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
- Spanning Tree Configuration
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Purpose of Spanning Tree

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

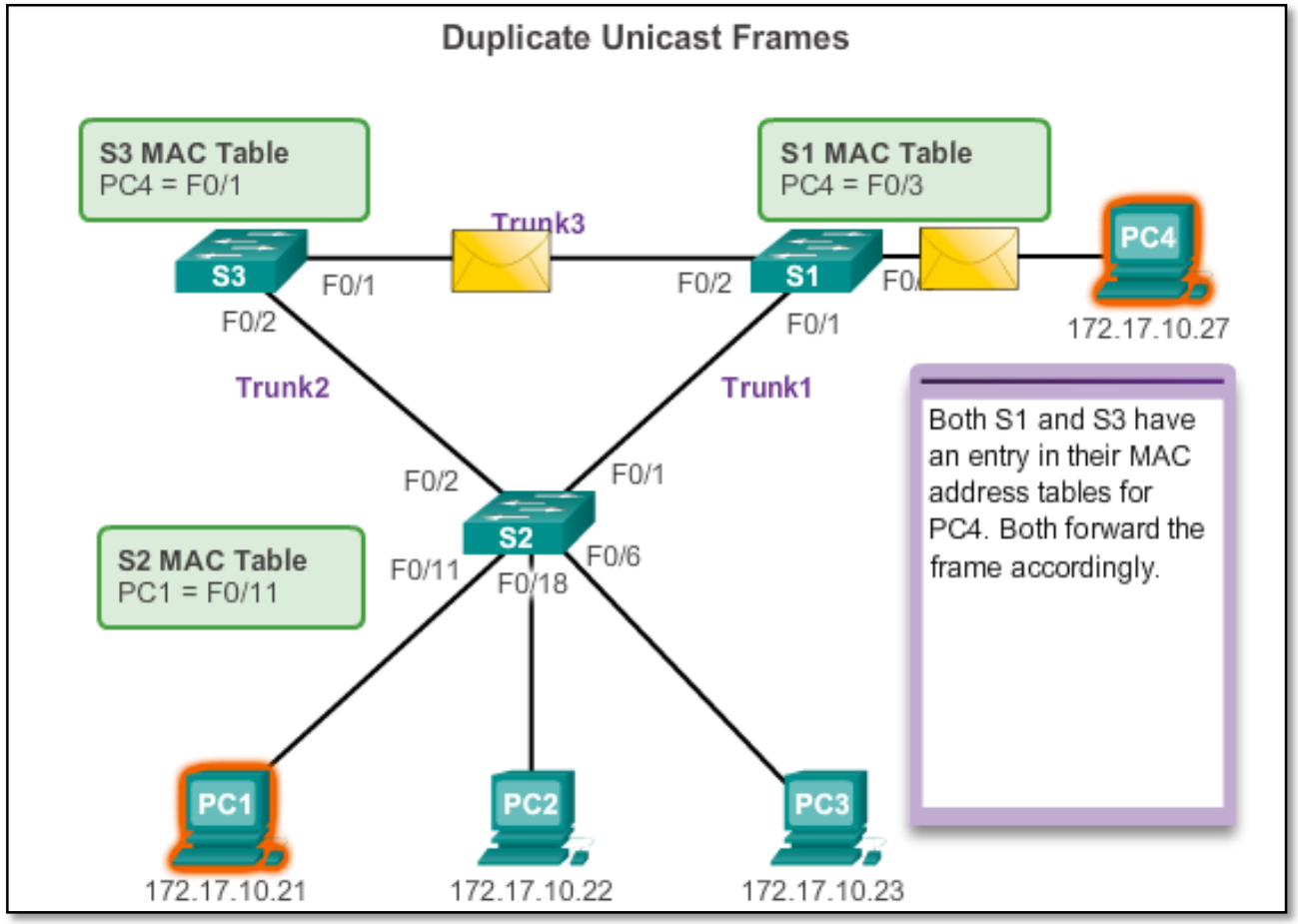
- A broadcast storm is inevitable on a looped network.
  - As more devices send broadcasts over the network, more traffic is caught within the loop; thus consuming more resources.
  - This eventually creates a broadcast storm that causes the network to fail.

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.

Purpose of Spanning Tree

Issues with Layer 1 Redundancy: Duplicate Unicast Frames

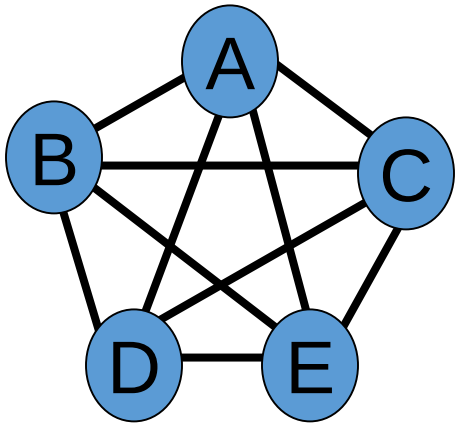


Spanning Tree Algorithm: Introduction

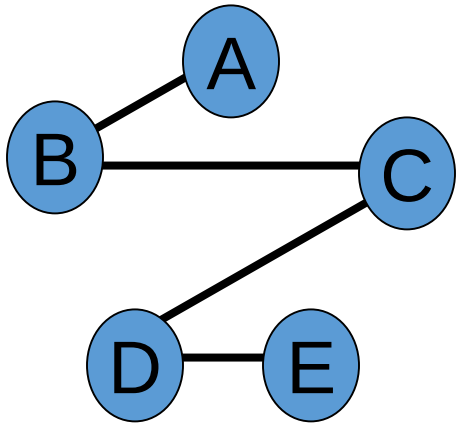
- STP ensures that there is only one logical path between all destinations on the network by intentionally blocking redundant paths that could cause a loop.
- A port is considered blocked when user data is prevented from entering or leaving that port. This does not include bridge protocol data unit (BPDU) 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

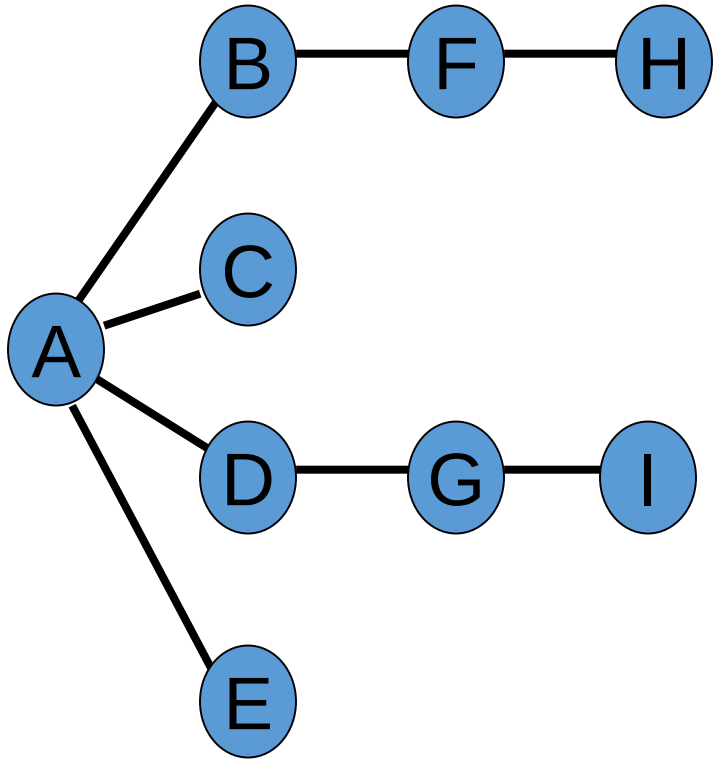


Minimum Number of Edges

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

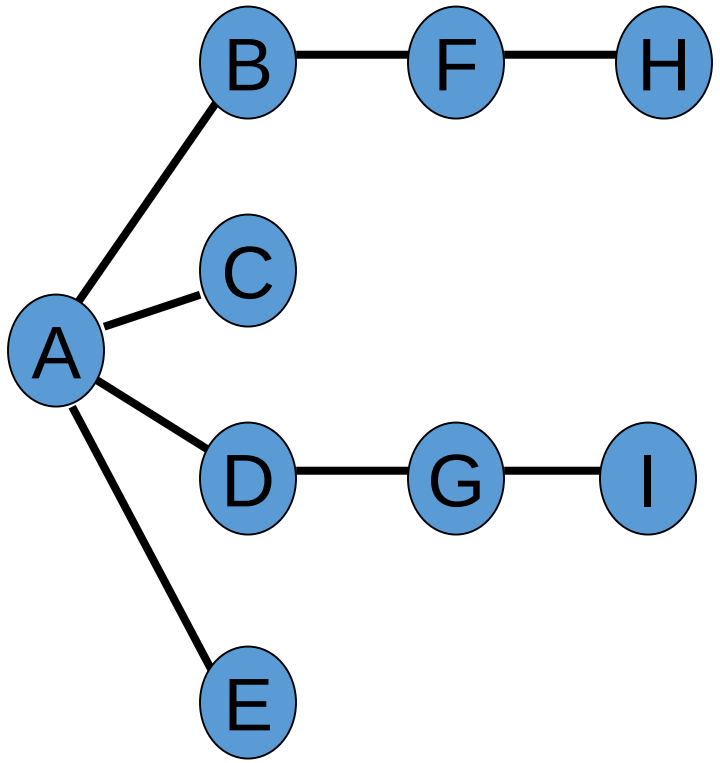
Depth-First Search



- 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

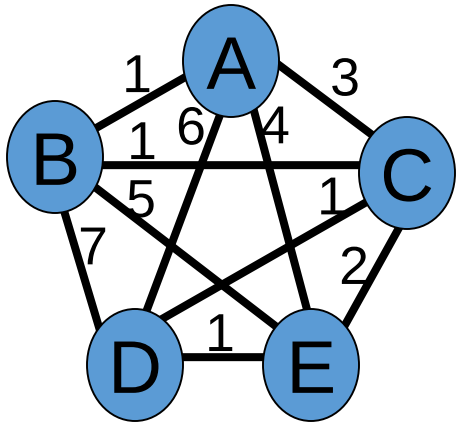


- Queue Contents

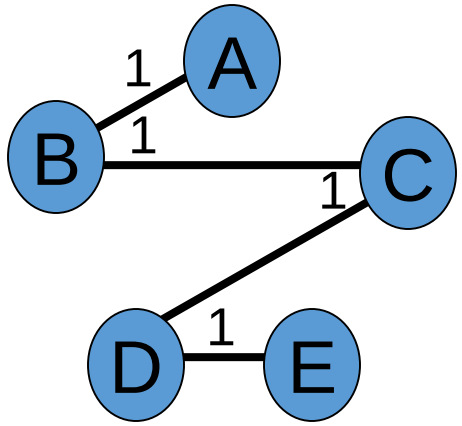
Event	Queue (Front to Rear)
Visit A	
Visit B	B
Visit C	BC
Visit D	BCD
Visit E	BCDE
Remove B	CDE
Visit F	CDEF
Remove C	DEF
Remove D	EF
Visit G	EFG
Remove E	FG
Remove F	G
Visit H	GH
Remove G	H
Visit I	HI
Remove H	I
Remove I	Empty
Done	

Minimum Spanning Trees with Weighted Graphs

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



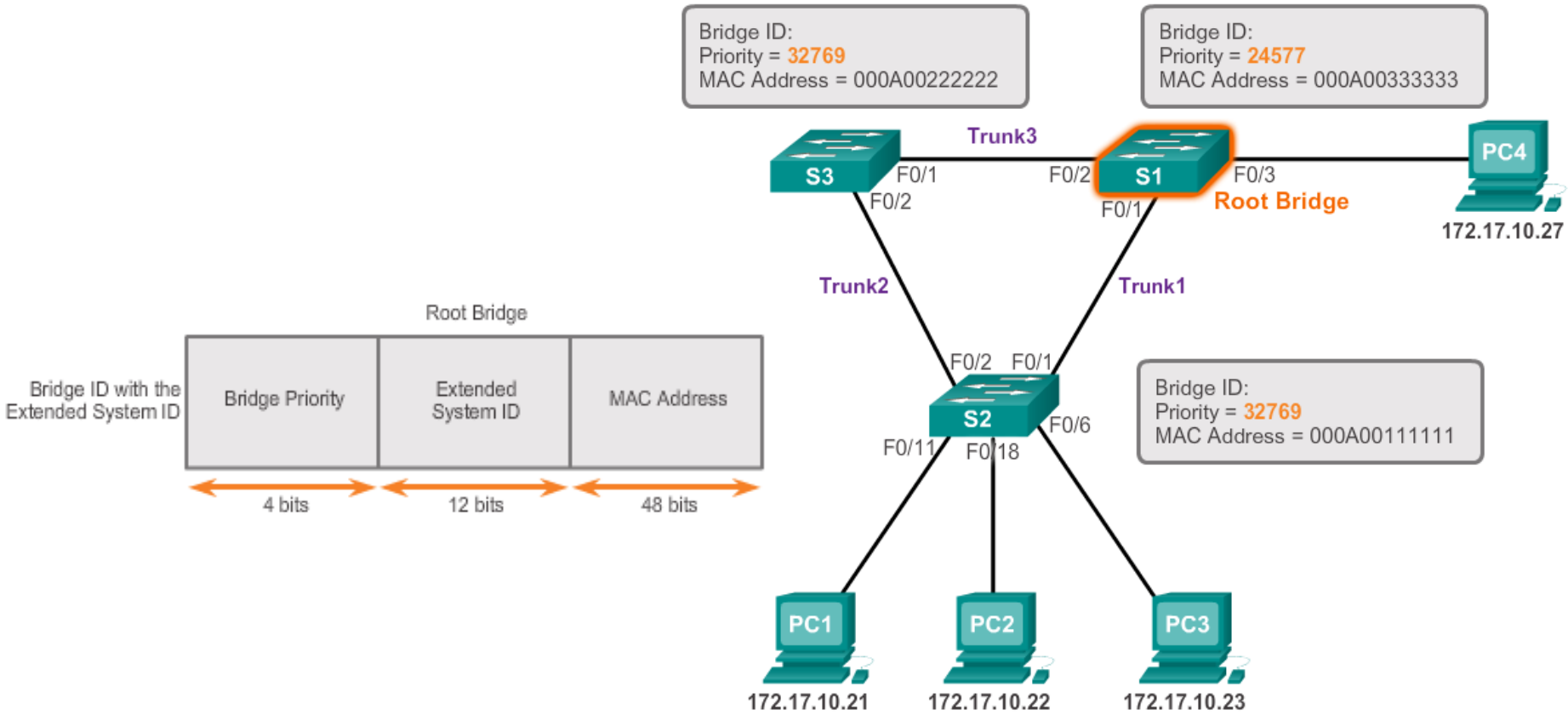
Weighted Graph

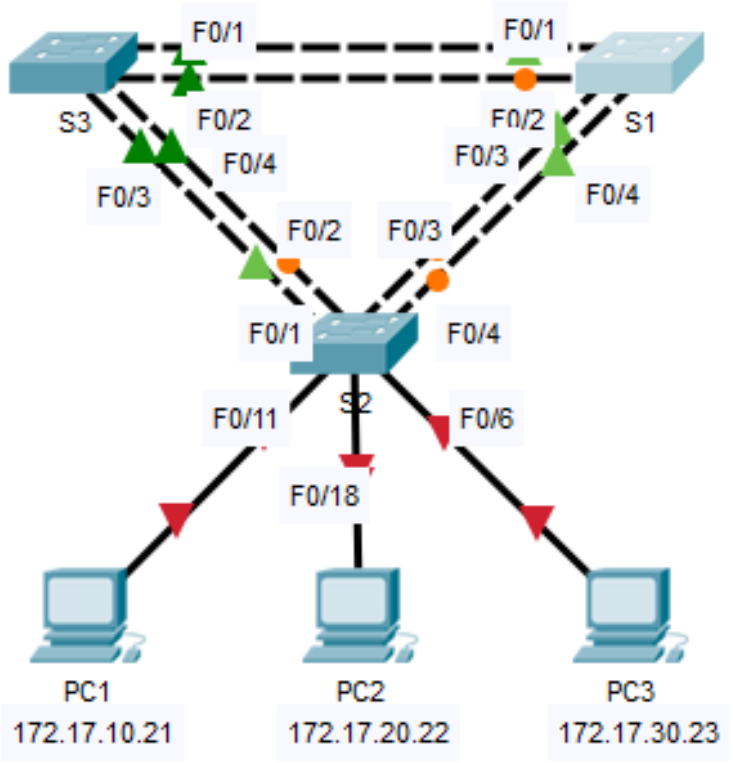


Minimum Cost = 4

STP Operation

Spanning Tree Algorithm: Root Bridge





S1

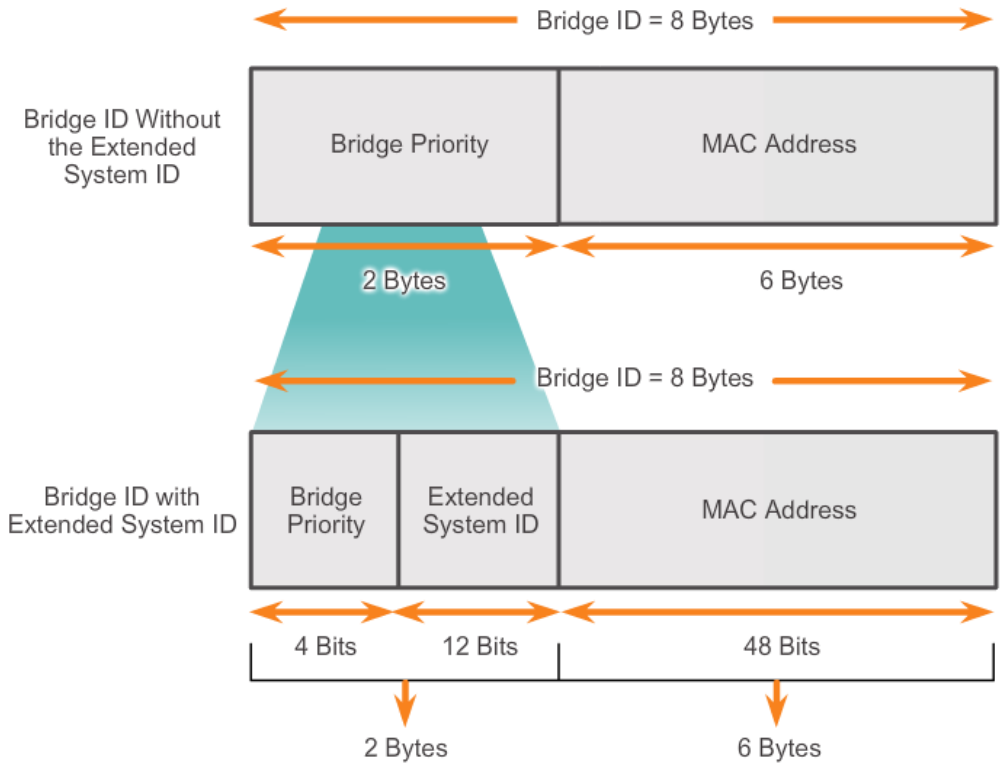
Physical Config CLI Attributes

IOS Command Line Interface

```
%LINEPROTO-5-UPDOWN: Line protocol on Interface FastEthernet0/4, changed
state to up


S1>en
S1#sh span
VLAN0001
  Spanning tree enabled protocol ieee
  Root ID     Priority    32769
              Address     0030.F20D.D6B1
              Cost        19
              Port        1(FastEthernet0/1)
              Hello Time  2 sec  Max Age 20 sec  Forward Delay 15 sec

  Bridge ID   Priority    32769  (priority 32768 sys-id-ext 1)
              Address     0050.0F68.146E
              Hello Time  2 sec  Max Age 20 sec  Forward Delay 15 sec
              Aging Time  20

Interface        Role Sts Cost      Prio.Nbr Type
---------------- ---- --- --------- --------
--------------------------------
Fa0/4            Desg FWD 19        128.4    P2p
Fa0/3            Desg FWD 19        128.3    P2p
Fa0/2            Altn BLK 19        128.2    P2p
Fa0/1            Root FWD 19        128.1    P2p

S1#
```

STP Operation

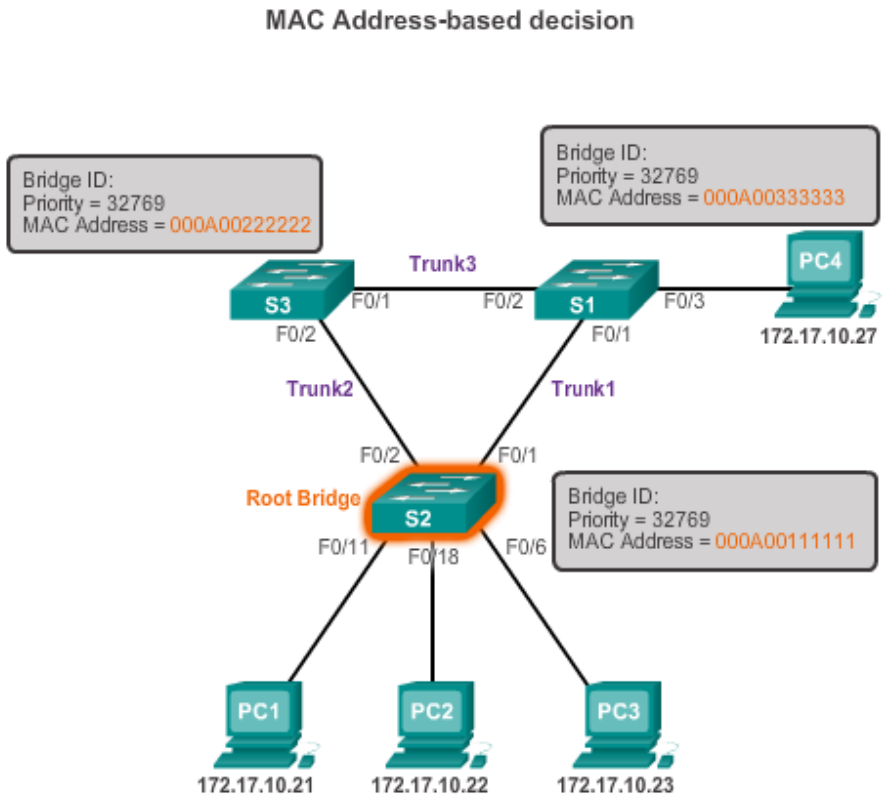
Extended System ID



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

STP Operation

Extended System ID

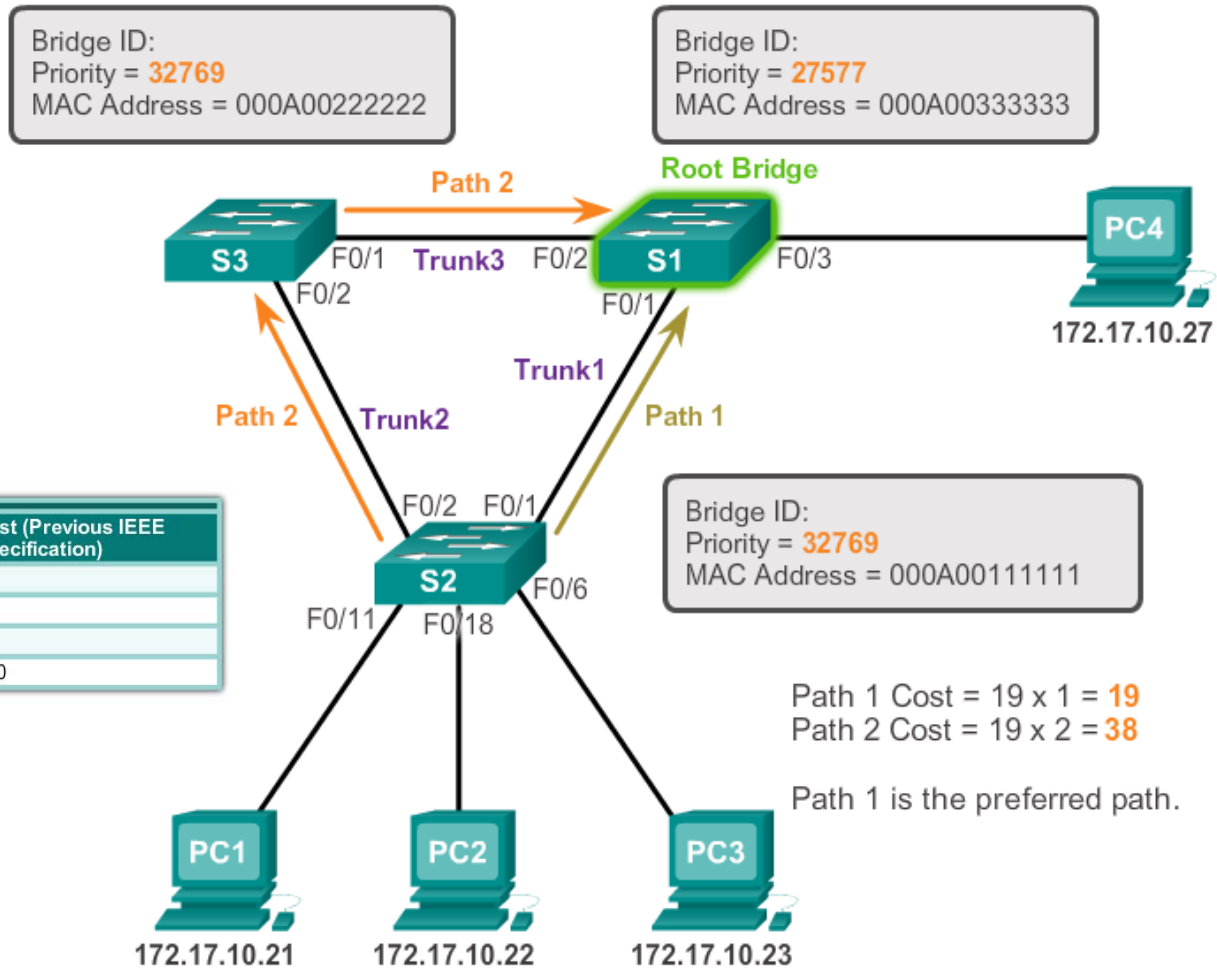


In the example, the priority of all the switches is 32769. The value is based on the 32768 default priority and the VLAN 1 assignment associated with each switch (32768+1).

STP Operation

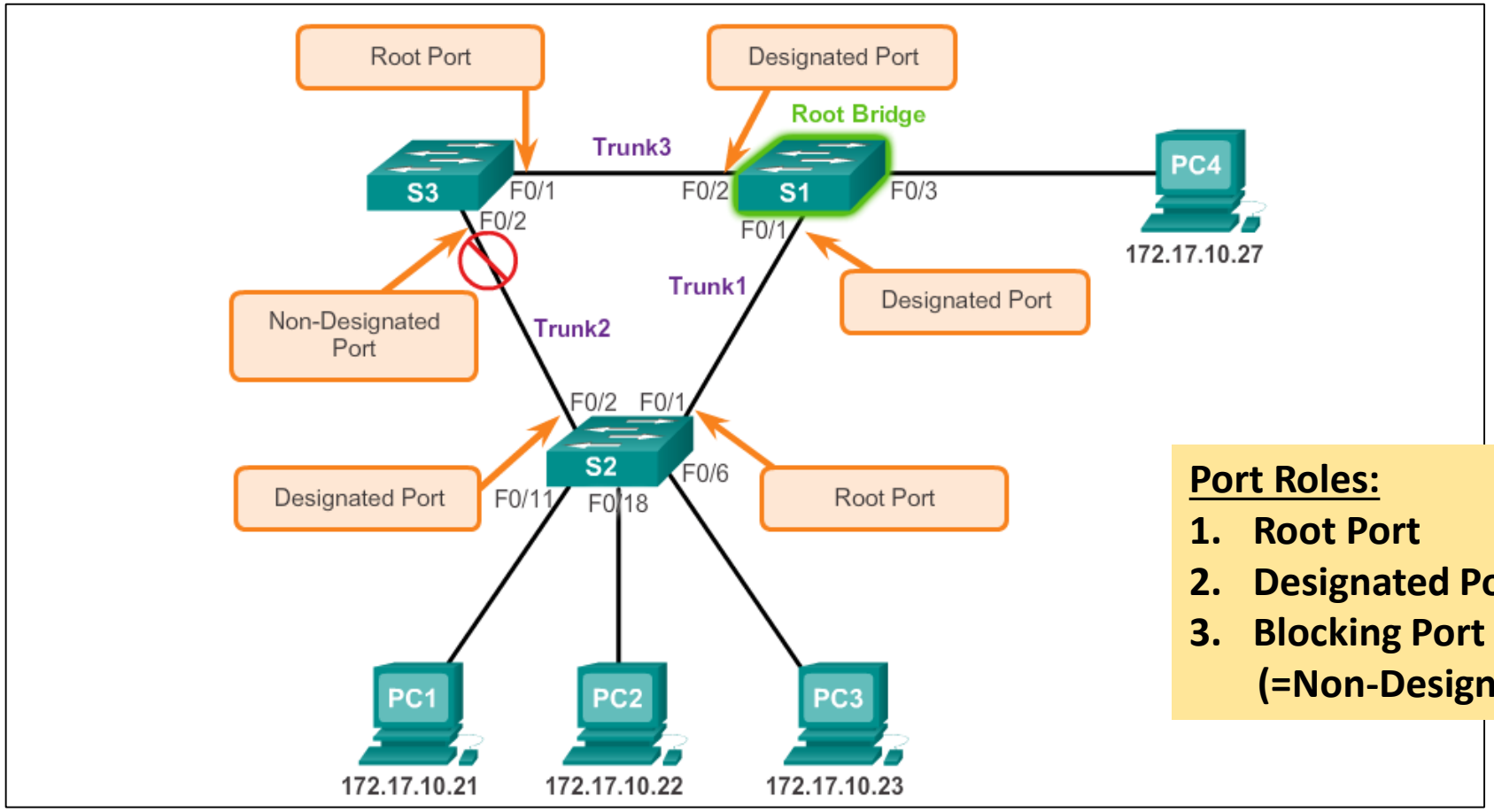
Spanning Tree Algorithm: Path Cost

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



STP Operation

Spanning Tree Algorithm: Port Roles



Port Roles:

1. **Root Port**
2. **Designated Port**
3. **Blocking Port**
   (=Non-Designated Port)

Characteristics of the Spanning Tree Protocols

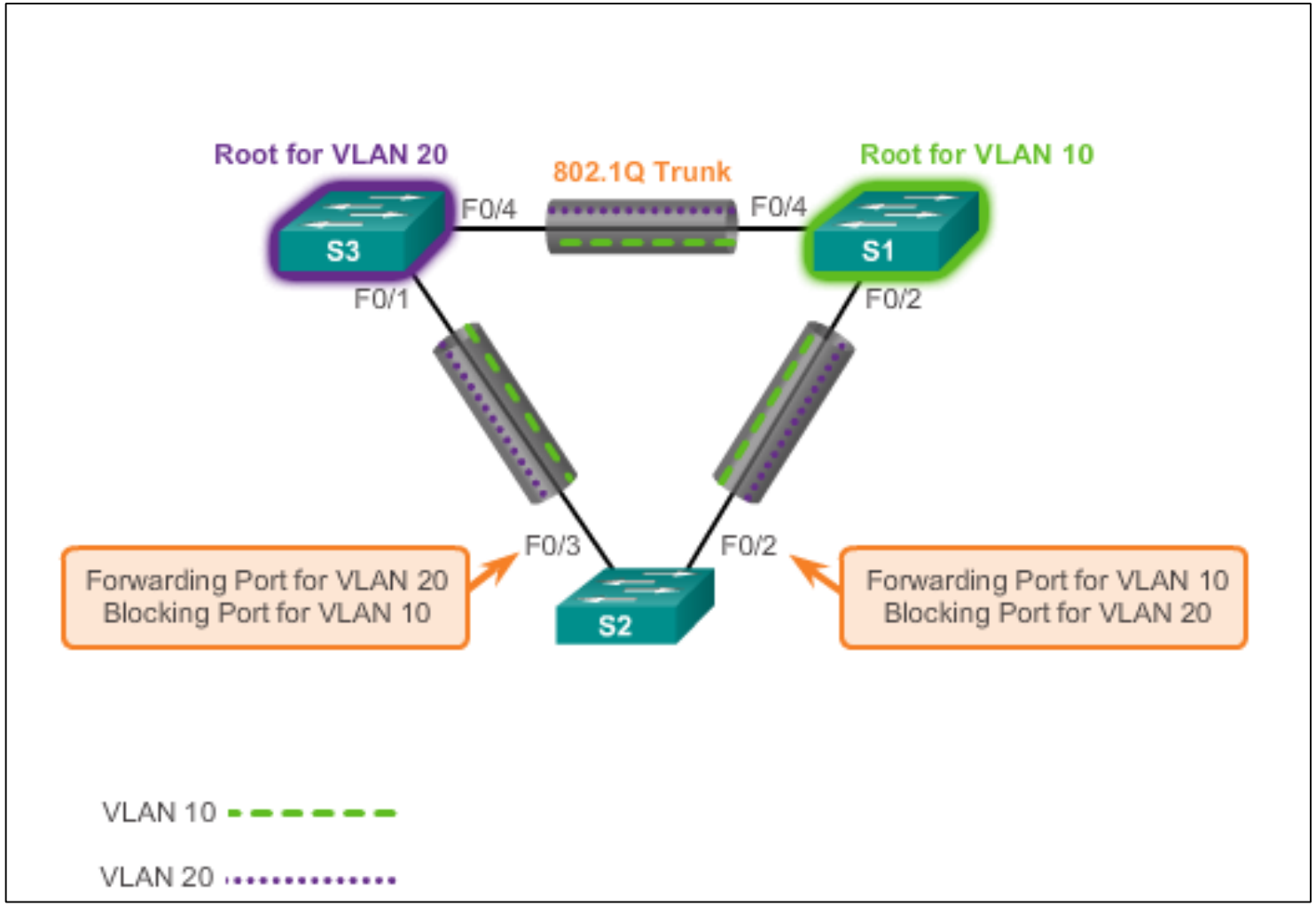
Protocol	Standard	Resources Needed	Convergence	Tree Calculation
STP	802.1D	Low	Slow	All VLANs
PVST+	Cisco	High	Slow	Per VLAN
RSTP	802.1w	Medium	Fast	All VLANs
Rapid PVST+	Cisco	Very high	Fast	Per VLAN
MSTP	802.1s Cisco	Medium or high	Fast	Per Instance

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

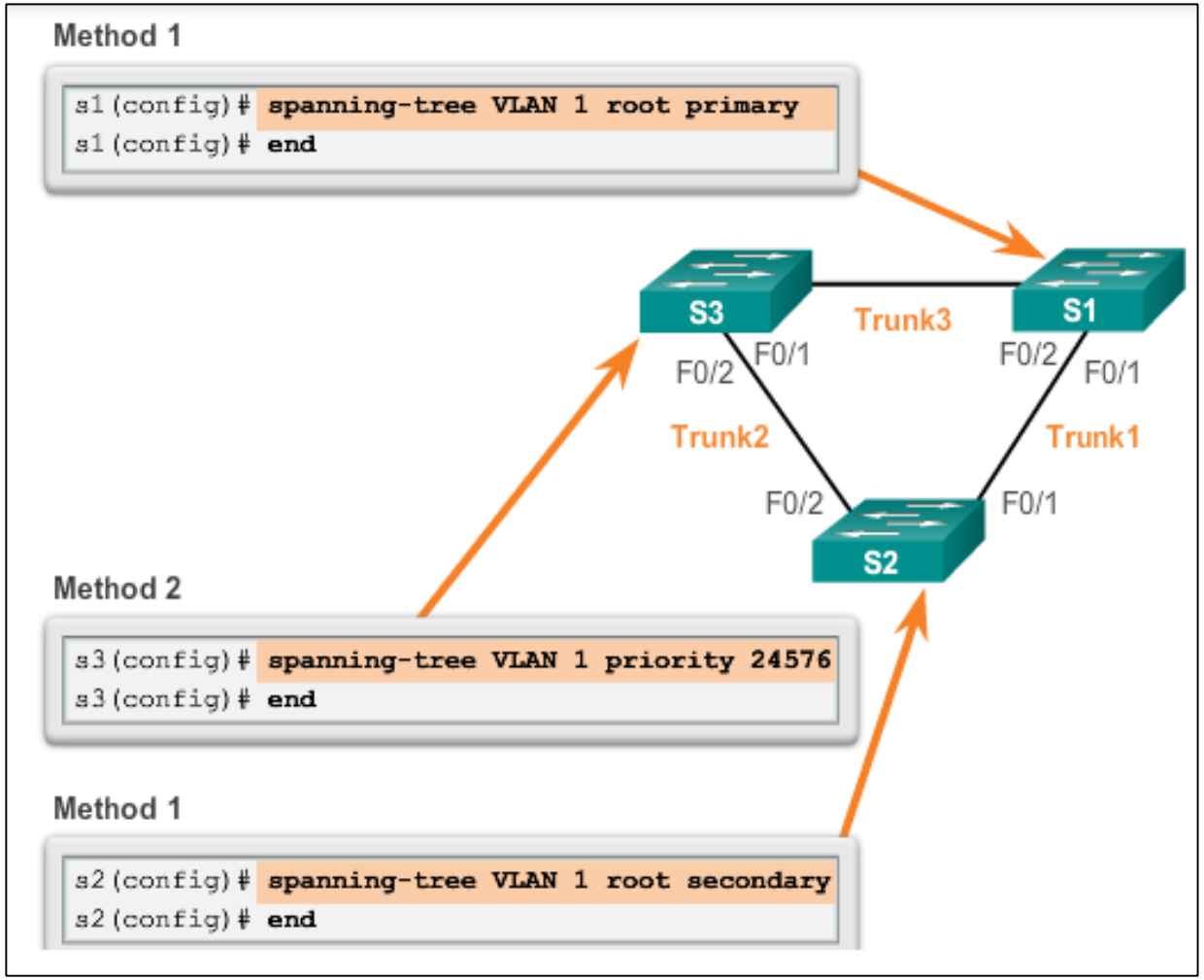
Processes	Blocking	Listening	Learning	Forwarding	Disabled
Processes received BPDUs	YES	YES	YES	YES	NO
Forward data frames received on interface	NO	NO	NO	YES	NO
Forward data frames switched from another interface	NO	NO	NO	YES	NO
Learn MAC addresses	NO	NO	YES	YES	NO

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

PVST+ Configuration

Configuring and Verifying the Bridge ID



PVST+ Configuration

Configuring and Verifying the Bridge ID

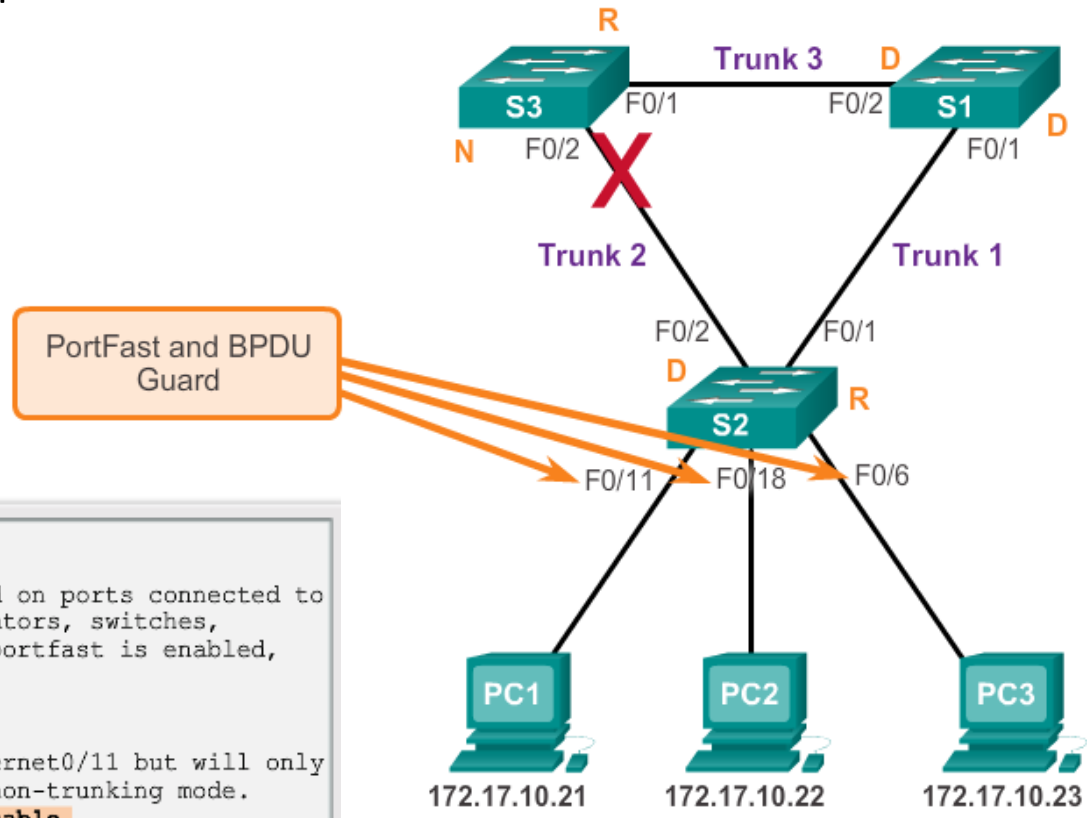
```
S3# show spanning-tree
VLAN0001
  Spanning tree enabled protocol ieee
  Root ID     Priority    24577
              Address     00A.0033.3333
              This bridge is the root
              Hello Time  2 sec Max Age 20 sec Forward Delay 15 sec
  Bridge ID   Priority    24577  (priority  24576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

PVST+ Configuration

PortFast and BPDU Guard

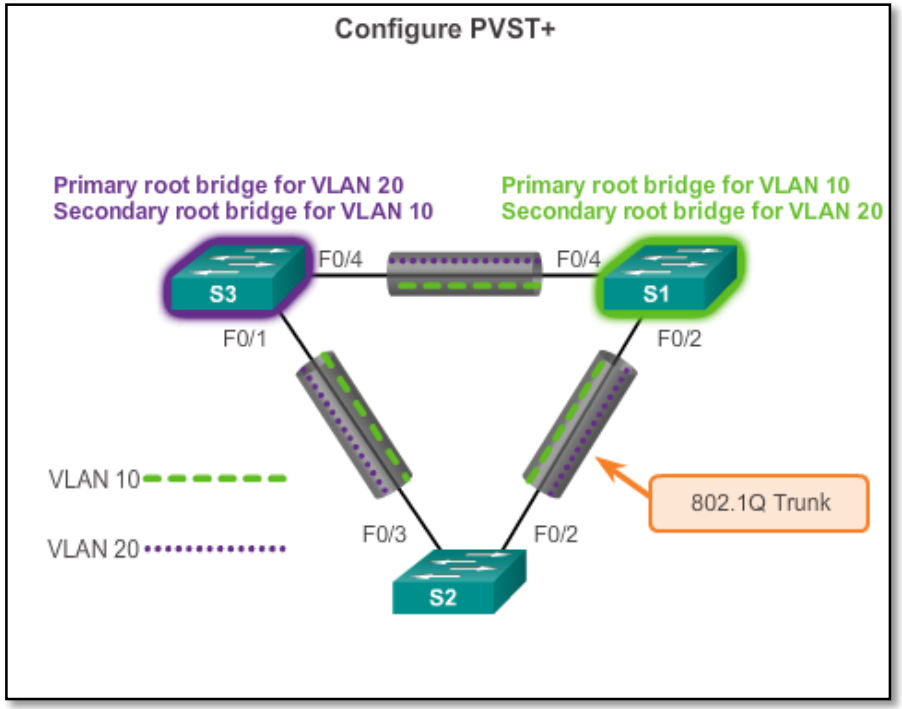
- When a switch port is configured with PortFast that port transitions from blocking to forwarding state immediately.
- BPDU guard puts the port in an *error-disabled* state on receipt of a BPDU.

```
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+ Configuration

PVST+ Load Balancing



Configure PVST+

```
S3(config)# spanning-tree vlan 20 root primary
```

This command forces S3 to be the primary root for VLAN 20.

```
S3(config)# spanning-tree vlan 10 root secondary
```

This command forces S3 to be the secondary root for VLAN 10.

```
S1(config)# spanning-tree vlan 10 root primary
```

This command forces S1 to be the primary root for VLAN 10.

```
S1(config)# spanning-tree vlan 20 root secondary
```

This command forces S1 to be the secondary root for VLAN 20.

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
```

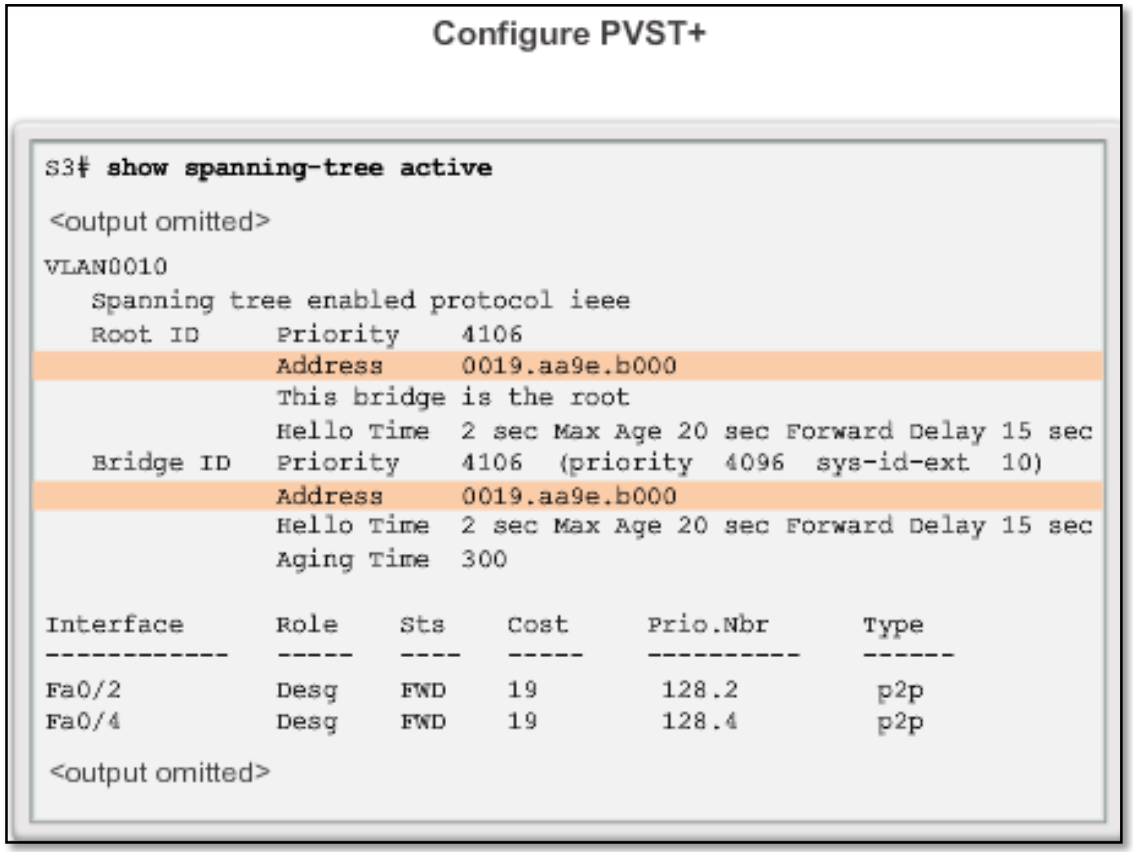
This command sets the priority for S3 to be the lowest possible, making it most likely that S3 will be the primary root for VLAN 20.

```
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.



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+

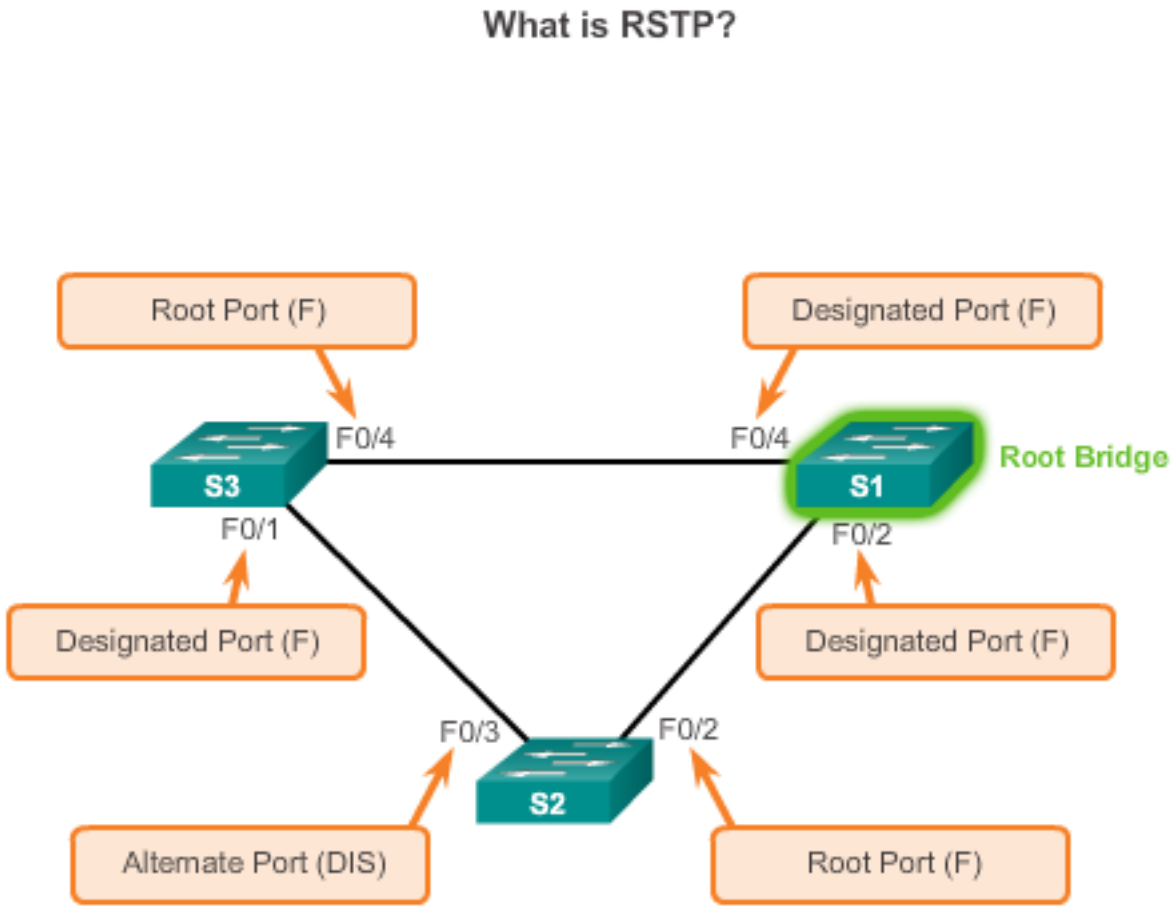
```
S2(config)#vlan 1
S2(config)#spanning-tree mode pvst
S2(config)#int fa0/1
S2(config-if)#switchport mode access
S2(config-if)#switchport access vlan 1
S2(config-if)#spanning-tree portfast
S2(config-if)#spanning-tree bpduguard enable
S2(config)#int gi0/1
S2(config-if)#switchport mode trunk
S2(config-if)#switchport 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+

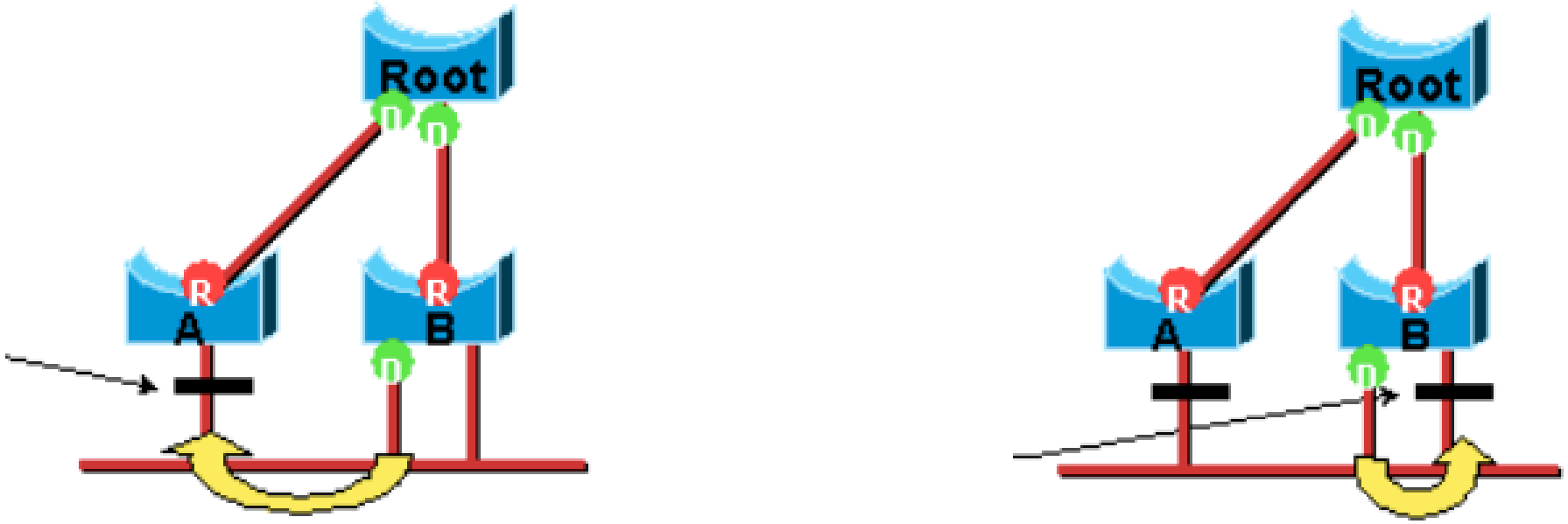


Port Roles:

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

Rapid-PVST+

Port States

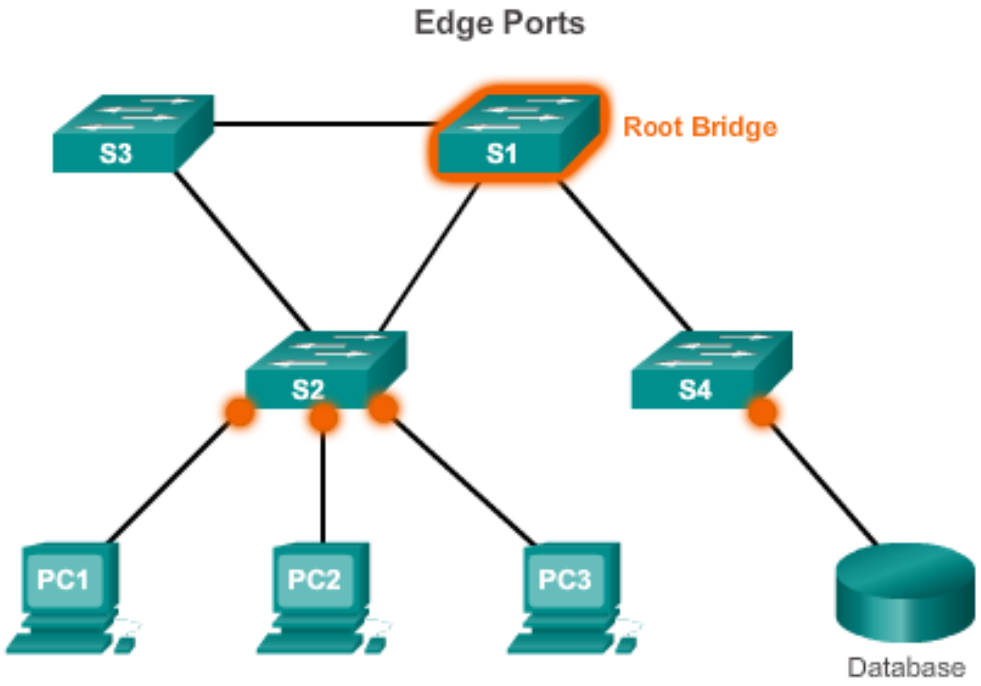
RSTP introduces the three port states:

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

Rapid PVST+

Edge Ports

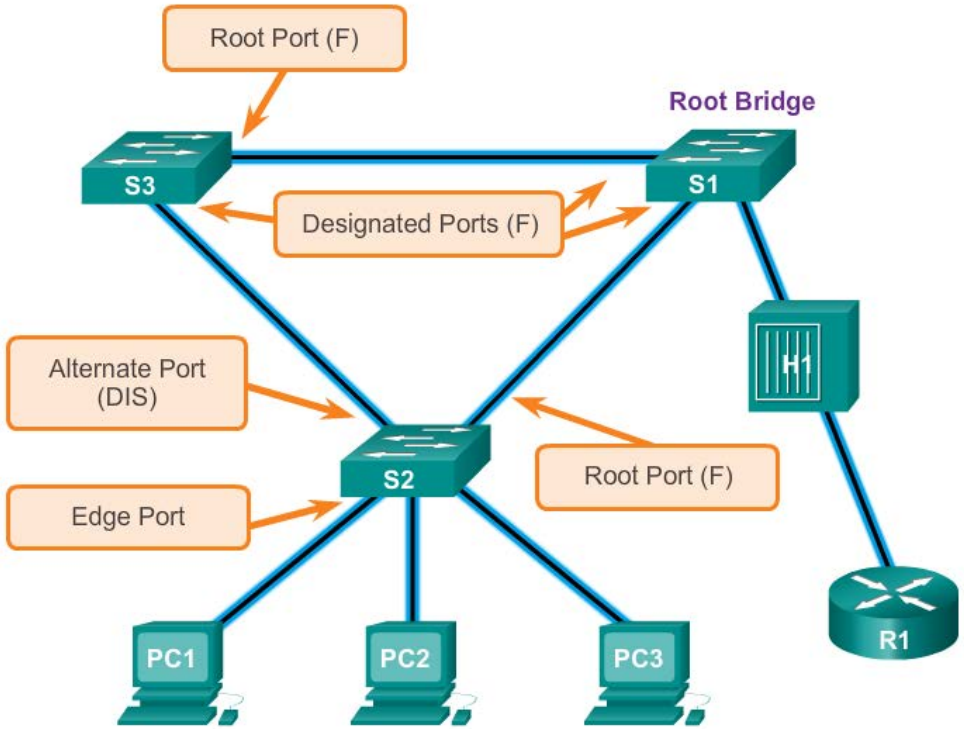


Edge Ports

- 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`

Rapid PVST+

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.

Rapid PVST+ Configuration

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

Edge Port

Non-Edge Port

```
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
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
```

Non-Edge Port

```
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