Spanning Tree Protocols

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Modified from Slides Courtesy of Cisco Networking Academy

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- Spanning Tree Concepts
- Varieties of Spanning Tree Protocols
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Redundancy at OSI Layers 1 and 2

Multiple cabled paths between switches:

- Provide physical redundancy in a switched network.

- Improves the reliability and availability of the network.

- Enables users to access network resources, despite path disruption.

Considerations When Implementing Redundancy:

- **MAC database instability** - Instability in the content of the MAC address table results from copies of the same frame being received on different ports of the switch. Data forwarding can be impaired when the switch consumes the resources that are coping with instability in the MAC address table.

- **Broadcast storms** - Without some loop-avoidance process, each switch may flood broadcasts endlessly. This situation is commonly called a broadcast storm.

- **Multiple frame transmission** - Multiple copies of unicast frames may be delivered to destination stations. Many protocols expect to receive only a single copy of each transmission. Multiple copies of the same frame can cause unrecoverable errors.

Issues with Layer 1 Redundancy: MAC Database Instability

- Ethernet frames do not have a time to live (TTL) attribute.
  - Frames continue to propagate between switches endlessly, or until a link is disrupted and breaks the loop.
  - Results in MAC database instability.
  - Can occur due to broadcast frames forwarding.

- If there is more than one path for the frame to be forwarded out, an endless loop can result.
  - When a loop occurs, it is possible for the MAC address table on a switch to constantly change with the updates from the broadcast frames, resulting in MAC database instability.

# Issues with Layer 1 Redundancy: Broadcast Storms

- A broadcast storm occurs when there are so many broadcast frames caught in a Layer 2 loop that all available bandwidth is consumed. It is also known as denial of service

- A broadcast storm is inevitable on a looped network.
  - As more devices send broadcasts over the network, more traffic is caught within the loop; thus consuming more resources.
  - This eventually creates a broadcast storm that causes the network to fail.

Purpose of Spanning Tree

Issues with Layer 1 Redundancy: Duplicate Unicast Frames

- Unicast frames sent onto a looped network can result in duplicate frames arriving at the destination device.

- Most upper layer protocols are not designed to recognize, or cope with, duplicate transmissions.

- Layer 2 LAN protocols, such as Ethernet, lack a mechanism to recognize and eliminate endlessly looping frames.

# Issues with Layer 1 Redundancy: Duplicate Unicast Frames
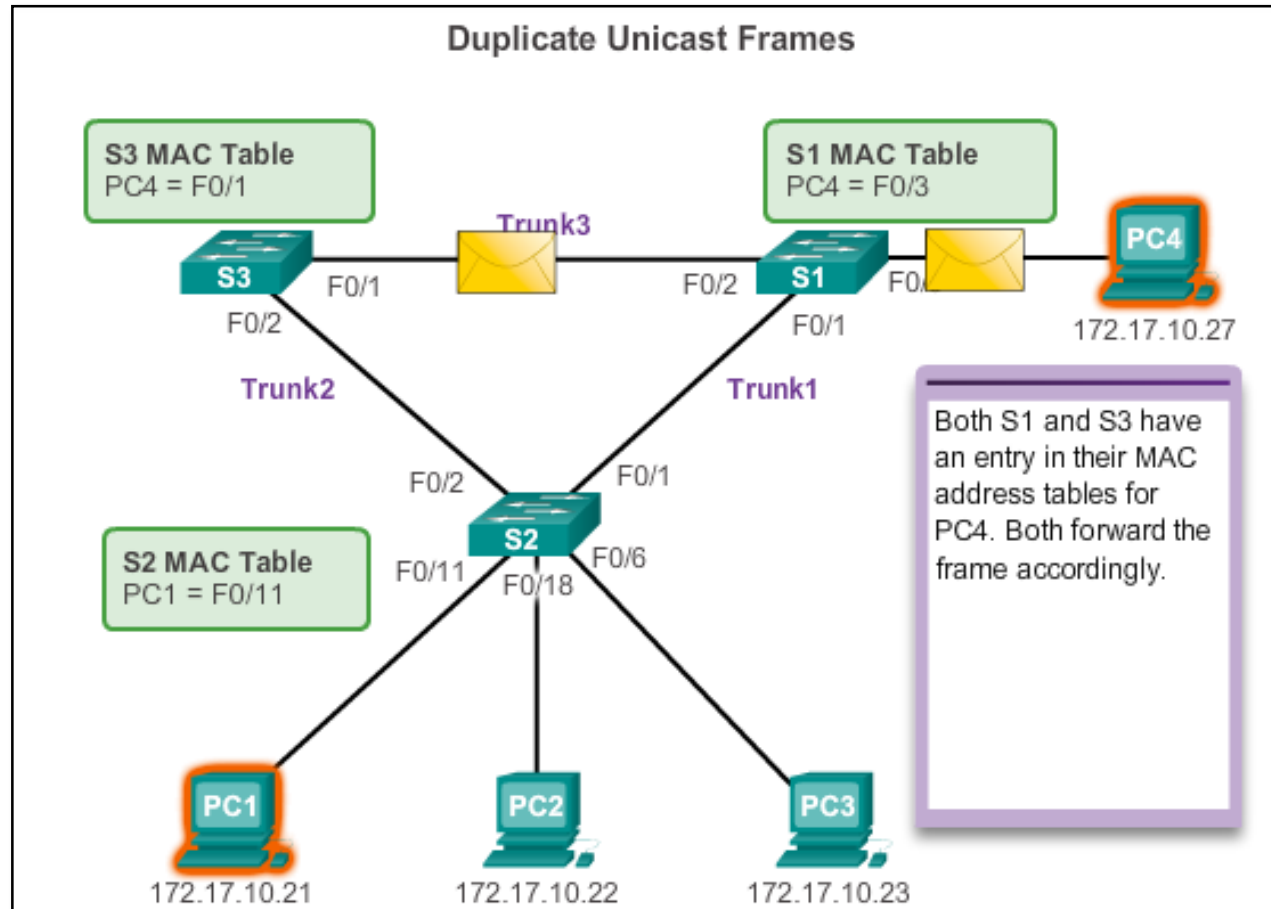
Spanning Tree Algorithm: Introduction

- STP ensures that there is only one logical path between all destinations on the network by intentionally blocking redundant paths that could cause a loop.

- A port is considered blocked when user data is prevented from entering or leaving that port. This does not include bridge protocol data unit (BPDU) frames that are used by STP to prevent loops.

- The physical paths still exist to provide redundancy, but these paths are disabled to prevent the loops from occurring.

- If the path is ever needed to compensate for a network cable or switch failure, STP recalculates the paths and unblocks the necessary ports to allow the redundant path to become active.

Minimum Spanning Trees (MST)

- To find the minimum number of edges necessary to connect all the edges in a graph.

- It can be implemented using DFS or BFS.
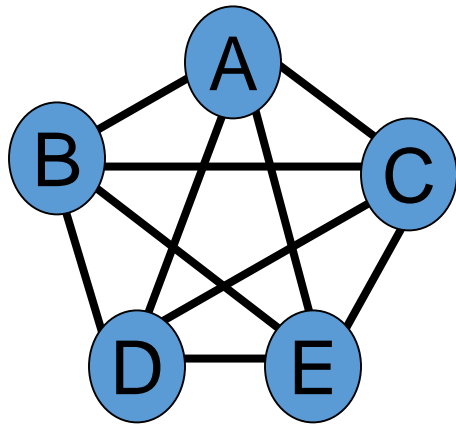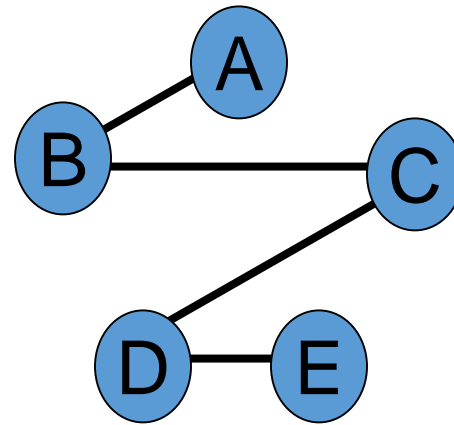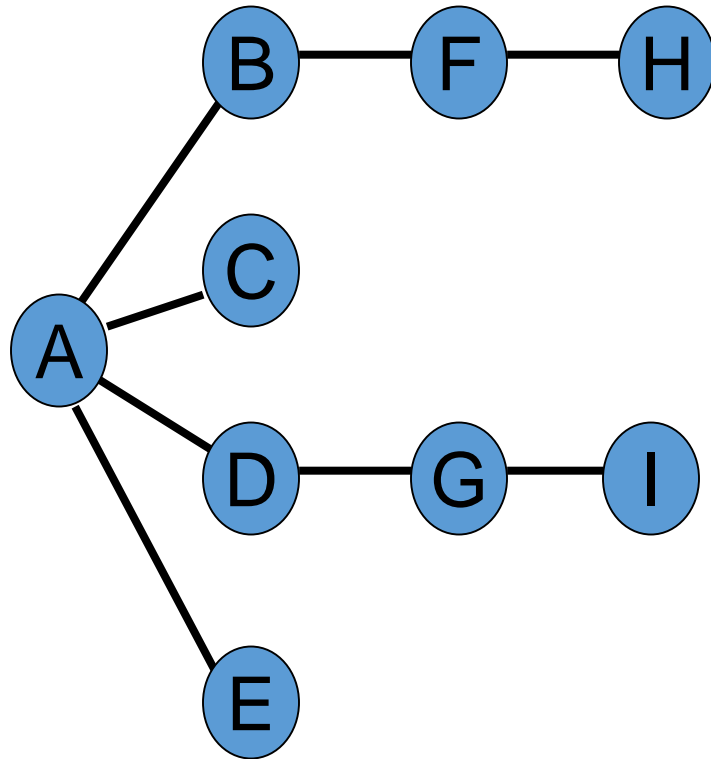

Extra Edges   Minimum Number of Edges

Searches

- Depth-first search
  - The algorithm acts as through it wants to get as far away from the starting point as quickly as possible.
  - Can use a stack

- Breadth-first search
  - The algorithm likes to stay as close as possible to the starting points.
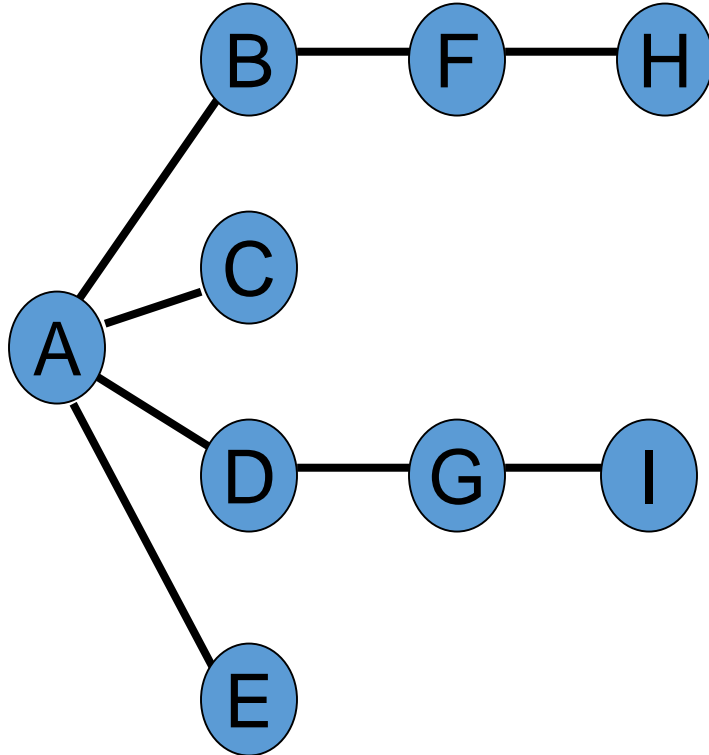 - Can use a queue

Depth-First Search

- Stack Contents

Event	Stack
Visit A	A
Visit B	AB
Visit F	ABF
Visit H	ABFH
Pop H	ABF
Pop F	AB
Pop B	A
Visit C	AC
Pop C	A
Visit D	AD
Visit G	ADG
Visit I	ADGI
Pop I	ADG
Pop G	AD
Pop D	A
Visit E	AE
Pop E	A
Pop A	Empty

Breadth-First Search

- Queue Contents

Event	Queue (Front to Rear)
Visit A	
Visit B	B
Visit C	BC
Visit D	BCD
Visit E	BCDE
Remove B	CDE
Visit F	CDEF
Remove C	DEF
Remove D	EF
Visit G	EFG
Remove E	FG
Remove F	G
Visit H	GH
Remove G	H
Visit I	HI
Remove H	I
Remove I	Empty
Done	

Minimum Spanning Trees with Weighted Graphs

- To find the <u>minimum cost</u> to connect all the edges in a graph.
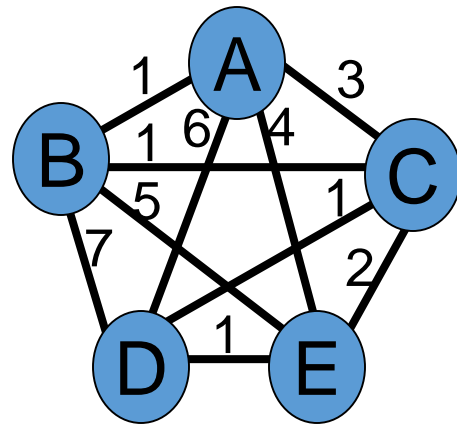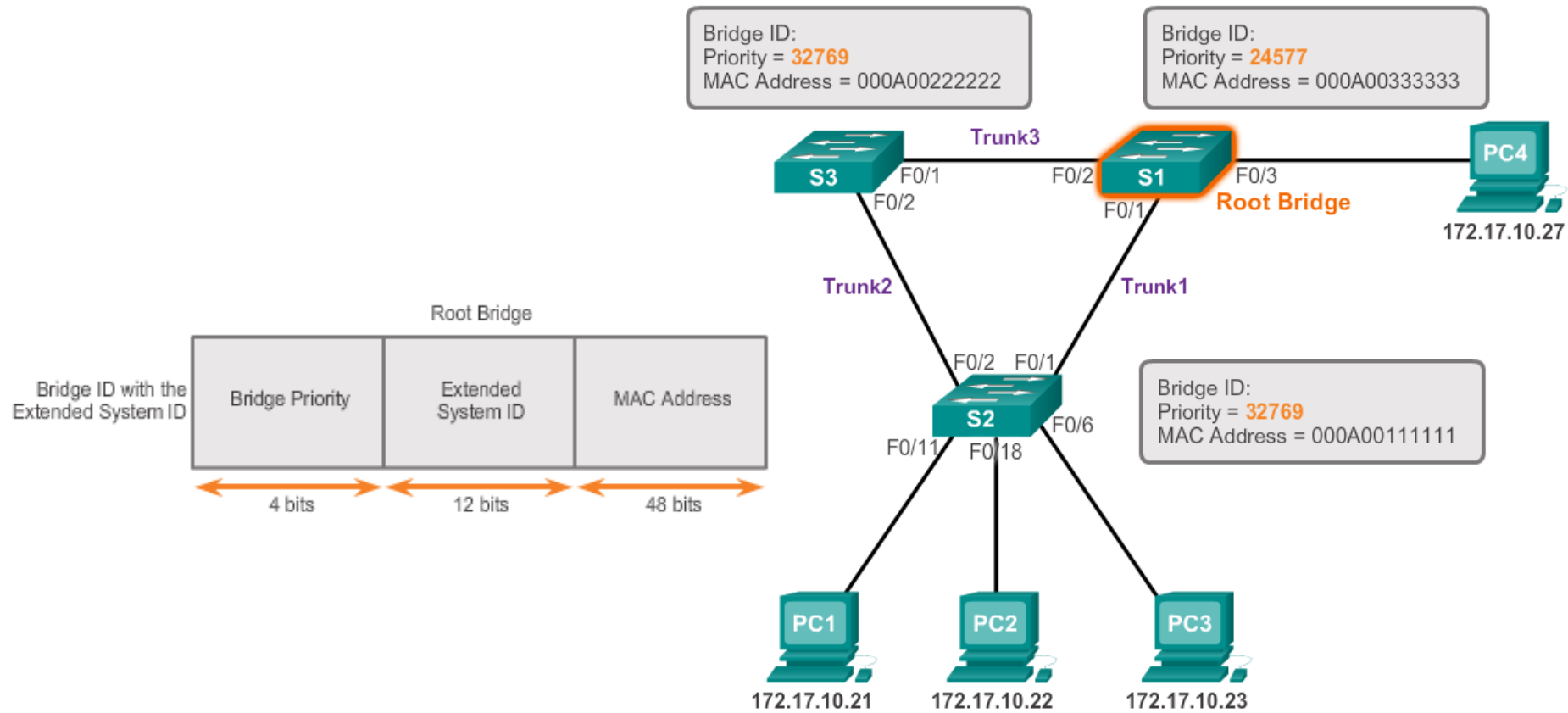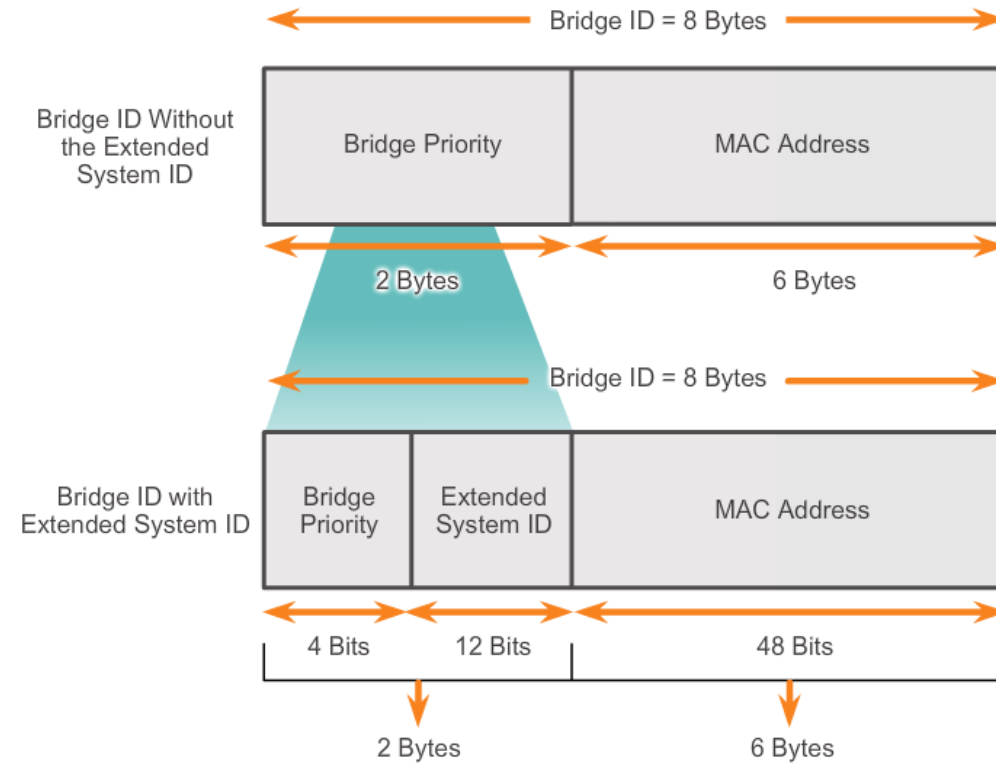

Weighted Graph
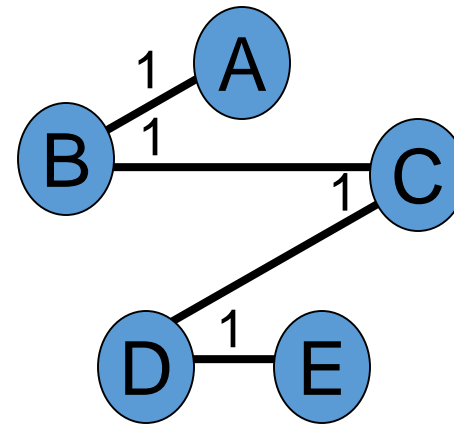
Minimum Cost = 4

Spanning Tree Algorithm: Root Bridge

Extended System ID
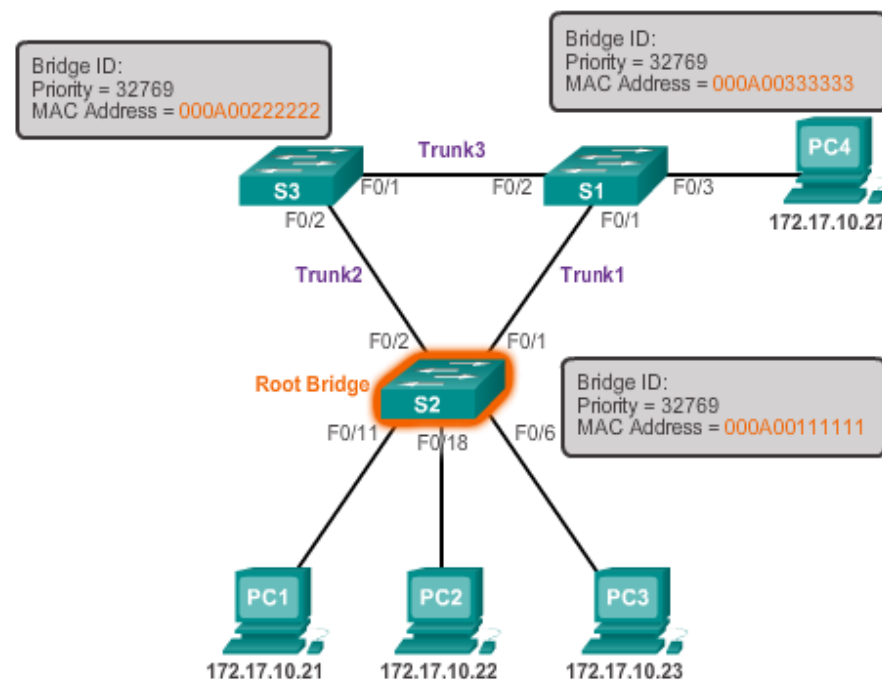

STP was enhanced to include support for VLANs, requiring the VLAN ID to be included in the BPDU frame through the use of the extended system ID
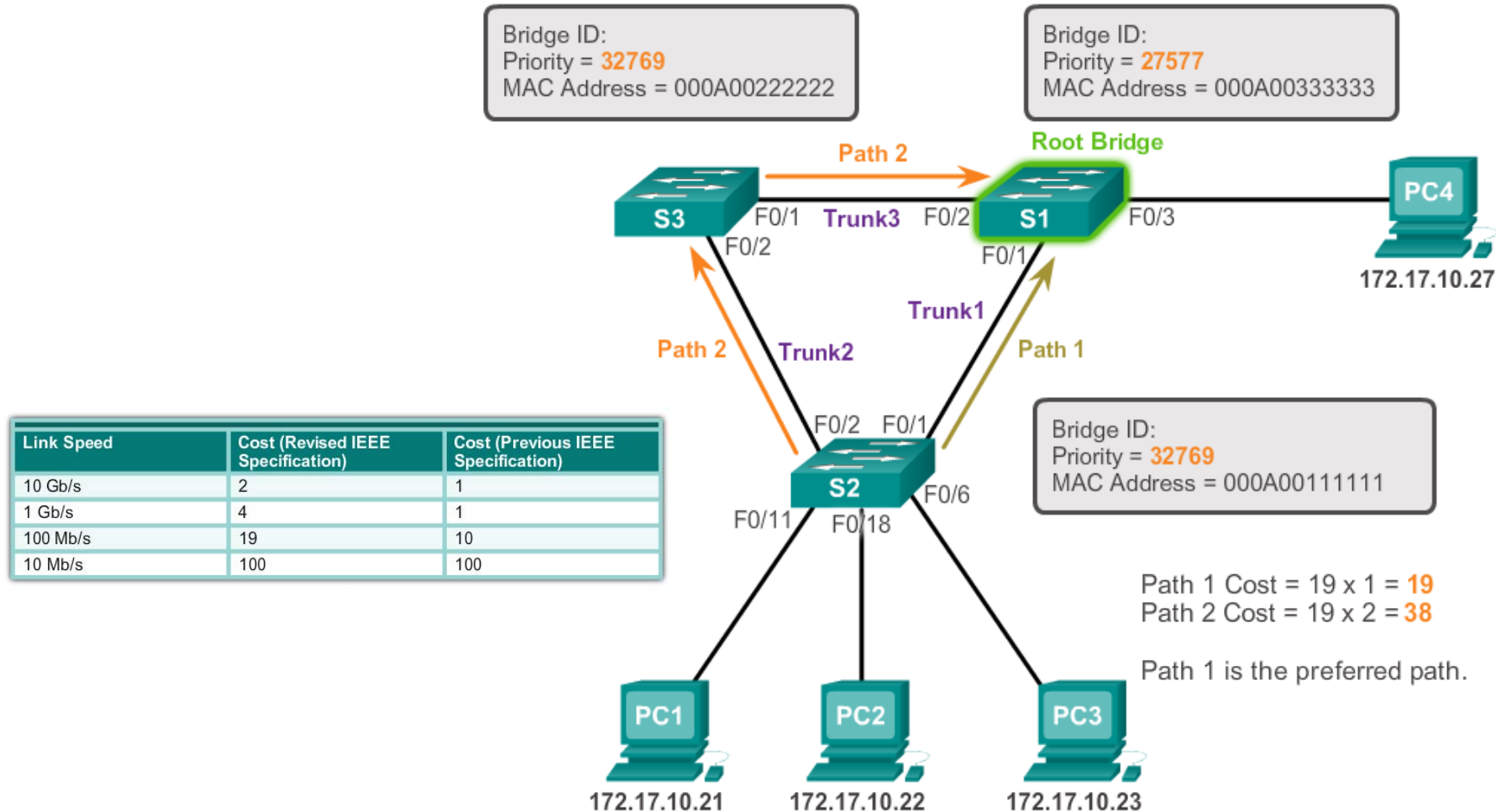
Extended System ID

MAC Address-based decision

In the example, the priority of all the switches is 32769. The value is based on the 32768 default priority and the VLAN 1 assignment associated with each switch (32768+1).

Spanning Tree Algorithm: Path Cost

Bridge ID:
Priority = **32769**
MAC Address = 000A00222222

Bridge ID:
Priority = **27577**
MAC Address = 000A00333333

Root Bridge

Path 2

S3 F0/1 **Trunk3** F0/2 S1 F0/3 PC4
F0/2 F0/1 172.17.10.27

Trunk1

Path 2 **Trunk2** **Path 1**

F0/2 F0/1

Link Speed	Cost (Revised IEEE Specification)	Cost (Previous IEEE Specification)
10 Gb/s	2	1
1 Gb/s	4	1
100 Mb/s	19	10
10 Mb/s	100	100

S2 F0/6

F0/11 F0/18

Bridge ID:
Priority = **32769**
MAC Address = 000A00111111

Path 1 Cost = 19 x 1 = **19**
Path 2 Cost = 19 x 2 = **38**

Path 1 is the preferred path.

PC1 PC2 PC3

172.17.10.21 172.17.10.22 172.17.10.23

Spanning Tree Algorithm: Port Roles

Root Port

Designated Port

Root Bridge

Trunk3

S3   F0/1   F0/2   S1   F0/3

PC4

172.17.10.27

F0/2

Non-Designated
Port

Trunk1

F0/1

Designated Port

Trunk2

F0/2   F0/1

Designated Port   S2   F0/6

F0/11   F0/18   Root Port

PC1   PC2   PC3

172.17.10.21   172.17.10.22   172.17.10.23

Port Roles:
1. **Root Port**
2. **Designated Port**
3. **Blocking Port**
   (=Non-Designated Port)
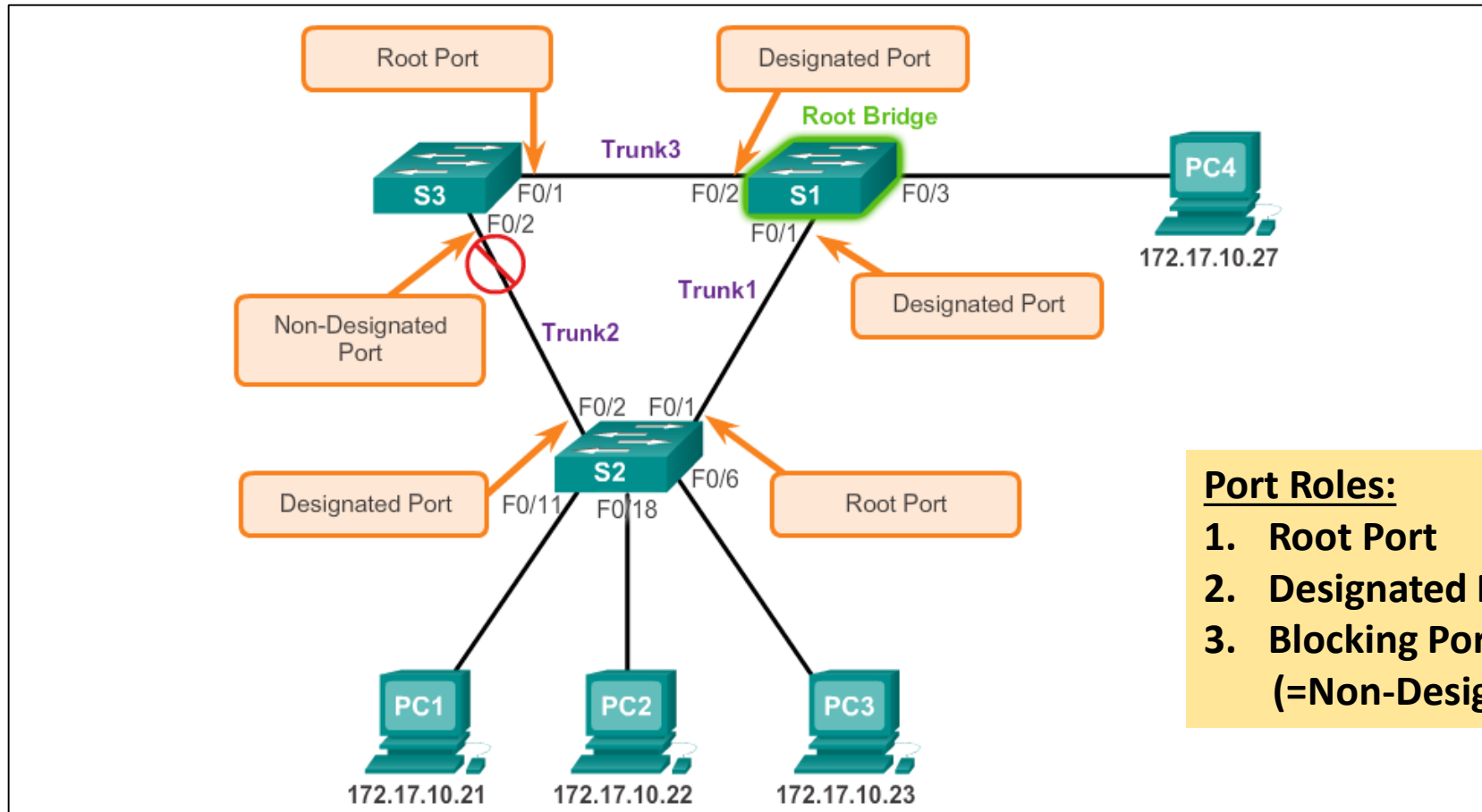
Characteristics of the Spanning Tree Protocols

| Protocol	Standard	Resources Needed	Convergence	Tree Calculation
STP	802.1D	Low	Slow	All VLANs
PVST+	Cisco	High	Slow	Per VLAN
RSTP	802.1w	Medium	Fast	All VLANs
Rapid PVST+	Cisco	Very high	Fast	Per VLAN
MSTP	802.1s Cisco	Medium or high	Fast	Per Instance

Overview of PVST+

Networks running PVST+ have these characteristics:

- A network can run an independent IEEE 802.1D STP instance for each VLAN in the network.

- Optimum load balancing can result.

- One spanning-tree instance for each VLAN maintained can mean a considerable waste of CPU cycles for all the switches in the network. In addition to the bandwidth that is used for each instance to send its own BPDU.

Overview of PVST+
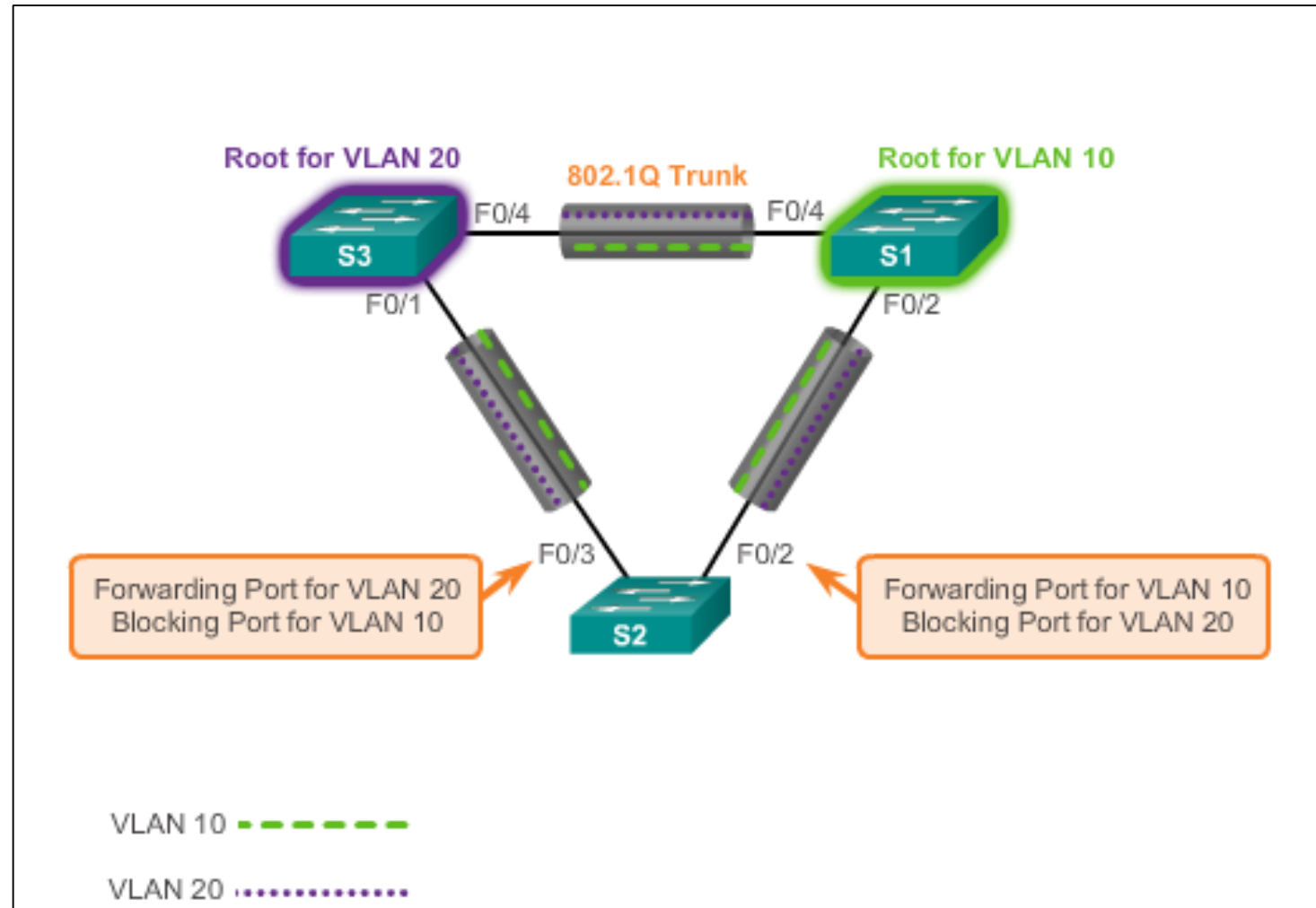
# Port States and PVST+ Operation

STP introduces the five port states:

Port States

Processes	Blocking	Listening	Learning	Forwarding	Disabled
Processes received BPDUs	YES	YES	YES	YES	NO
Forward data frames received on interface	NO	NO	NO	YES	NO
Forward data frames switched from another interface	NO	NO	NO	YES	NO
Learn MAC addresses	NO	NO	YES	YES	NO

Catalyst 2960 Default Configuration

Feature	Default Setting
Enable state	Enabled on VLAN 1
Spanning-tree mode	PVST+ (Rapid PVST+ and MSTP are disabled.)
Switch priority	32768
Spanning-tree port priority (configurable on a per-interface basis)	128
Spanning-tree port cost (configurable on a per-interface basis)	1000 Mb/s: 4 100 Mb/s: 19 10 Mb/s: 100
Spanning-tree VLAN port priority (configurable on a per-VLAN basis)	128
Spanning-tree VLAN port cost (configurable on a per-VLAN basis)	1000 Mb/s: 4 100 Mb/s: 19 10 Mb/s: 100
Spanning-tree timers	Hello time: 2 seconds Forward-delay time: 15 seconds Maximum-aging time: 20 seconds Transmit hold count: 6 BPDUs

Configuring and Verifying the Bridge ID
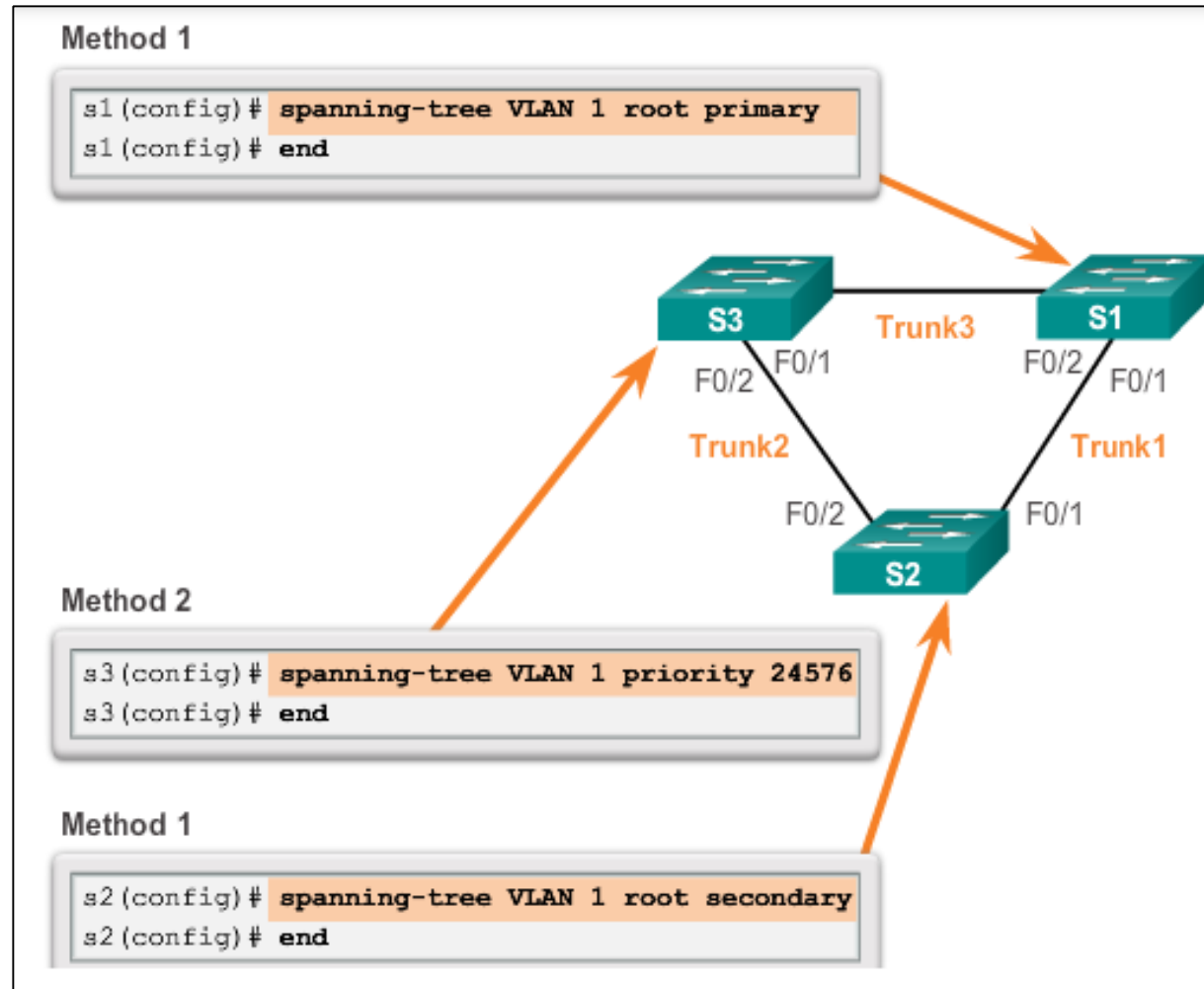
Configuring and Verifying the Bridge ID

```
S3# show spanning-tree
VLAN0001
  Spanning tree enabled protocol ieee
  Root ID     Priority    24577
              Address       00A.0033.3333
              This bridge is the root
              Hello Time  2 sec Max Age 20 sec Forward Delay 15 sec
  Bridge ID   Priority    24577   (priority  24576  sys-id-ext  1)
              Address       000A.0033.3333
              Hello Time  2 sec Max Age 20 sec Forward Delay 15 sec
              Aging Time  300


Interface       Role    Sts   Cost      Prio.Nbr      Type
------------    -----   ----  -----    ----------    ------
Fa0/1           Desg    FWD   4         128.1         p2p
Fa0/2           Desg    FWD   4         128.2         p2p
S3#
```

PortFast and BPDU Guard

- When a switch port is configured with PortFast that port transitions from blocking to forwarding state immediately.

- BPDU guard puts the port in an *error-disabled* state on receipt of a BPDU.

PortFast and BPDU Guard

```
S2(config)# interface FastEthernet 0/11
S2(config-if)# spanning-tree portfast
%Warning: portfast should only be enabled on ports connected to
a single host. Connecting hubs, concentrators, switches,
bridges, etc... to this interface  when portfast is enabled,
can cause temporary bridging loops.
 Use with CAUTION

%Portfast has been configured on FastEthernet0/11 but will only
 have effect when the interface is in a non-trunking mode.
S2(config-if)# spanning-tree bpduguard enable
S2(config-if)# end
```
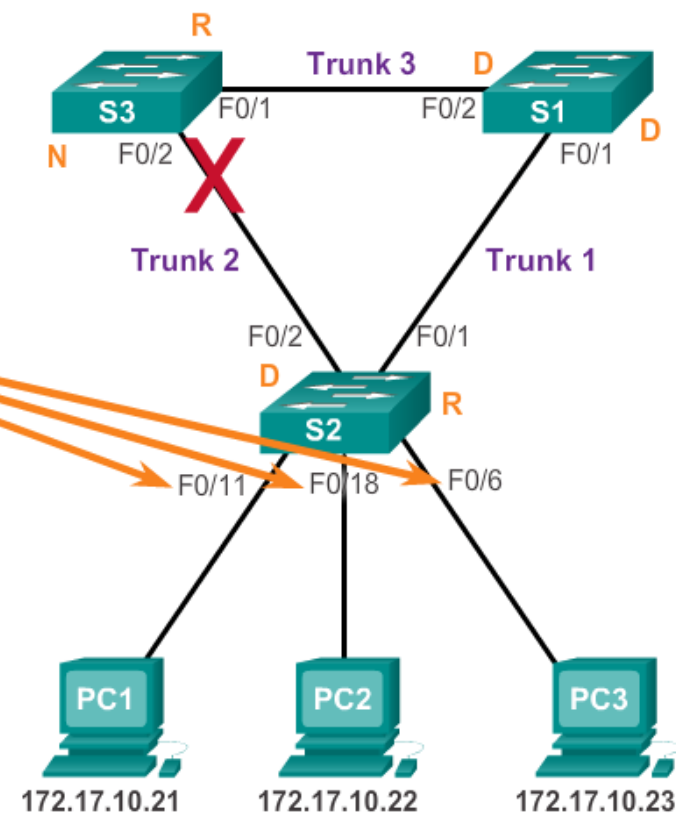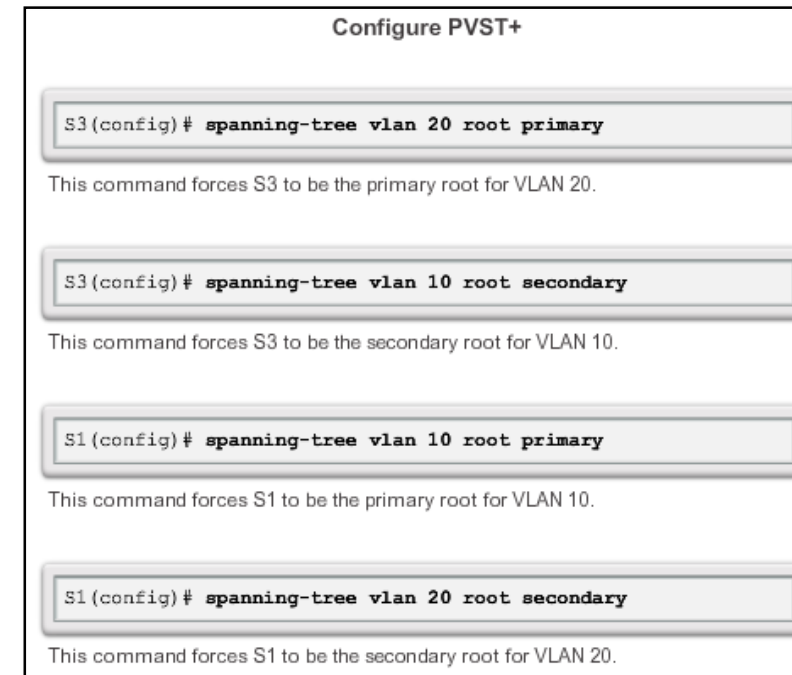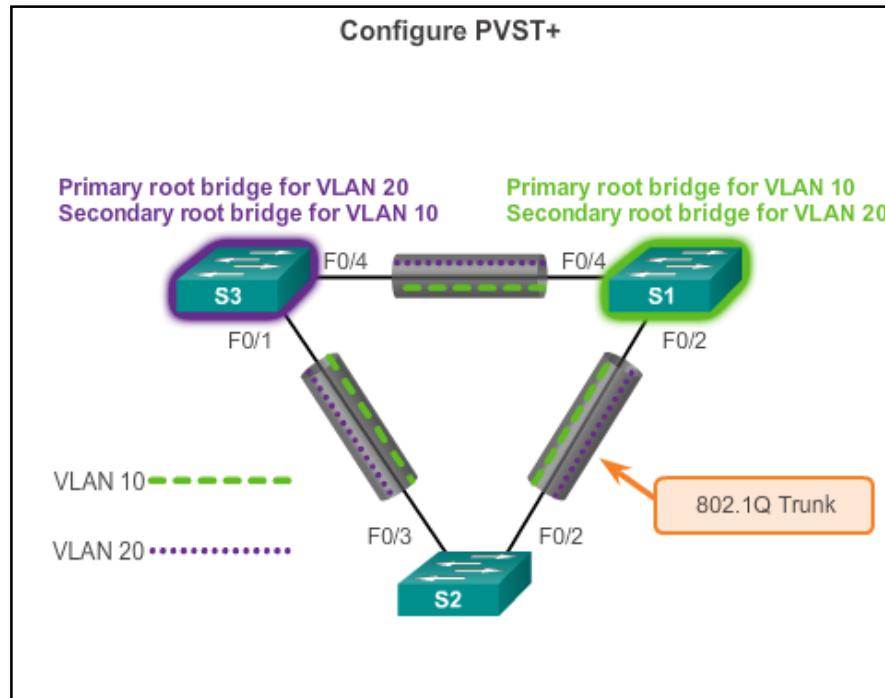
PVST+ Load Balancing

PVST+ Load Balancing

- Another method to specify the root bridge is to set the spanning tree priority on each switch to the lowest value so that the switch is selected as the primary bridge for its associated VLAN.

Configure PVST+

```
S3(config)# spanning-tree vlan 20 priority 4096
```

This command sets the priority for S3 to be the lowest possible, making it most likely that S3 will be the primary root for VLAN 20.

```
S1(config)# spanning-tree vlan 10 priority 4096
```

This command sets the priority for S1 to be the lowest possible, making it most likely that S1 will be the primary root for VLAN 10.

PVST+ Load Balancing

- Display and verify spanning tree configuration details.


```
Configure PVST+

S3# show spanning-tree active

<output omitted>

VLAN0010
    Spanning tree enabled protocol ieee
    Root ID      Priority     4106
                 Address      0019.aa9e.b000
                 This bridge is the root
                 Hello Time   2 sec Max Age 20 sec Forward Delay 15 sec
    Bridge ID    Priority     4106  (priority  4096  sys-id-ext  10)
                 Address      0019.aa9e.b000
                 Hello Time   2 sec Max Age 20 sec Forward Delay 15 sec
                 Aging Time   300


Interface       Role    Sts    Cost     Prio.Nbr      Type
-----------     -----   ----   -----    ----------    ------
Fa0/2           Desg    FWD    19       128.2         p2p
Fa0/4           Desg    FWD    19       128.4         p2p

<output omitted>
```

PVST+ Load Balancing

Configure PVST+

```
S1# show running-config
Building configuration...

Current configuration : 1595 bytes
!
version 12.2
 <output omitted>

!
spanning-tree mode pvst
spanning-tree extend system-id
spanning-tree vlan 1 priority 24576
spanning-tree vlan 10 priority 4096
spanning-tree vlan 20 priority 28672
!
 <output omitted>
```

Sample Configuration – PVST+

S2(config)#vlan 1

S2(config)#spanning-tree mode pvst

S2(config)#int fa0/1

S2(config-if)#switchport mode access

S2(config-if)#switchport access vlan 1

S2(config-if)#spanning-tree portfast

S2(config-if)#spanning-tree bpduguard enable

S2(config)#int gi0/1

S2(config-if)#switchport mode trunk

S2(config-if)#switchport trunk allowed vlan 1-10

S1(config)#vlan 1

S1(config)#spanning-tree mode pvst

S1(config)#spanning-tree vlan 1 root primary

S1(config)#spanning-tree vlan 5 root secondary

Overview of Rapid PVST+

- RSTP is the preferred protocol for preventing Layer 2 loops in a switched network environment.

- With Rapid PVST+, an independent instance of RSTP runs for each VLAN.

- RSTP supports a new port type: an alternate port in discarding state.

- There are no blocking ports. RSTP defines port states as discarding, learning, or forwarding.

- RSTP (802.1w) supersedes STP (802.1D) while retaining backward compatibility

- RSTP keeps the same BPDU format as IEEE 802.1D, except that the version field is set to 2 to indicate RSTP, and the flags field uses all 8 bits.
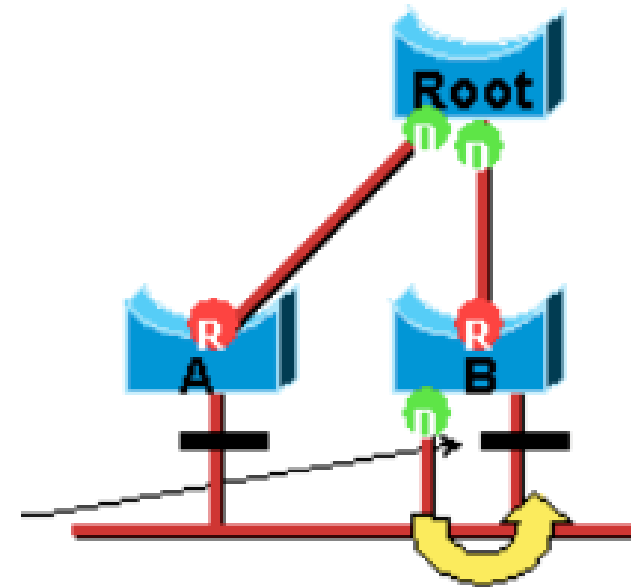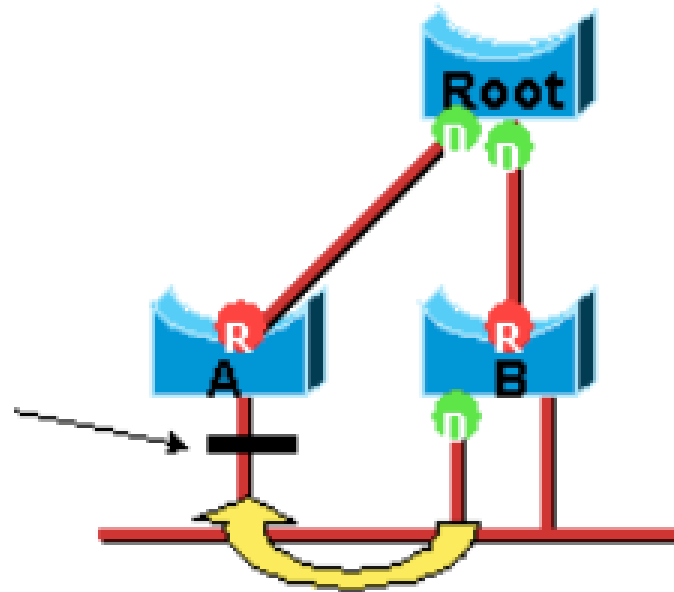
Overview of Rapid PVST+
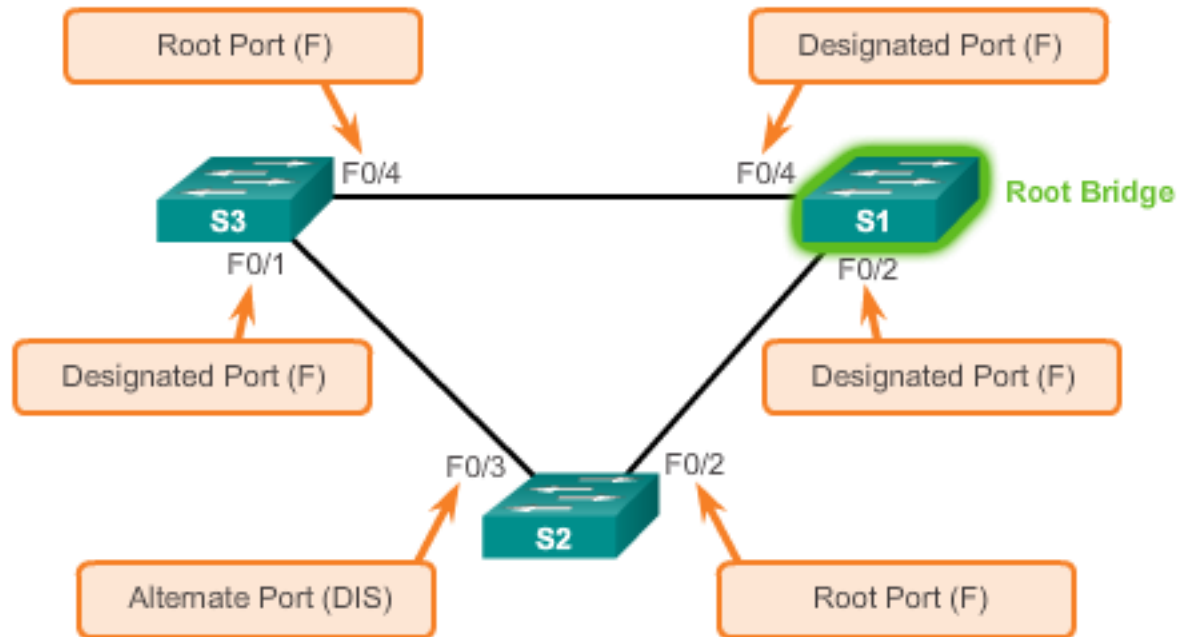
Port Roles:
1. Root Port
2. Designated Port
3. Alternate Port
4. Backup Port

Rapid-PVST+

Port Roles: Alternate Port vs. Backup

[Image Source] https://www.cisco.com/c/en/us/support/docs/lan-switching/spanning-tree-protocol/24062-146.html#anc13

Port States

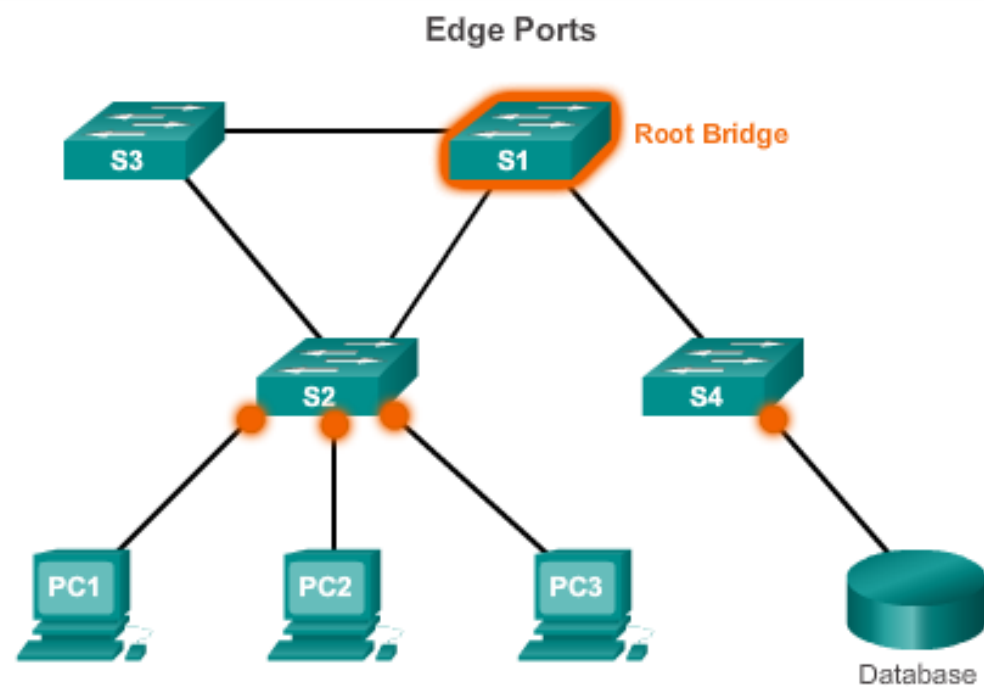RSTP introduces the three port states:

STP (802.1D) Port State	RSTP (802.1w) Port State	Is Port Included in Active Topology?	Is Port Learning MAC Addresses?
Disabled	Discarding	No	No
Blocking	Discarding	No	No
Listening	Discarding	Yes	No
Learning	Learning	Yes	Yes
Forwarding	Forwarding	Yes	Yes

[Reference] https://www.cisco.com/c/en/us/support/docs/lan-switching/spanning-tree-protocol/24062-146.html#anc13
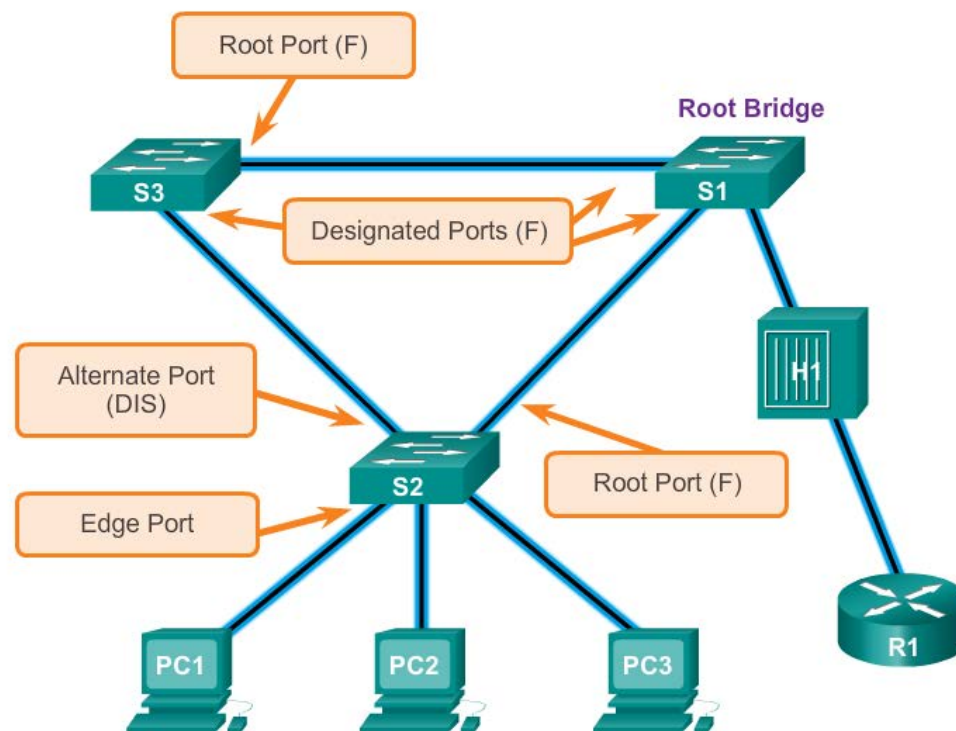
Edge Ports

Edge Ports

Edge Ports
- Will never have a switch connected to it
- Immediately transitions to forwarding
- Functions similarly to a port configured with Cisco PortFast
- On a Cisco switch configured using the `spanning-tree portfast`

Link Types

The link type can determine whether the port can immediately transition to forwarding state. Edge port connections and point-to-point connections are candidates for rapid transition to forwarding state.

Spanning Tree Mode

Rapid PVST+ is the Cisco implementation of RSTP. It supports RSTP on a per-VLAN basis.

```
S1# configure terminal
S1(config)# spanning-tree mode rapid-pvst
S1(config)# interface f0/2
S1(config-if)# spanning-tree link-type point-to-point
S1(config-if)# end
S1# clear spanning-tree detected-protocols
```

Cisco IOS Command Syntax	
Enter global configuration mode.	`configure terminal`
Configure Rapid PVST+ spanning-tree mode.	`spanning-tree mode rapid-pvst`
Enter interface configuration mode and specify an interface to configure. Valid interfaces include physical ports, VLANs, and port channels.	`interface interface-id`
Specify that the link type for this port is point-to-point.	`spanning-tree link-type point-to-point`
Return to privileged EXEC mode.	`end`
Clear all detected STP.	`clear spanning-tree detected-protocols`

Sample Configuration – rapid-pvst+

S2(config)#vlan 1

S2(config)#spanning-tree mode rapid-pvst

S2(config)#int fa0/1 — Edge Port

S2(config-if)#switchport mode access

S2(config-if)#switchport access vlan 1

S2(config-if)#spanning-tree portfast

S2(config-if)#spanning-tree bpduguard enable

S2(config)#int gi0/1 — Non-Edge Port

S2(config-if)#switchport mode trunk

S2(config-if)#switchport trunk allowed vlan 1-10

S2(config-if)#spanning-tree link-type point-to-point

S2(config)#clear spanning-tree detected-protocols

S1(config)#vlan 1

S1(config)#spanning-tree mode rapid-pvst

S1(config)#spanning-tree vlan 1 root primary

S1(config)#spanning-tree vlan 5 root secondary

S1(config)#int gi0/1 — Non-Edge Port

S1(config-if)#switchport mode trunk

S1(config-if)#switchport trunk allowed vlan 1-10

S1(config-if)#spanning-tree link-type point-to-point

S1(config)#clear spanning-tree detected-protocols

Summary

- IEEE 802.1D is implemented on Cisco switches on a per-VLAN basis in the form of PVST+. This is the default configuration on Cisco switches.

- RSTP, can be implemented on Cisco switches on a per-VLAN basis in the form of Rapid PVST+.

- With PVST+ and Rapid PVST+, root bridges can be configured proactively to enable spanning tree load balancing.

Protocol	Standard	Resources Needed	Convergence	Tree Calculation
STP	802.1D	Low	Slow	All VLANs
PVST+	Cisco	High	Slow	Per VLAN
RSTP	802.1w	Medium	Fast	All VLANs
Rapid PVST+	Cisco	Very high	Fast	Per VLAN
MSTP	802.1s Cisco	Medium or high	Fast	Per Instance