Spanning Tree Protocols

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Modified from Slides Courtesy of Cisco Networking Academy
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- Summary
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.
Purpose of Spanning Tree

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.
Purpose of Spanning Tree

Issues with Layer 1 Redundancy: Duplicate Unicast Frames

Both S1 and S3 have an entry in their MAC address tables for PC4. Both forward the frame accordingly.
STP Operation

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.
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

<table>
<thead>
<tr>
<th>Event</th>
<th>Stack</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visit A</td>
<td>A</td>
</tr>
<tr>
<td>Visit B</td>
<td>AB</td>
</tr>
<tr>
<td>Visit F</td>
<td>ABF</td>
</tr>
<tr>
<td>Visit H</td>
<td>ABFH</td>
</tr>
<tr>
<td>Pop H</td>
<td>ABF</td>
</tr>
<tr>
<td>Pop F</td>
<td>AB</td>
</tr>
<tr>
<td>Pop B</td>
<td>A</td>
</tr>
<tr>
<td>Visit C</td>
<td>AC</td>
</tr>
<tr>
<td>Pop C</td>
<td>A</td>
</tr>
<tr>
<td>Visit D</td>
<td>AD</td>
</tr>
<tr>
<td>Visit G</td>
<td>ADG</td>
</tr>
<tr>
<td>Visit I</td>
<td>ADGI</td>
</tr>
<tr>
<td>Pop I</td>
<td>ADG</td>
</tr>
<tr>
<td>Pop G</td>
<td>AD</td>
</tr>
<tr>
<td>Pop D</td>
<td>A</td>
</tr>
<tr>
<td>Visit E</td>
<td>AE</td>
</tr>
<tr>
<td>Pop E</td>
<td>A</td>
</tr>
<tr>
<td>Pop A</td>
<td>Empty</td>
</tr>
</tbody>
</table>
Breadth-First Search

- Queue Contents

<table>
<thead>
<tr>
<th>Event</th>
<th>Queue (Front to Rear)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visit A</td>
<td></td>
</tr>
<tr>
<td>Visit B</td>
<td>B</td>
</tr>
<tr>
<td>Visit C</td>
<td>BC</td>
</tr>
<tr>
<td>Visit D</td>
<td>BCD</td>
</tr>
<tr>
<td>Visit E</td>
<td>BCDE</td>
</tr>
<tr>
<td>Remove B</td>
<td>CDE</td>
</tr>
<tr>
<td>Visit F</td>
<td>CDEF</td>
</tr>
<tr>
<td>Remove C</td>
<td>DEF</td>
</tr>
<tr>
<td>Remove D</td>
<td>EF</td>
</tr>
<tr>
<td>Visit G</td>
<td>EFG</td>
</tr>
<tr>
<td>Remove E</td>
<td>FG</td>
</tr>
<tr>
<td>Remove F</td>
<td>G</td>
</tr>
<tr>
<td>Visit H</td>
<td>GH</td>
</tr>
<tr>
<td>Remove G</td>
<td>H</td>
</tr>
<tr>
<td>Visit I</td>
<td>HI</td>
</tr>
<tr>
<td>Remove H</td>
<td>I</td>
</tr>
<tr>
<td>Remove I</td>
<td>Empty</td>
</tr>
<tr>
<td>Done</td>
<td></td>
</tr>
</tbody>
</table>
Minimum Spanning Trees with Weighted Graphs

• To find the minimum cost to connect all the edges in a graph.

Weighted Graph

Minimum Cost = 4
STP Operation

Spanning Tree Algorithm: Root Bridge

Bridge ID:
Priority = 32769
MAC Address = 000A00222222

Bridge ID:
Priority = 24577
MAC Address = 000A00333333

Bridge ID:
Priority = 32769
MAC Address = 000A00111111

000A00111111

Trunk3

Trunk2

Trunk1

F0/2  F0/1
F0/0
S1

S2

S3

PC1

PC2

PC3

172.17.10.21
172.17.10.22
172.17.10.23

172.17.10.27

F0/1
F0/2
F0/3

F0/1
F0/2
F0/3

F0/1
F0/2
F0/3

000A00222222

000A00333333

000A00111111

4 bits

12 bits

48 bits

Root Bridge

Bridge ID with the
Extended System ID

S1

S2

S3

PC4

PC1

PC2

PC3

172.17.10.21
172.17.10.22
172.17.10.23

172.17.10.27

F0/1
F0/2
F0/3

F0/1
F0/2
F0/3

F0/1
F0/2
F0/3

000A00222222

000A00333333

000A00111111

4 bits

12 bits

48 bits

Root Bridge

Bridge ID with the
Extended System ID
S1

`%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

<table>
<thead>
<tr>
<th>Interface</th>
<th>Role</th>
<th>Sts</th>
<th>Cost</th>
<th>Prio.Nbr</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fa0/4</td>
<td>Desg FWD</td>
<td>19</td>
<td>128.4</td>
<td>P2p</td>
<td></td>
</tr>
<tr>
<td>Fa0/3</td>
<td>Desg FWD</td>
<td>19</td>
<td>128.3</td>
<td>P2p</td>
<td></td>
</tr>
<tr>
<td>Fa0/2</td>
<td>Altn BLK</td>
<td>19</td>
<td>128.2</td>
<td>P2p</td>
<td></td>
</tr>
<tr>
<td>Fa0/1</td>
<td>Root FWD</td>
<td>19</td>
<td>128.1</td>
<td>P2p</td>
<td></td>
</tr>
</tbody>
</table>
```

S1#
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.
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

<table>
<thead>
<tr>
<th>Link Speed</th>
<th>Cost (Revised IEEE Specification)</th>
<th>Cost (Previous IEEE Specification)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 Gb/s</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>1 Gb/s</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>100 Mb/s</td>
<td>19</td>
<td>10</td>
</tr>
<tr>
<td>10 Mb/s</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

Bridge ID:
Priority = 32769
MAC Address = 000A00222222

Bridge ID:
Priority = 27577
MAC Address = 000A00333333

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

Path 1 is the preferred path.
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

<table>
<thead>
<tr>
<th>Protocol</th>
<th>Standard</th>
<th>Resources Needed</th>
<th>Convergence</th>
<th>Tree Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>STP</td>
<td>802.1D</td>
<td>Low</td>
<td>Slow</td>
<td>All VLANs</td>
</tr>
<tr>
<td>PVST+</td>
<td>Cisco</td>
<td>High</td>
<td>Slow</td>
<td>Per VLAN</td>
</tr>
<tr>
<td>RSTP</td>
<td>802.1w</td>
<td>Medium</td>
<td>Fast</td>
<td>All VLANs</td>
</tr>
<tr>
<td>Rapid PVST+</td>
<td>Cisco</td>
<td>Very high</td>
<td>Fast</td>
<td>Per VLAN</td>
</tr>
<tr>
<td>MSTP</td>
<td>802.1s</td>
<td>Medium or high</td>
<td>Fast</td>
<td>Per Instance</td>
</tr>
</tbody>
</table>
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+
STP introduces the five port states:

<table>
<thead>
<tr>
<th>Processes</th>
<th>Blocking</th>
<th>Listening</th>
<th>Learning</th>
<th>Forwarding</th>
<th>Disabled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processes received BPDUs</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>NO</td>
</tr>
<tr>
<td>Forward data frames received on interface</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
<td>YES</td>
<td>NO</td>
</tr>
<tr>
<td>Forward data frames switched from another interface</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
<td>YES</td>
<td>NO</td>
</tr>
<tr>
<td>Learn MAC addresses</td>
<td>NO</td>
<td>NO</td>
<td>YES</td>
<td>YES</td>
<td>NO</td>
</tr>
</tbody>
</table>
# PVST+ Configuration

## Catalyst 2960 Default Configuration

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

Configuring and Verifying the Bridge ID

Method 1

```
sl(config)# spanning-tree VLAN 1 root primary
sl(config)# end
```

Method 2

```
s3(config)# spanning-tree VLAN 1 priority 24576
s3(config)# end
```

Method 1

```
s2(config)# spanning-tree VLAN 1 root secondary
s2(config)# end
```
### PVST+ Configuration

#### Configuring and Verifying the Bridge ID

S3# `show spanning-tree`

<table>
<thead>
<tr>
<th>VLAN0001</th>
<th>Spanning tree enabled protocol ieee</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Root ID</strong></td>
<td><strong>Priority</strong> 24577</td>
</tr>
<tr>
<td>Address</td>
<td>00A.0033.3333</td>
</tr>
<tr>
<td><strong>This bridge is the root</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Bridge ID</strong></td>
<td><strong>Priority</strong> 24577 (priority 24576 sys-id-ext 1)</td>
</tr>
<tr>
<td>Address</td>
<td>000A.0033.3333</td>
</tr>
<tr>
<td>Hello Time</td>
<td>2 sec Max Age 20 sec Forward Delay 15 sec</td>
</tr>
<tr>
<td>Aging Time</td>
<td>300</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Interface</th>
<th>Role</th>
<th>Sts</th>
<th>Cost</th>
<th>Prio.Nbr</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fa0/1</td>
<td>Desg</td>
<td>FWD</td>
<td>4</td>
<td>128.1</td>
<td>p2p</td>
</tr>
<tr>
<td>Fa0/2</td>
<td>Desg</td>
<td>FWD</td>
<td>4</td>
<td>128.2</td>
<td>p2p</td>
</tr>
<tr>
<td>S3#</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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+

Primary root bridge for VLAN 20
Secondary root bridge for VLAN 10

S3
F0/4
F0/1
VLAN 10

Primary root bridge for VLAN 10
Secondary root bridge for VLAN 20

S1
F0/4
F0/2

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+ Configuration

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+ Configuration

PVST+ Load Balancing

- Display and verify spanning tree configuration details.

```bash
S3# show spanning-tree active
<output omitted>
VLAN0010
  Spanning tree enabled protocol ieee
  Root ID  Priority  4106
  Address  0019.ee9a.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.ee9a.b000
  Hello Time 2 sec Max Age 20 sec Forward Delay 15 sec
  Aging Time 300

<table>
<thead>
<tr>
<th>Interface</th>
<th>Role</th>
<th>Sts</th>
<th>Cost</th>
<th>Prio.Nbr</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fa0/2</td>
<td>Desg</td>
<td>FWD</td>
<td>19</td>
<td>128.2</td>
<td>p2p</td>
</tr>
<tr>
<td>Fa0/4</td>
<td>Desg</td>
<td>FWD</td>
<td>19</td>
<td>128.4</td>
<td>p2p</td>
</tr>
</tbody>
</table>
<output omitted>
```
PVST+ Configuration

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

What is RSTP?

Diagram showing port roles:
- Root Port (F)
- Designated Port (F)
- Alternate Port (DIS)
- Root Bridge
Rapid-PVST+

Port Roles: Alternate Port vs. Backup

Rapid-PVST+

Port States

RSTP introduces the three port states:

<table>
<thead>
<tr>
<th>STP (802.1D) Port State</th>
<th>RSTP (802.1w) Port State</th>
<th>Is Port Included in Active Topology?</th>
<th>Is Port Learning MAC Addresses?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disabled</td>
<td>Discarding</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Blocking</td>
<td>Discarding</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Listening</td>
<td>Discarding</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Learning</td>
<td>Learning</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Forwarding</td>
<td>Forwarding</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Cisco IOS Command Syntax</th>
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<tbody>
<tr>
<td><strong>Enter global configuration mode.</strong></td>
</tr>
<tr>
<td>configure terminal</td>
</tr>
<tr>
<td><strong>Configure Rapid PVST+ spanning-tree mode.</strong></td>
</tr>
<tr>
<td>spanning-tree mode rapid-pvst</td>
</tr>
<tr>
<td><strong>Enter interface configuration mode and specify an interface to configure. Valid interfaces include physical ports, VLANs, and port channels.</strong></td>
</tr>
<tr>
<td>interface interface-id</td>
</tr>
<tr>
<td><strong>Specify that the link type for this port is point-to-point.</strong></td>
</tr>
<tr>
<td>spanning-tree link-type point-to-point</td>
</tr>
<tr>
<td><strong>Return to privileged EXEC mode.</strong></td>
</tr>
<tr>
<td>end</td>
</tr>
<tr>
<td><strong>Clear all detected STP.</strong></td>
</tr>
<tr>
<td>clear spanning-tree detected-protocols</td>
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</table>
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
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
S1(config)#clear spanning-tree detected-protocols
• 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.

<table>
<thead>
<tr>
<th>Protocol</th>
<th>Standard</th>
<th>Resources Needed</th>
<th>Convergence</th>
<th>Tree Calculation</th>
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</thead>
<tbody>
<tr>
<td>STP</td>
<td>802.1D</td>
<td>Low</td>
<td>Slow</td>
<td>All VLANs</td>
</tr>
<tr>
<td>PVST+</td>
<td>Cisco</td>
<td>High</td>
<td>Slow</td>
<td>Per VLAN</td>
</tr>
<tr>
<td>RSTP</td>
<td>802.1w</td>
<td>Medium</td>
<td>Fast</td>
<td>All VLANs</td>
</tr>
<tr>
<td>Rapid PVST+</td>
<td>Cisco</td>
<td>Very high</td>
<td>Fast</td>
<td>Per VLAN</td>
</tr>
<tr>
<td>MSTP</td>
<td>802.1s Cisco</td>
<td>Medium or high</td>
<td>Fast</td>
<td>Per Instance</td>
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</tbody>
</table>