Chapter 3: STP

Scaling Networks

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Chapter 3- Sections & Objectives

- 3.1 Spanning Tree Concepts
  - Examine the purpose of STP and how the spanning tree algorithm is used create a loop-free topology.
- 3.2 Varieties of Spanning Tree Protocols
  - Examine the varieties of Spanning Tree protocols including PVST+ and Rapid PVST+.
- 3.3 Spanning Tree Configuration
  - Configure PVST+ and Rapid PVST+ to improve network performance.

3.1 Spanning Tree Concepts

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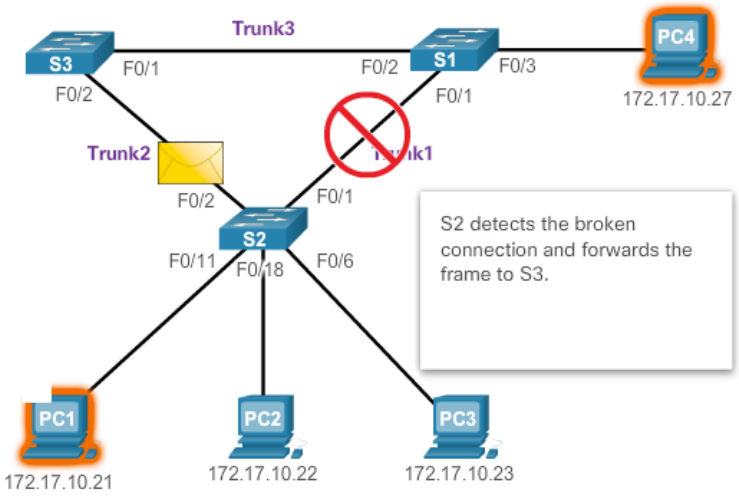
Purpose of Spanning Tree

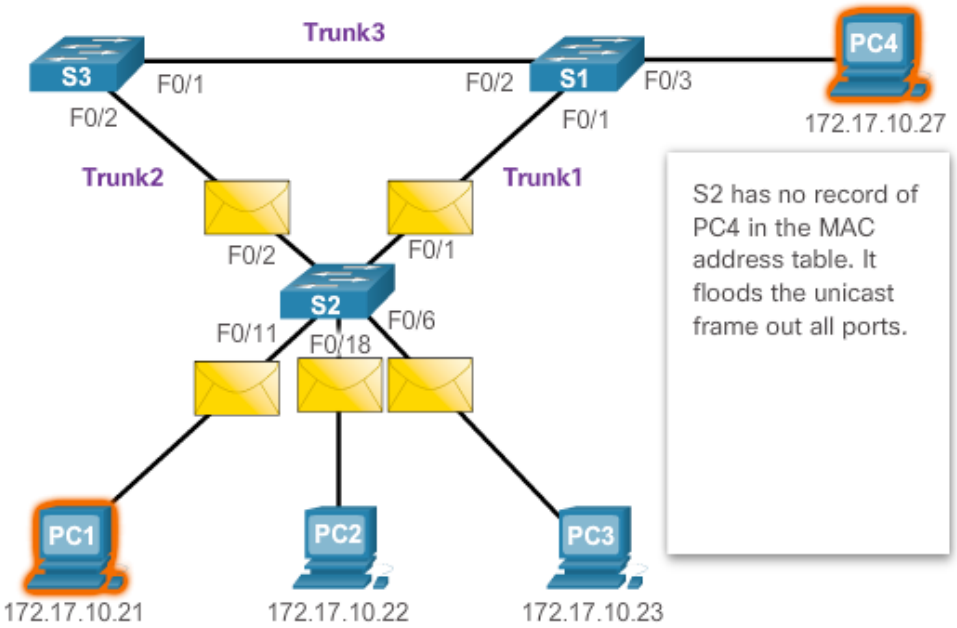
- Redundancy at OSI Layers 1 and 2
  - When multiple paths exist between two devices on a network, and there is no spanning tree implementation on the switches, a **Layer 2 loop** occurs.
  - See the animation in 3.1.1.1



- Issues with Layer 1 Redundancy: MAC Database Instability
  - **Ethernet has no mechanism (like TTL) enabled to block continued propagation of frames** on a switched network that continue to propagate between switches. See the animation in 3.1.1.2
- 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. See the animation in 3.1.1.3

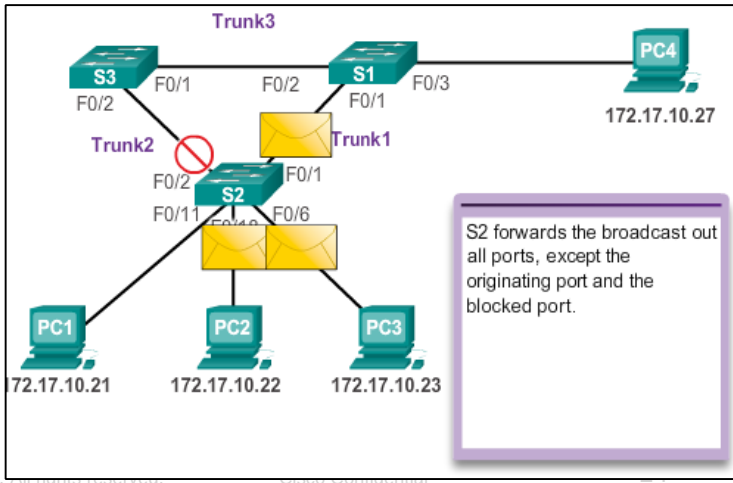
Purpose of Spanning Tree

- Issues with Layer 1 Redundancy: Duplicate Unicast Frames
  - An unknown unicast frame is when the switch does not have the destination MAC address in its MAC address table and must forward the frame out all ports, except the ingress port.
  - Unknown unicast frames sent onto a looped network can result in duplicate frames arriving at the destination device.
  - See the animation in 3.1.1.4



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 **a network cable or switch failure, STP recalculates the paths and unblocks the necessary ports** to allow the redundant path to become active.
- **See the 3.1.2.1 animation**



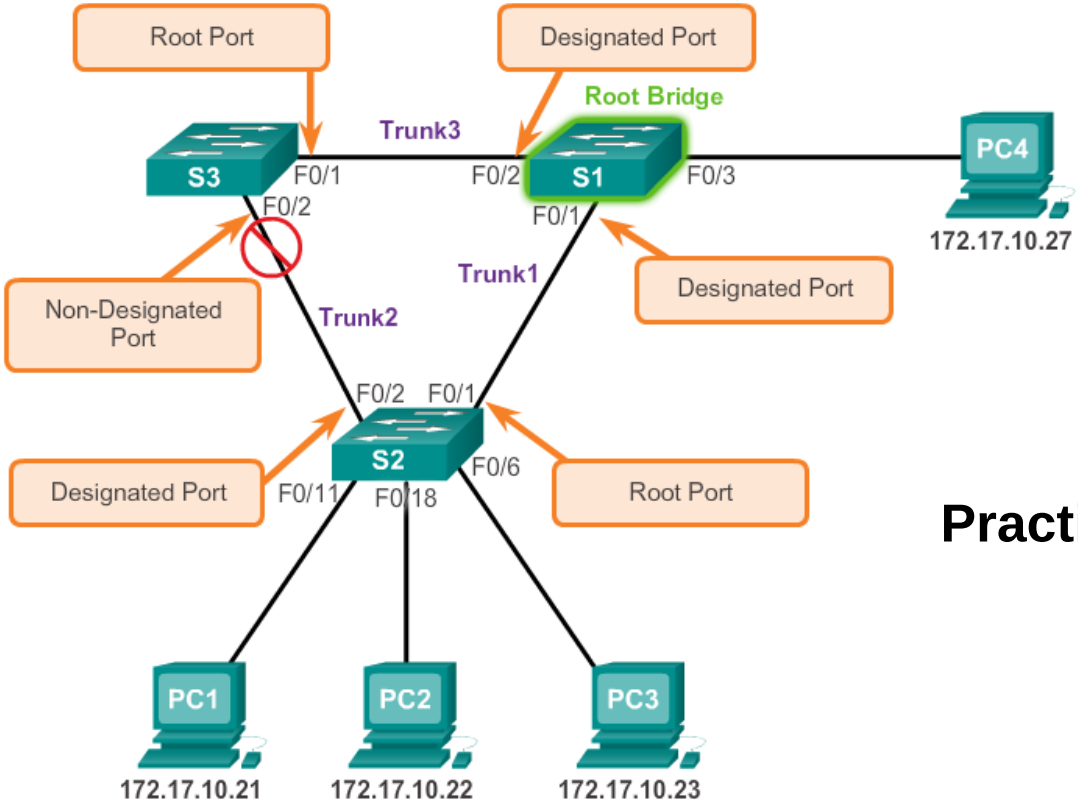
STP Operation

- 802.1D BPDU Frame Format
  - The spanning tree algorithm depends on the exchange of BPDUs.
  - By default, BPDU frames are sent every two seconds.
  - Each switch maintains local information about its own BID, the root ID, and the root path cost.
  - The BPDU frame information is included in the Data portion of an Ethernet frame and identifies the following fields:

Field Number	Bytes	Field
1-4	2	Protocol ID
	1	Version
	1	Message Type
	1	Flags
5-8	8	Root ID
	4	Root Path Cost
	8	Bridge ID
	2	Port ID
9-12	2	Message Age
	2	Max Age
	2	Hello Time
	2	Forward Delay

Spanning Tree Algorithm: Port Roles

- **Root ports** - Ports closest to the root bridge.
- **Designated ports** - Non-root ports permitted to forward traffic.
- **Alternate and backup ports** - Blocking state to prevent loops.
- **Disabled ports** - A disabled port is a switch port that is shut down.



Practice with 3.1.2.10

Summary of STP Operation

1. Elect the **Root Bridge**

   Exchange **BPDU Frames** and find out who has

   1. the **lowest priority** value
   2. if priorities are the same, who has the **lowest MAC**

   Also consider the optional **extended system ID** (for VLANs)

2. Use STA to calculate the **shortest path** to the Root Bridge

   Consider **path and port costs** to the Root Bridge and **select the port with the lowest path cost** (=closest to the Root Bridge) to become the **Root Port**

3. Select the **Designated Ports**

   All ports in the Root Bridge will always become Designated Ports

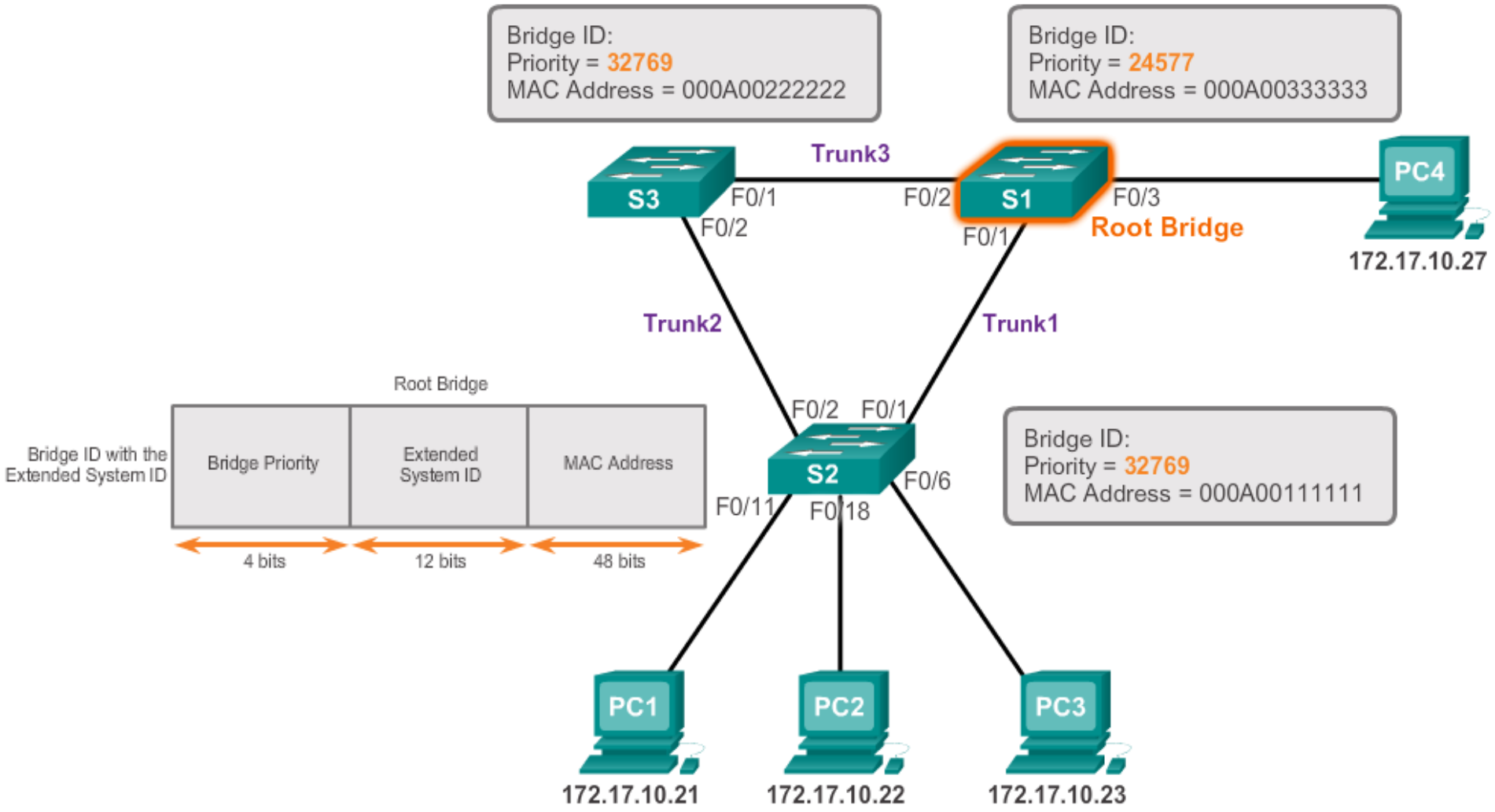
   If the other end of the trunk is Root Port, the other end will be **Designated Port**

4. Select the **Alternate Ports**

   If neither ends of a trunk are Root Ports, block (=set as **Alternate**) the port from the switch that has higher path cost to the Root Bridge. If equal cost, then BID is used.

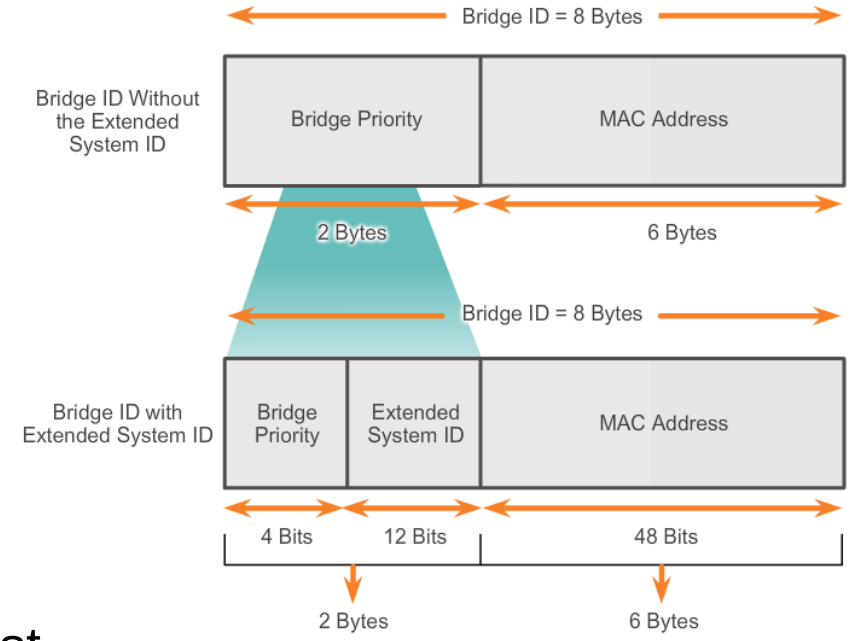
(Note that **during the STP process (15 seconds by default), switch ports only send/receive BPDU frames**)

STP Operation Step 1: Elect the Root Bridge



STP Operation

- The **bridge ID (BID) is used to determine the root bridge on a network**. The BID field of a BPDU frame contains three separate fields:
  - **Bridge priority** – Default is **32768** (from 0 to 61440 in **increments of 4096**)
  - **Extended system ID** - Identifies the **VLAN** participating in STP
  - **MAC address** - When the bridge priorities are equal, the MAC address is the deciding factor as to which switch is going to become the root bridge.

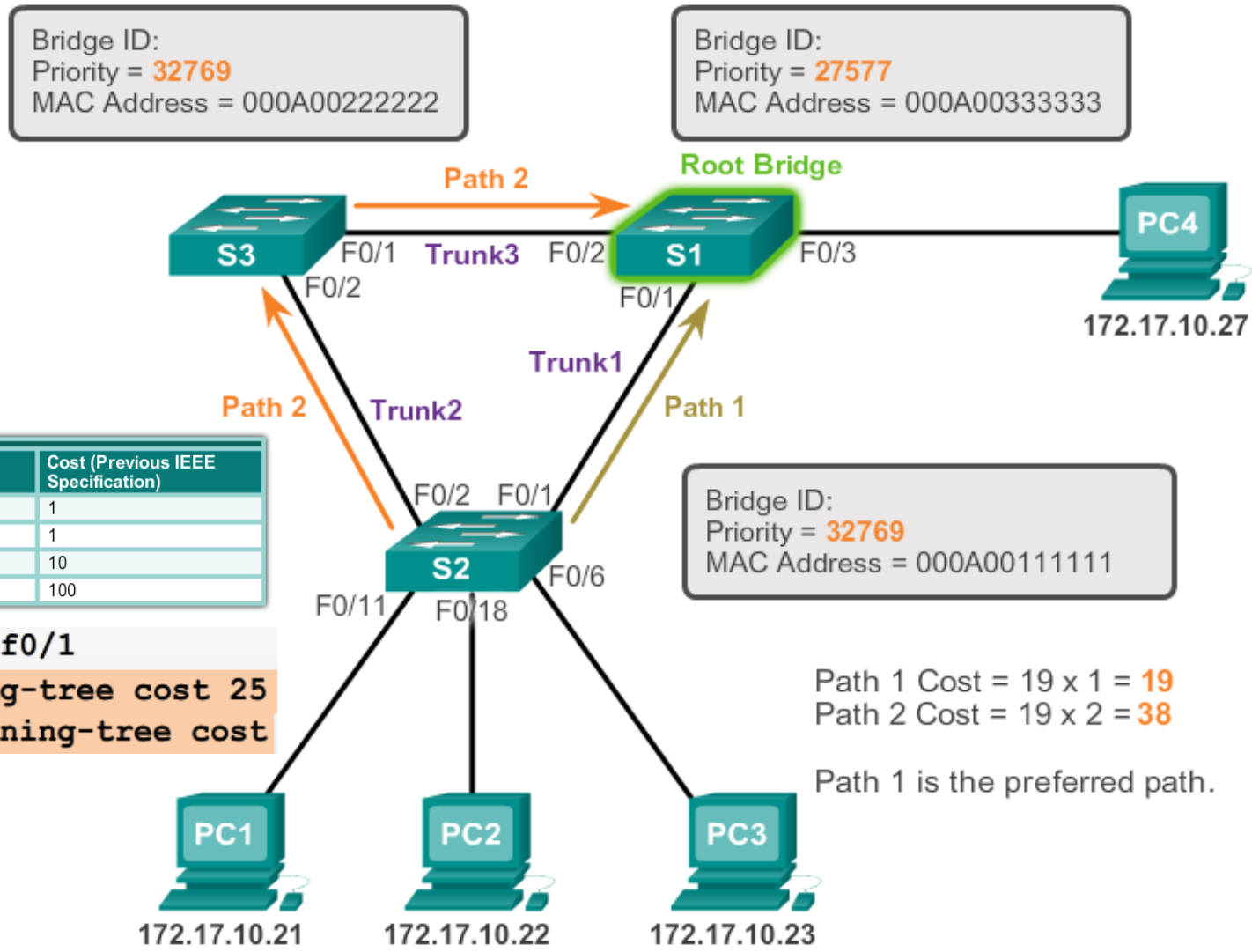


- To ensure that the root bridge decision best meets network requirements, **it is recommended that the administrator configures the desired root bridge switch with a lower priority**.

For example in VLAN 1, the default priority of the switch is 32769 (32768+1)

- This also **ensures that the addition of new switches to the network does not trigger a new spanning tree election**, which can disrupt network communication while a new root bridge is being selected.

STP Operation Step 2: Path Cost →Root Ports



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(config)# interface f0/1
S2(config-if)# spanning-tree cost 25
S2(config-if)# no spanning-tree cost
```

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

Path 1 is the preferred path.

STP Operation Steps 3-4: Designated & Alternate Ports

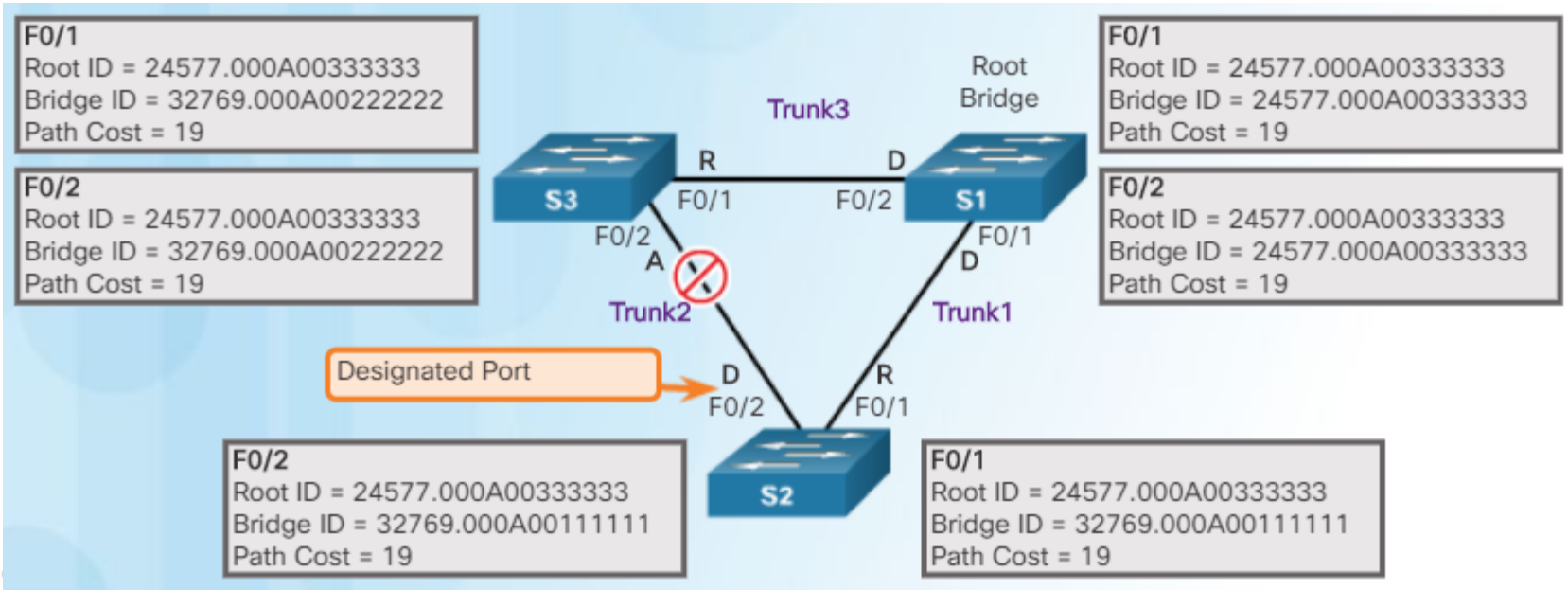
3. Select the **Designated Ports**

   All ports in the Root Bridge will always become Designated Ports

   If the other end of the trunk is Root Port, the other end will be Designated Port

4. Select the **Alternate Ports**

   If neither ends of a trunk are Root Ports, block (=set as Alternate) the port from the switch that has higher path cost to the Root Bridge. If equal cost, then BID is used.



3.2 Varieties of Spanning Tree Protocols

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Overview

- Types of Spanning Tree Protocols
  - Several varieties of spanning tree protocols have emerged since the original IEEE 802.1D.

802.1D-1998: The legacy standard for bridging and STP.
CST: Assumes one spanning-tree instance for the entire bridged network, regardless of the number of VLANs.
PVST+: A Cisco enhancement of STP that provides a separate 802.1D spanning-tree instance for each VLAN configured in the network.
802.1D-2004: An updated bridging and STP standard.
802.1w (RSTP): Improves convergence over 1998 STP by adding roles to ports and enhancing BPDU exchanges.
Rapid PVST+: A Cisco enhancement of RSTP using PVST+.
802.1s (MSTP): Maps multiple VLANs into the same spanning-tree instance.

- 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

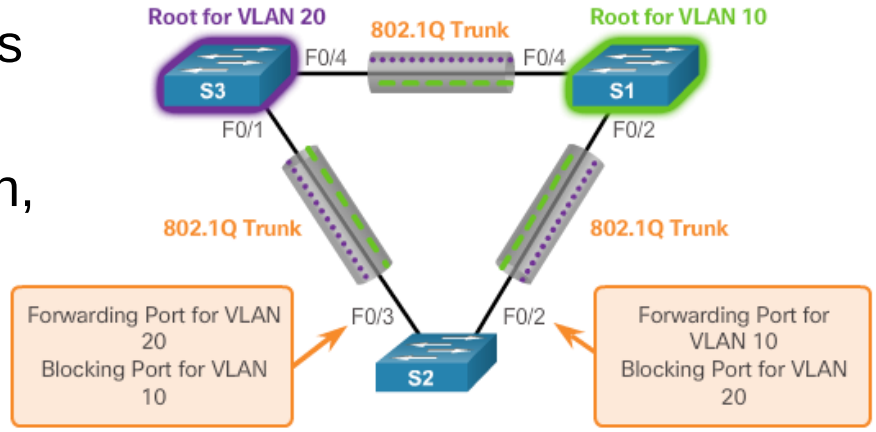
Cisco switches running IOS 15.0 or later, run PVST+ by default.

Practice with 3.2.1.3

PVST+

- Overview of PVST+
  - Cisco developed PVST+ to run an **independent instance of the Cisco implementation of IEEE 802.1D for each VLAN in the network. Allows different STP configurations and switch roles for different VLANs → optimum load balancing**.
- Port States and PVST+ Operation
  - STP and PVST+ use five port states consisting of Blocking, Listening, Learning, Forwarding, and Disabled.
- Extended System ID and PVST+ Operation
  - Extended system ID ensures switches have **unique BIDs for each VLAN**.
  - To manipulate the root-bridge election, assign a lower priority to the desired root bridge switch for the VLAN(s).

Practice with 3.2.2.4

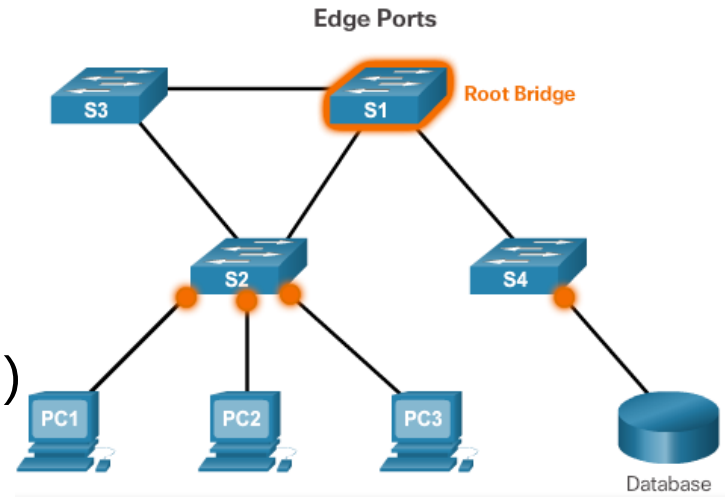


Rapid PVST+

- Rapid PVST+ is the Cisco implementation of per-VLAN RSTP.
  - RSTP **can achieve much faster convergence**.
- RSTP BPDU
  - RSTP uses type 2, version 2 BPDUs and populates the flag byte in a slightly different manner than in the original 802.1D.
- Edge Ports
  - RSTP edge port is a switch port that is **never intended to be connected to another switch**.
  - It **immediately transitions to the forwarding state when enabled:**

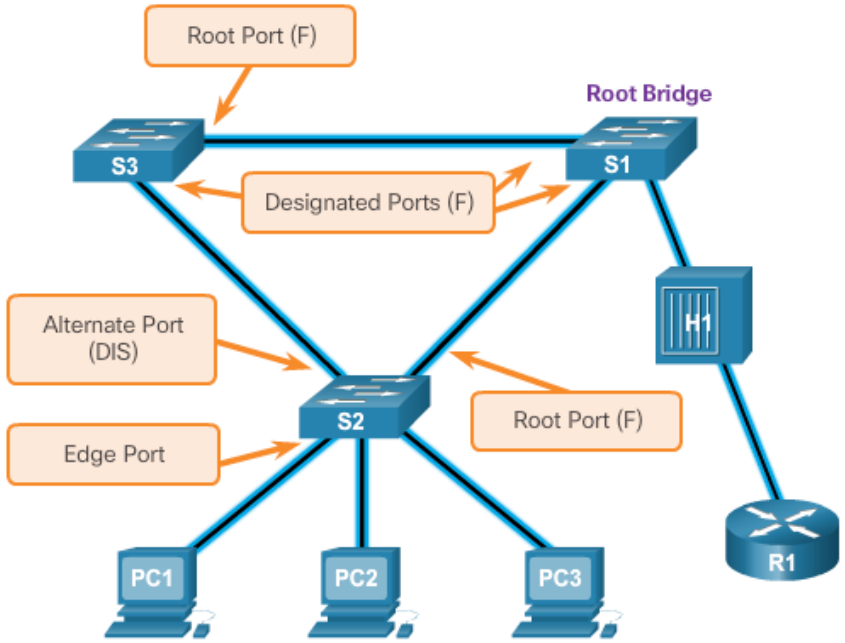
```
spanning-tree portfast
```

- A L2 loop is possible if a switch is connected to an edge port (**BPDU Guard** should be used!)



Rapid PVST+

- Link Types
  - **Point-to-Point** - A port operating in full-duplex mode typically connects a switch to a switch and is a candidate for a rapid transition to a forwarding state.
  - **Shared** - A port operating in half-duplex mode connects a switch to a legacy hub that attaches multiple devices.
  - RSTP must determine the port role:
    - Root ports and Alternate (backup) ports do not use the link-type parameter in most cases.
    - Designated ports make the most use of the link-type parameter and transition to the forwarding state if the link-type parameter is set to point-to-point.



Practice with 3.2.3.5

3.3 Spanning Tree Configuration

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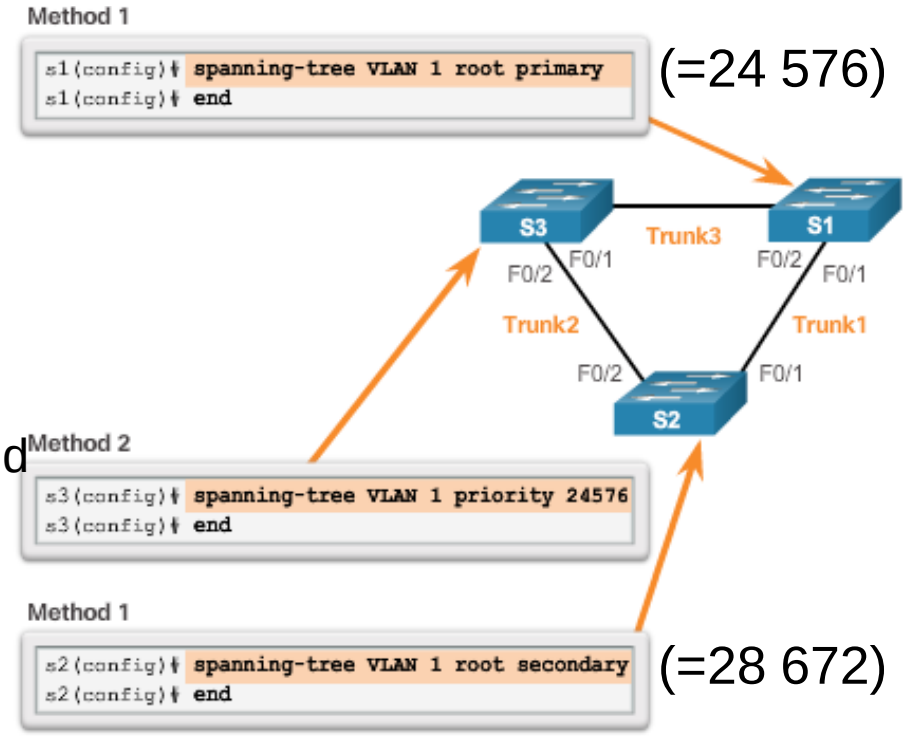
PVST+ Configuration

- Catalyst 2960 default config
  - Default mode is **PVST+**.

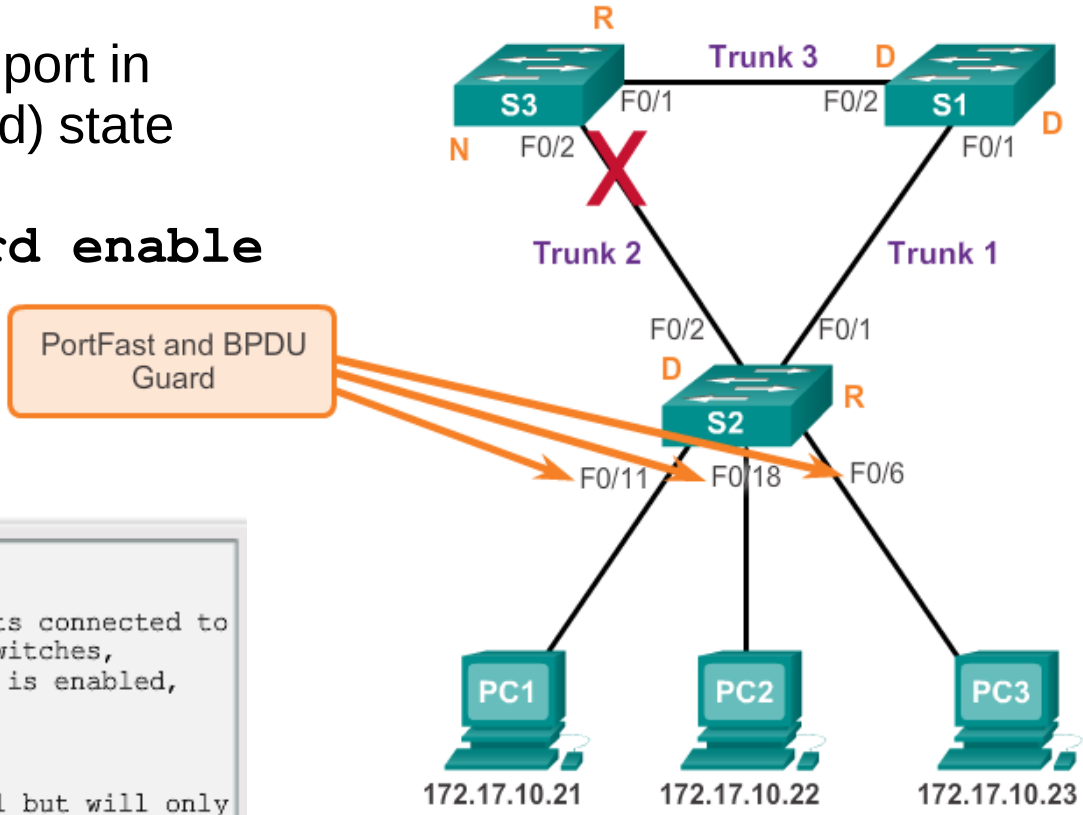
Feature	Default Setting
Enable state	Enabled on VLAN 1
Spanning-tree mode	PVST+ (Rapid PVST+ and MSTP are disabled.)
Switch priority	32768
Spanning-tree port priority (configurable on a per-interface basis)	128
Spanning-tree port cost (configurable on a per-interface basis)	1000 Mb/s: 4 100 Mb/s: 19 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
  - **Method 1:**
    - Use the **`spanning-tree vlan`** *`vlan-id`* **`root primary`** command
  - **Method 2:**
    - Use the **`spanning-tree vlan`** *`vlan-id`* **`priority`** *`value`* command
  - Use the **`show spanning-tree`** command to verify the bridge priority of a switch



PVST+ Configuration

- **PortFast** immediately transitions an access port from blocking to forwarding state: **`spanning-tree portfast`**
- **BPDU guard** puts an access port in an **errdisabled** (error-disabled) state if it receives a BPDU: **`spanning-tree bpduguard enable`**



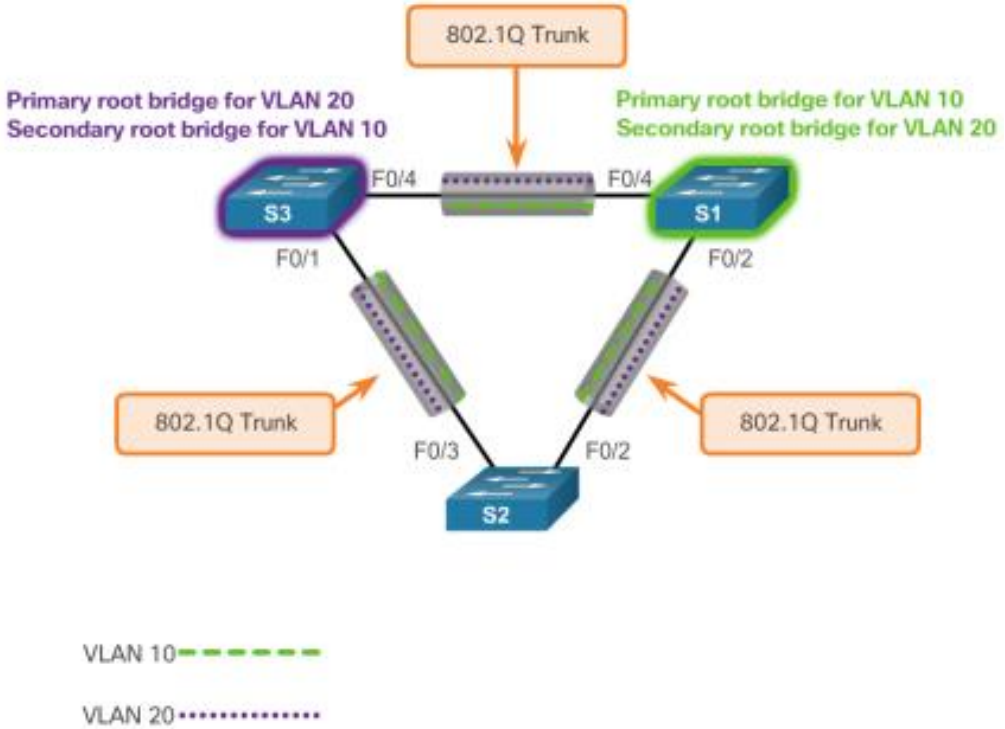

```
S2(config)# interface FastEthernet 0/11
S2(config-if)# spanning-tree portfast
%Warning: portfast should only be enabled on ports connected to
a single host. Connecting hubs, concentrators, switches,
bridges, etc... to this interface  when portfast is enabled,
can cause temporary bridging loops.
 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
  - The goal is to configure two or more root bridges for different sets of VLANs and make use of redundant links.

```
S3(config)# spanning-tree vlan 20 root primary
S3(config)# spanning-tree vlan 10 root secondary
S3(config)#
```

```
S1(config)# spanning-tree vlan 10 root primary
S1(config)# spanning-tree vlan 20 root secondary
S1(config)#
```



Rapid PVST+ Configuration

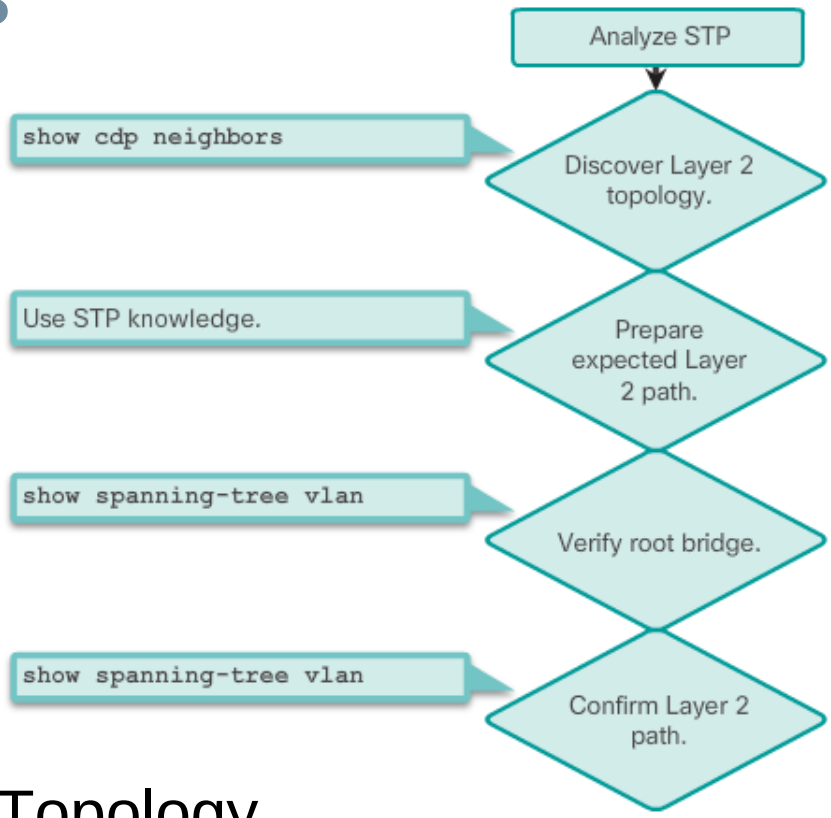
- Rapid PVST+ is the Cisco implementation of RSTP. It **supports RSTP on a per-VLAN basis**.
- The default spanning tree configuration on a Catalyst 2960 Series switch is PVST+ and the switch supports additionally Rapid PVST+, and MST (only one version can be active for all VLANs at any time).
- In most cases, the only difference between configuring PVST+ and Rapid PVST+ is the **`spanning-tree mode rapid-pvst`** command.

```
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
```

```
S1# show spanning-tree vlan 10

VLAN0010
  Spanning tree enabled protocol rstp
  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
```

STP Configuration Issues

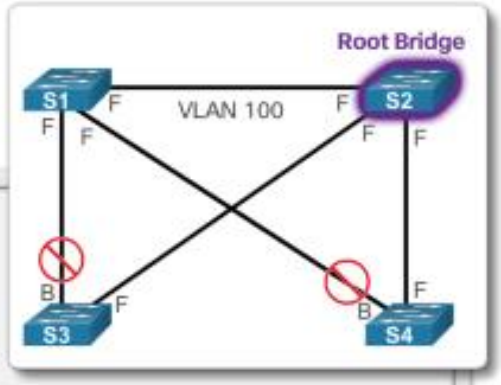
- Analyzing the STP Topology
  1. Use **`show cdp neighbors`** to discover topology
  2. Use STP knowledge to determine the root switch
  3. Use **`show spanning-tree vlan`** to verify which switch is the root and port status (forwarding or blocking).



- Expected Topology versus Actual Topology
  - Troubleshooting consists of comparing the actual state of the network against the expected state of the network and spotting the differences.

STP Configuration Issues

- Overview of STP Status
  - Use the **`show spanning-tree`** command without specifying any additional options provides a quick overview of the status of STP for all VLANs that are defined on a switch.
  - Use the **`show spanning-tree vlan`** *`vlan_id`* command to get STP information for a particular VLAN.




```
S1# show spanning-tree vlan 100

VLAN0100
 Spanning tree enabled protocol rstp
 Root ID     Priority    28772
             Address     0000.0c9f.3127
             Cost        2
             Port        88 (TenGigabit9/1)
             Hello Time  2 sec Max Age 20 sec Forward Delay 15 sec
 Bridge ID   Priority    28772 (priority 28672 sys-id-ext 100)
             Address     0000.0cab.3724
             Hello Time  2 sec Max Age 20 sec Forward Delay 15 sec
             Aging Time  300

Interface        Role Sts Cost      Prio.Nbr Type
---------        ---------------    --------------------------------
Gi3/1            Desg FWD 4         128.72   P2p
Gi3/2            Desg FWD 4         128.80   P2p
Te9/1            Root FWD 2         128.88   P2p
```

STP Configuration Issues

- There are two types of STP failures:
  - STP might erroneously block ports that should have gone into the forwarding state.
  - STP might erroneously move one or more ports into the forwarding state → L2 loop
- Repairing a Spanning Tree Problem
  - Manually remove redundant links in the switched network, either physically or through configuration, until all loops are eliminated.
  - Chances are that restoring the redundant links will trigger a new broadcast storm.
  - Before restoring the redundant links, determine and correct the cause of the spanning tree failure.
  - Carefully monitor the network to ensure that the problem is fixed.

Practice with 3.3.3.6

Switch Stacking Concepts

- Switch Stacking Concepts
  - A switch stack can consist of up to nine Catalyst 3750 switches connected through their StackWise ports.
  - **One of the switches controls the operation** of the stack and is called the **stack master**.
  - The switch is **managed as a single switch, through a single IP address**, including passwords, VLANs, and interfaces.
- Spanning Tree and Switch Stacks
  - Another benefit to switch stacking is the ability to **add more switches to a single STP instance without increasing the STP diameter**.
  - The IEEE recommends a maximum diameter of seven switches for the default STP timers.

3.3 Chapter Summary

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Chapter Summary

Summary

- Problems that can result from a redundant Layer 2 network include **broadcast storms**, **MAC database instability**, and **duplicate unicast frames**. **STP is a Layer 2 protocol that ensures that there is only one logical path between all destinations on the network by intentionally blocking redundant paths that could cause a loop**.
- STP sends **BPDU frames** for communication between switches. One switch is elected as the **root bridge** for each instance of spanning tree. An administrator can control this election by changing the bridge priority. Root bridges can be configured to enable spanning tree load balancing by VLAN or by a group of VLANs, depending on the spanning tree protocol used. STP then assigns a **port role** to each participating port using a path cost. The root path cost is equal to the sum of all the port costs along the path to the root bridge. A port cost is automatically assigned to each port; however, it can also be manually configured. Paths with the lowest cost become preferred, and all other redundant paths are blocked.
- **PVST+** is the default configuration of IEEE 802.1D on Cisco switches. It runs one instance of STP for each VLAN. A newer, faster-converging spanning tree protocol, RSTP, can be implemented on Cisco switches on a per-VLAN basis in the form of **Rapid PVST+**. Multiple Spanning Tree (MST) is the Cisco implementation of Multiple Spanning Tree Protocol (MSTP), where one instance of spanning tree runs for a defined group of VLANs. Features such as **PortFast** and **BPDU guard** ensure that hosts in the switched environment are provided immediate access to the network without interfering with spanning tree operation.
- **Switch stacking** allows connection of up to nine Catalyst 3750 switches to be configured and presented to the network as a single entity. STP views the switch stack as a single switch. This additional benefit helps ensure the IEEE recommended maximum diameter of seven switches.