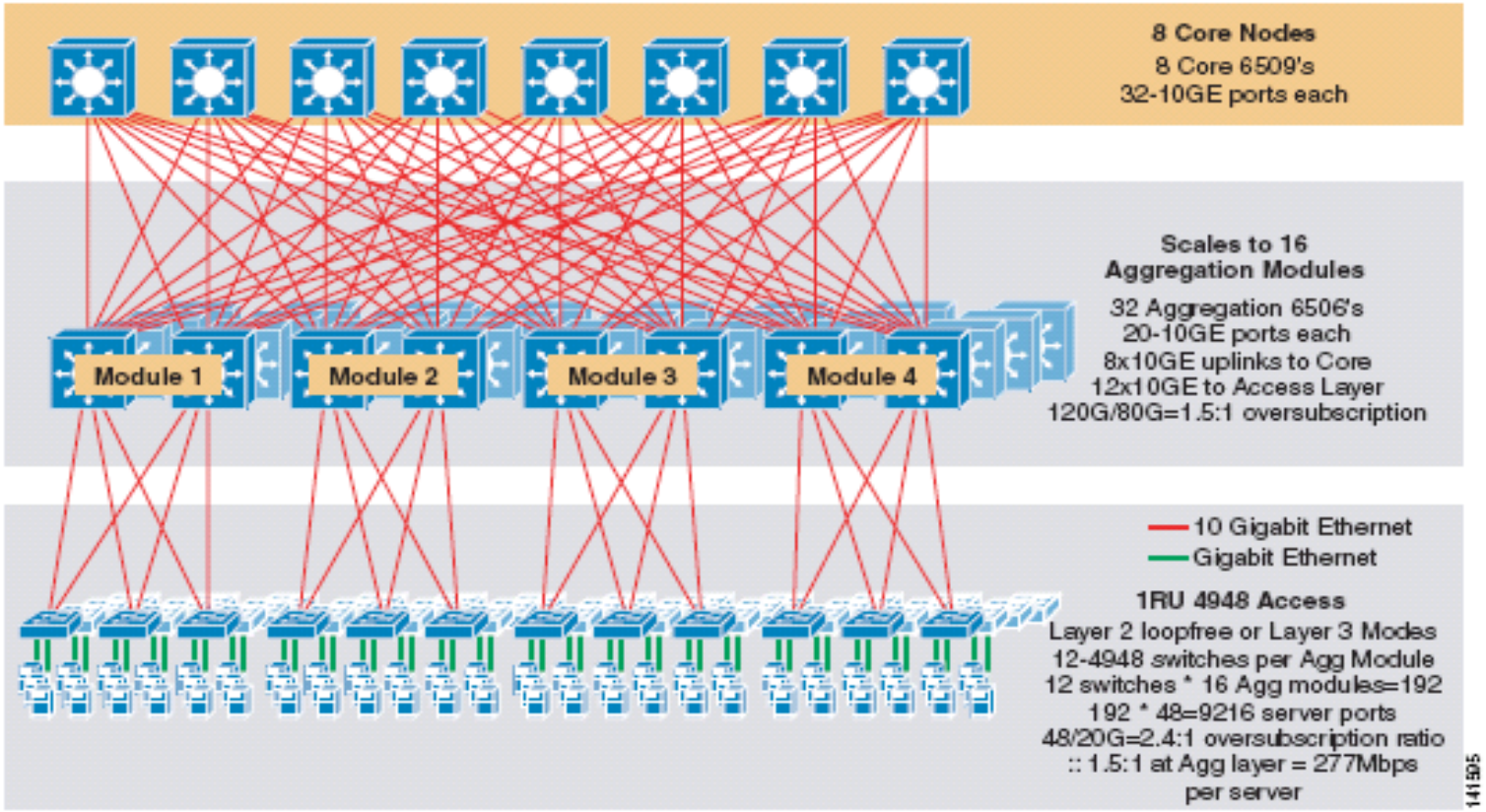
N·(K Gb/s) ≤ M·(R Gb/s) →Thrput = N·(K Gb/s) / M

Oversubscr ratio = (R Gb/s)/Thrput (Gb/s):1

- **Data Center Access Layer**
  - If you want better performance:
    - Improving the uplink between access and aggregation improves the oversubscription ratio:
      - Instead of 40 Gbps we have 80 Gbps maintaining the 336 servers → we obtain 240 Mbps and a 4.2:1 oversubscription ratio
    - Increase the number of access switches maintaining the oversubscription ratio
      - Increase the number of total servers at the cost of increasing the number of access switches
    - What limits scalability???
      - The uplink capacity of the access switch

- **Data Center Access Layer**
  - Optimized Oversubscription ratios:
    - Web servers → 15:1
    - Application servers → 6:1
    - Database servers → 4:1
    - HPC → 2.5:1 a 8:1

- **Data Center Access Layer**



- **Example:**
  - Calculate the oversubscription ratio:

Access layer:

oversubscription: 48 GE servers 2x10GE uplink towards aggregation → 2.4:1
Bandwidth per server→ 20Gbps/48Gbps = 416 Mbps

Aggregation layer

oversubscription: 120 GE downlinks to access per 8x10GE uplink a core
→ 1.5:1 → 80/120 = 666 Mbps

Calculate the real bandwidth per server: apply formula a:b = c:d

if the access has 416 Mbps and the aggregation has 1.5:1 oversubscription, then

2.4:1 = x:1.5 **→ x=3.6 → 3.6:1**
0.416:1 = x:0.666 **→ x=277 Mbps**