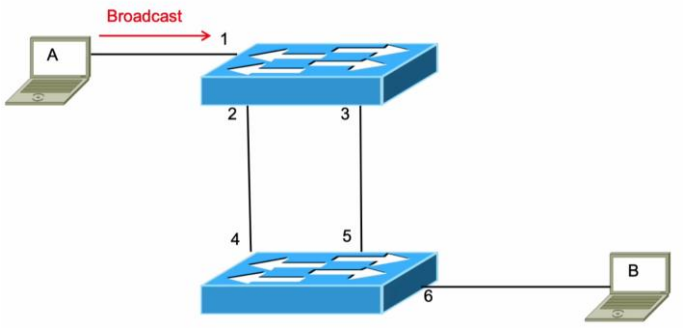
Rapid Spanning-Tree Protocol

Bridging Loop



In the given topology, we have two switches connected with **redundant links** (ports 2–4 and 3–5). A broadcast frame from PC-A enters **Switch 1** on port 1.

- Since broadcasts are **not stored in the MAC address table**, Switch 1 floods the frame out of all other ports (2 and 3).
- These frames reach Switch 2 on ports 4 and 5.
- Switch 2 receives the same broadcast on both ports. Each time, it processes the frame and floods it again out of all ports except the incoming one.
- If it processes port 4 first → it floods to ports 5 and 6.

- Then when it processes port 5 → it floods to ports 4 and 6 again.
- As a result, the same broadcast frame keeps circulating between ports 2–3–4–5 endlessly, creating a **bridging loop**.
- Because switches do not have a built-in mechanism to stop this looping (without Spanning Tree Protocol), the frame continues forever.

Problems Caused by the Bridging Loop

MAC Address Table Instability

- Switch 1 starts learning the MAC address of PC-A incorrectly. Sometimes it thinks PC-A is on port 2, sometimes on port 3, because the same frame arrives from both sides.
- This causes confusion, and frames destined for PC-A may never reach the correct port (port 1).

Bandwidth Wastage

- The looping frames keep consuming link capacity on all redundant links (ports 2–3–4–5).
- This reduces available bandwidth for legitimate traffic.

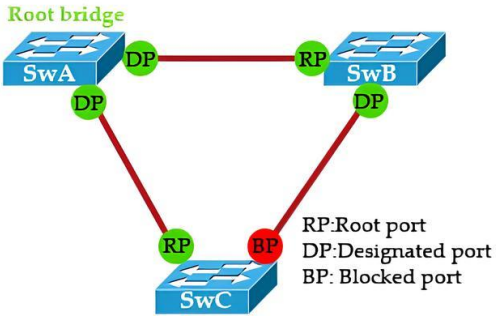
CPU Overload and Potential Switch Failure

- Constantly updating MAC address tables and processing endless broadcast frames consumes high CPU resources.
- In worst cases, the switch CPU may **crash or fail**, causing a complete network outage.

This is why **Spanning Tree Protocol (STP)** was introduced

Rapid Spanning-Tree

- Introduced in 2001 as **IEEE 802.1w** standard.
- Later incorporated into **IEEE 802.1D** in 2004.
- Commonly referred to as CST (Common Spanning Tree).
- **Prevents bridging loops** by logically blocking redundant links.
- Certain switch ports are placed into a **blocking (discarding) state**:



    - No user data can **enter or leave** through these ports.
    - The port still listens for **BPDUs** to detect topology changes.
    - Ensures that only **one active forwarding** path exists, while backup paths remain unused unless the primary fails.
- **Drawback:** No redundancy for traffic under normal conditions—only one path is active at a time.
- **Improvement over classic STP:** RSTP converges in just a few seconds, compared to 30–50 seconds with legacy STP.

How RSTP Works

- **Elect one Root Bridge** (the central reference switch in the topology).
- **Elect one Root Port** on every non-root switch (the port with the best path to the root bridge).
- **Elect Designated Ports** on each network segment (the port responsible for forwarding traffic toward that segment).
- **Block Non-Designated Ports** (these ports enter the discarding state to prevent loops).

Root Bridge

- The **Root Bridge** acts as the logical center of the spanning-tree topology.
- Every switch in the network **sends Bridge Protocol Data Units (BPDUs)** to announce itself as a candidate for the root bridge.
- The switch with the **lowest Bridge ID (BID)** becomes the Root Bridge.

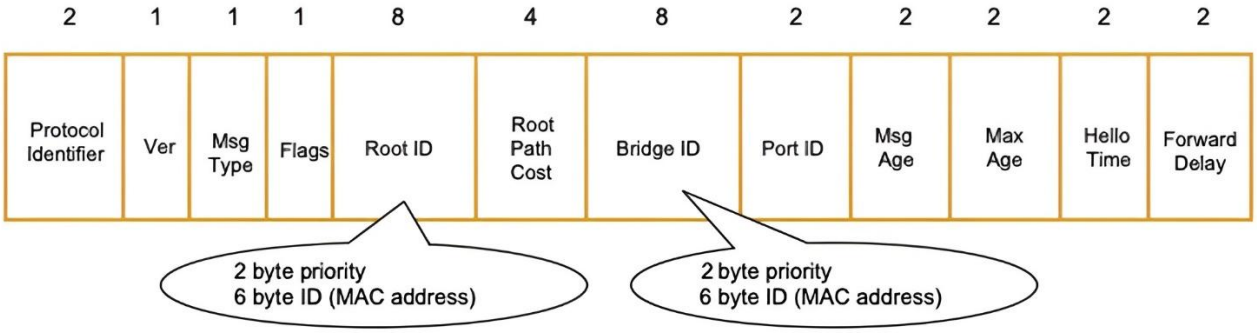
Bridge ID (BID)

- The **Bridge ID** is carried in the BPDU and is used to compare switches during the election. It is made up of:
- **Bridge Priority**
- Range: **0 – 61440**, in increments of **4096 only**.
- You **cannot configure** an arbitrary value (e.g., 1234) — it must be one of the allowed increments.
- **System ID Extension**
- Usually represents the **VLAN ID** (0–4095).
- This is a **12-bit field** in the 16-bit Bridge Priority value.
- **MAC Address**

- If two switches have the same priority and system ID, the switch with the **lowest MAC address** wins.

Important Note:

- The **Bridge Priority field** in the BPDU is 16 bits:
- **4 bits** → Configurable Bridge Priority (increments of 4096).
- **12 bits** → System ID Extension (VLAN ID).
- Example: If the **priority = 4096** and **VLAN ID = 4**, then:
- BID = **4096 + 4 = 4100 + MAC Address**.
- Thus, the switch with the **lowest BID** becomes the Root Bridge.
- In BPDUs:
- **Bridge ID** = the switch's own ID.
- **Root ID** = the Bridge ID of the current Root Bridge.



RSTP Port Roles

- **Root Port (RP):**
  - The port on a non-root switch with the **best path cost** to reach the Root Bridge.
  - Only **one Root Port per switch** (except the Root Bridge itself).
- **Designated Port (DP):**
  - The port on a LAN segment that is responsible for forwarding traffic **toward that segment**.
  - Each segment has **one Designated Port**.
  - All the ports on Root Bridge are **Designated Ports**.
- **Non-Designated Ports:**
  - Ports that are neither Root nor Designated.
  - Placed into **Discarding (Blocking) state** to prevent loops.
- **Edge Port:**
  - A port connected directly to an **end device (like a PC)**, not to another switch.

- **Alternate Port:**
  - Provides a **backup path** to the Root Bridge in case the Root Port fails.
  - Normally in **discarding state** until needed.
- **Backup Port:**
  - A redundant port on the **same switch** and **same segment** as a Designated Port.
  - Also in **discarding state** unless the Designated Port fails.

Essential RSTP Commands

1. Enabling Rapid-PVST Mode

- Command:

  spanning-tree mode rapid-pvst

- This enables **Rapid-PVST+**, where each VLAN runs its own spanning tree instance (independent root bridge election, forwarding/blocking states, etc.).

2. Configuring PortFast (for Edge Ports)

- Used for **end devices** (PCs, servers, printers), not for switch-to-switch links.
- On an individual interface:

  spanning-tree portfast

- To enable PortFast globally on all **access ports**:

  spanning-tree portfast default

- Never use PortFast on trunk or uplink ports (can cause loops).

3. Root Bridge Election & Priority

Default priority = 32768 (per VLAN).

- If priorities are equal across switches, the **lowest MAC address** becomes root bridge.
- This often results in the **oldest switch** with the smallest MAC becoming root, which may not be desirable.

4. Configuring the Root Bridge

Option 1: Make a switch the primary root bridge

spanning-tree vlan <vlan-id> root primary

- This automatically lowers the switch priority to as low as **4096**.
- Works if no other switch has lower priority.

Option 2: Explicitly set the priority

spanning-tree vlan <vlan-id> priority <value>

- Priority must be a multiple of **4096** (0, 4096, 8192, 12288, … up to 61440).
- To guarantee root bridge status, use:

spanning-tree vlan <vlan-id> priority 0

- Example:
  - If another switch already has **priority 4096** and a lower MAC address, *root primary* will not override it. In that case, you must explicitly set your desired switch to **priority 0**.

5. Verification Commands

- Show root bridge per VLAN:

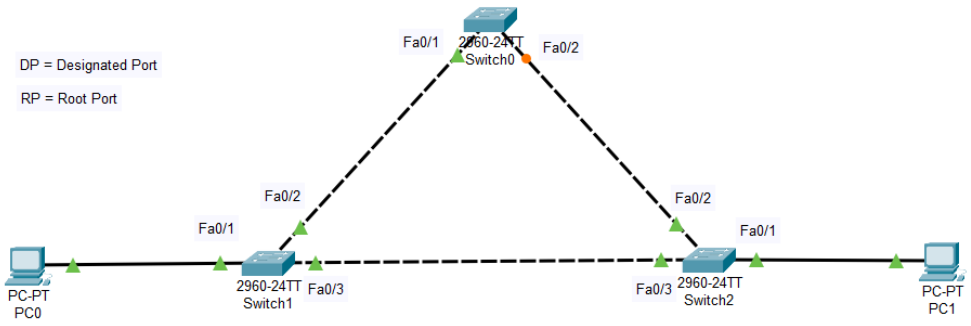
show spanning-tree root

- Show spanning tree details for a VLAN:

show spanning-tree vlan <vlan-id>

- Show summary info:

show spanning-tree summary



Switch1

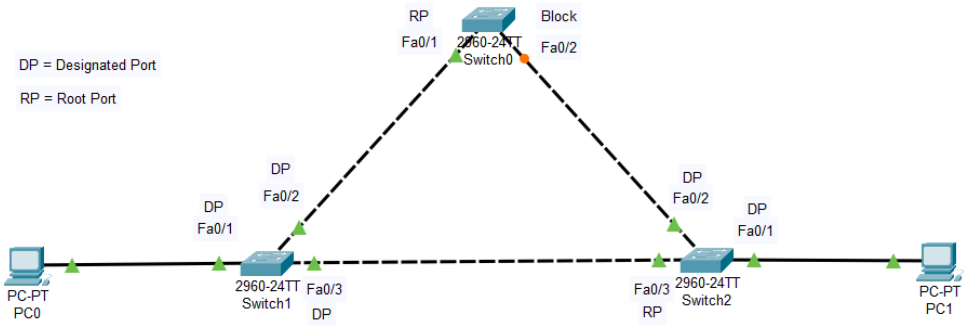
```
Switch>en
Switch#show spanning-tree vlan 1
VLAN0001
  Spanning tree enabled protocol ieee
  Root ID     Priority    32769
              Address     0001.96C7.2203
              This bridge is the root
              Hello Time  2 sec  Max Age 20 sec  Forward Delay 15 sec

  Bridge ID   Priority    32769  (priority 32768 sys-id-ext 1)
              Address     0001.96C7.2203
              Hello Time  2 sec  Max Age 20 sec  Forward Delay 15 sec
              Aging Time  20

Interface        Role Sts Cost      Prio.Nbr Type
---------------- ---- --- --------- -------- --------------------------------
Fa0/2            Desg FWD 19        128.2    P2p
Fa0/3            Desg FWD 19        128.3    P2p
Fa0/1            Desg FWD 19        128.1    P2p
```

Switch2

```
Switch#show spanning-tree vlan 1
VLAN0001
  Spanning tree enabled protocol ieee
  Root ID     Priority    32769
              Address     0001.96C7.2203
              Cost        19
              Port        3(FastEthernet0/3)
              Hello Time  2 sec  Max Age 20 sec  Forward Delay 15 sec

  Bridge ID   Priority    32769  (priority 32768 sys-id-ext 1)
              Address     0002.1781.128C
              Hello Time  2 sec  Max Age 20 sec  Forward Delay 15 sec
              Aging Time  20

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

Switch0

```
Switch>en
Switch#show spanning-tree vlan 1
VLAN0001
  Spanning tree enabled protocol ieee
  Root ID     Priority    32769
              Address     0001.96C7.2203
              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     0009.7C21.2462
              Hello Time  2 sec  Max Age 20 sec  Forward Delay 15 sec
              Aging Time  20

Interface        Role Sts Cost      Prio.Nbr Type
---------------- ---- --- --------- -------- --------------------------------
Fa0/1            Root FWD 19        128.1    P2p
Fa0/2            Altn BLK 19        128.2    P2p
```



Let's make Switch0 as Root bridge and enable portfast on interface fa0/1 on switch1 and switch2

Switch0

```
Switch#conf t
Enter configuration commands, one per line.  End with CNTL/Z.
Switch(config)#spanning-tree mode rapid-pvst
Switch(config)#spanning-tree vlan 1 priority 0
Switch(config)#end
Switch#
%SYS-5-CONFIG_I: Configured from console by console

Switch#show spanning-tree vlan 1
VLAN0001
  Spanning tree enabled protocol rstp
  Root ID     Priority    1
              Address     0009.7C21.2462
              This bridge is the root
              Hello Time  2 sec  Max Age 20 sec  Forward Delay 15 sec

  Bridge ID   Priority    1  (priority 0 sys-id-ext 1)
              Address     0009.7C21.2462
              Hello Time  2 sec  Max Age 20 sec  Forward Delay 15 sec
              Aging Time  20

Interface        Role Sts Cost      Prio.Nbr Type
---------------- ---- --- --------- -------- --------------------------------
Fa0/1            Desg FWD 19        128.1    P2p
Fa0/2            Desg FWD 19        128.2    P2p
```

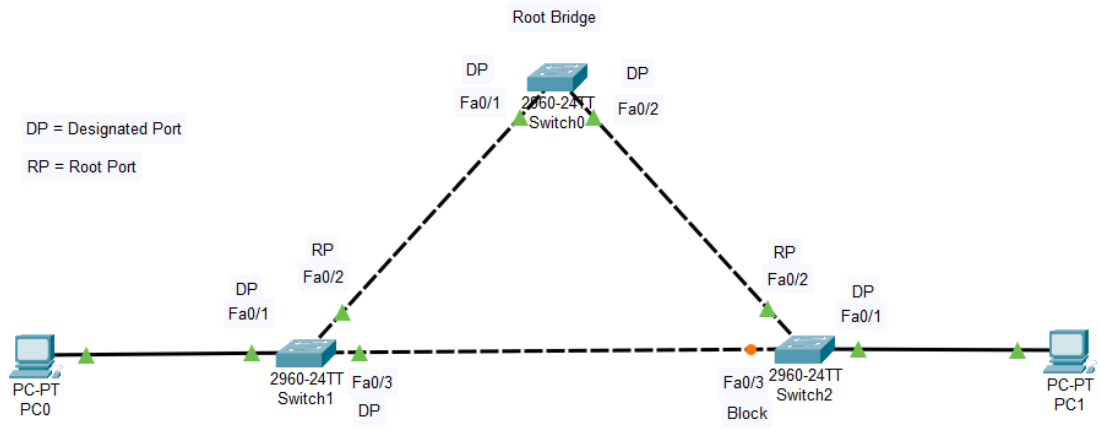
Switch1

```
Switch#conf t
Enter configuration commands, one per line.  End with CNTL/Z.
Switch(config)#spanning-tree mode rapid-pvst
Switch(config)#int fa0/1
Switch(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 FastEthernet0/1 but will only
have effect when the interface is in a non-trunking mode.
Switch(config-if)#end
Switch#
%SYS-5-CONFIG_I: Configured from console by console

Switch#show spanning-tree vlan 1
VLAN0001
  Spanning tree enabled protocol rstp
  Root ID    Priority    1
             Address     0009.7C21.2462
             Cost        19
             Port        2(FastEthernet0/2)
             Hello Time  2 sec  Max Age 20 sec  Forward Delay 15 sec

  Bridge ID  Priority    32769  (priority 32768 sys-id-ext 1)
             Address     0001.96C7.2203
             Hello Time  2 sec  Max Age 20 sec  Forward Delay 15 sec
             Aging Time  20

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

Switch#show spanning-tree interface fa0/1 detail


Port 1 (FastEthernet0/1) of VLAN0001 is designated forwarding
  Port path cost 19, Port priority 128, Port Identifier 128.1
  Designated root has priority 1, address 0009.7C21.2462
  Designated bridge has priority 32769, address 0001.96C7.2203
  Designated port id is 128.1, designated path cost 19
  Timers: message age 16, forward delay 0, hold 0
  Number of transitions to forwarding state: 1
  The port is in the portfast mode
  Link type is point-to-point by default
Switch#
```

Switch2

```
Switch#conf t
Enter configuration commands, one per line.  End with CNTL/Z.
Switch(config)#spanning-tree mode rapid-pvst
Switch(config)#int fa0/1
Switch(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 FastEthernet0/1 but will only
have effect when the interface is in a non-trunking mode.
Switch(config-if)#end
Switch#
%SYS-5-CONFIG_I: Configured from console by console
```

```
Switch#show spanning-tree vlan 1
VLAN0001
  Spanning tree enabled protocol rstp
  Root ID     Priority    1
              Address     0009.7C21.2462
              Cost        19
              Port        2(FastEthernet0/2)
              Hello Time  2 sec  Max Age 20 sec  Forward Delay 15 sec

  Bridge ID   Priority    32769  (priority 32768 sys-id-ext 1)
              Address     0002.1781.128C
              Hello Time  2 sec  Max Age 20 sec  Forward Delay 15 sec
              Aging Time  20

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

Switch#show spanning-tree int fa0/1 deta


Port 1 (FastEthernet0/1) of VLAN0001 is designated forwarding
  Port path cost 19, Port priority 128, Port Identifier 128.1
  Designated root has priority 1, address 0009.7C21.2462
  Designated bridge has priority 32769, address 0002.1781.128C
  Designated port id is 128.1, designated path cost 19
  Timers: message age 16, forward delay 0, hold 0
  Number of transitions to forwarding state: 1
  The port is in the portfast mode
  Link type is point-to-point by default
```



Root Port (RP) in Spanning Tree

Definition

- The **Root Port (RP)** is the port on a non-root switch that is **upstream-facing toward the Root Bridge**.
- It represents the **best path** from that switch to reach the Root Bridge.

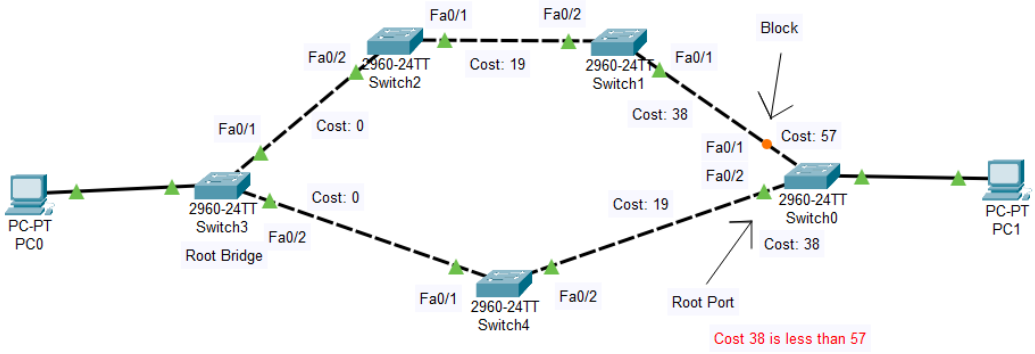
- Each **non-root switch** has exactly **one Root Port** (except the Root Bridge itself, which has none).

Election of the Root Port

The Root Port is chosen based on the following rules:

1. Lowest Root Path Cost

- The path with the **lowest cumulative cost** (sum of link costs) to reach the Root Bridge is preferred.
- **Example:**
  - Switch A → Root Bridge: **cost 19**
  - Switch A → Switch B → Root Bridge: **cost 38**
  - Root Port = link directly to Root Bridge (cost 19).



2. Cost Calculation (Based on Bandwidth)

- **Higher bandwidth = lower cost**.
- Example IEEE 802.1D standard costs:
  - 10 Mbps = 100
  - 100 Mbps = 19
  - 1 Gbps = 4
  - 10 Gbps = 2
  - **Example:**
    - A 100 Mbps link → cost = 19
    - A 1 Gbps link → cost = 4
    - Switch will choose the **1 Gbps link** as Root Port.
- **Not Linear**
  - If cost of 100 Mbps = 19, it **does not mean** 1 Gbps (10x faster) will have cost = 1.9.
  - Instead, the standard defines **discrete values** (e.g., 1 Gbps = 4, not 1.9).

Parameter	Link Speed	Recommended value	Recommended range	Range
Path Cost	4 Mb/s	250	100–1000	1–65 535
Path Cost	10 Mb/s	100	50–600	1–65 535
Path Cost	16 Mb/s	62	40–400	1–65 535
Path Cost	100 Mb/s	19	10–60	1–65 535
Path Cost	1 Gb/s	4	3–10	1–65 535
Path Cost	10 Gb/s	2	1–5	1–65 535

3. Tie-Breaking Rules

If multiple ports have the same Root Path Cost:

Lowest Upstream Bridge ID (BID)

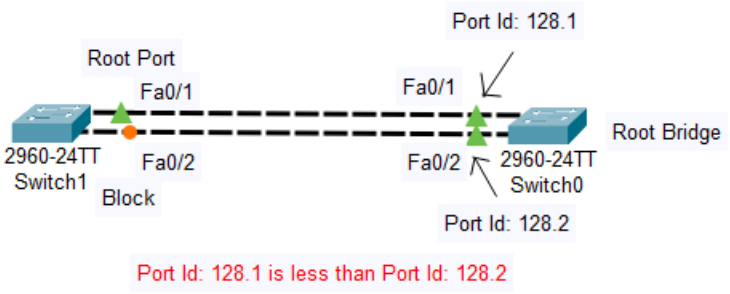
- The switch prefers the port connected to the **neighbor switch** with the lowest BID.
- BID = Bridge Priority + MAC address.

Lowest Upstream Port ID (if BIDs are also equal)

- If both paths go through the **same upstream switch**, the tie is broken using **Port ID**.

Port ID Structure

- Port ID = **Port Priority (default 128)** + **Port Number**.
- Example:
  - Port Fa0/1 → Port ID = 128.1
  - Port Fa0/2 → Port ID = 128.2
- If two ports on the same switch lead to the Root Bridge with equal cost, the **lower Port ID wins**.
  In this case, **Fa0/1 (128.1)** would be chosen as the Root Port.



Designated Ports (DP) in Spanning Tree

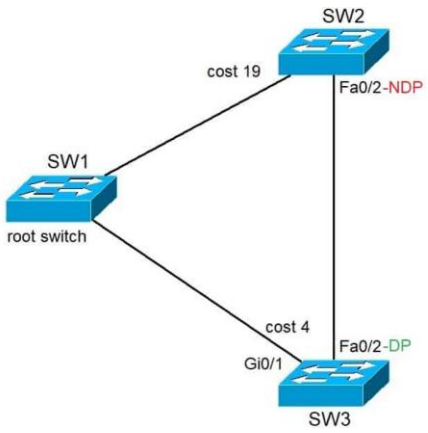
Definition

- A **Designated Port (DP)** is the **downstream-facing port, away from the Root Bridge**, that is selected to **forward traffic toward the Root Bridge** for a given network segment (collision domain).
- On every **link/segment**, there is always **one Designated Port** (the one that provides the best path to the Root Bridge).
- The DP is the **forwarding port** on the segment, while other ports on the same segment go into **blocking/discarding** state.

Election of the Designated Port

Like Root Port selection, the Designated Port is elected based on:

- **Lowest Root Path Cost**
  - The switch port on the segment that has the **lowest cumulative cost to the Root Bridge** becomes the DP.
- **Lowest Bridge ID (BID)**
  - If two switches have the **same path cost** to the Root Bridge, the one with the **lower BID** wins, and its port becomes the DP.
- **Lowest Port ID**
  - If both switches have the **same Root Path Cost** *and* the same BID (i.e., ports are on the same switch), then the port with the **lowest Port ID** becomes the Designated Port.



Non-Designated Ports in RSTP

Definition

- **Non-Designated Ports** are ports that are **neither Root Ports (RP) nor Designated Ports (DP)**.
- These ports do **not forward traffic**; their role is always **Discarding** (blocking state in STP).
- They provide redundancy: ready to take over if the active path fails.

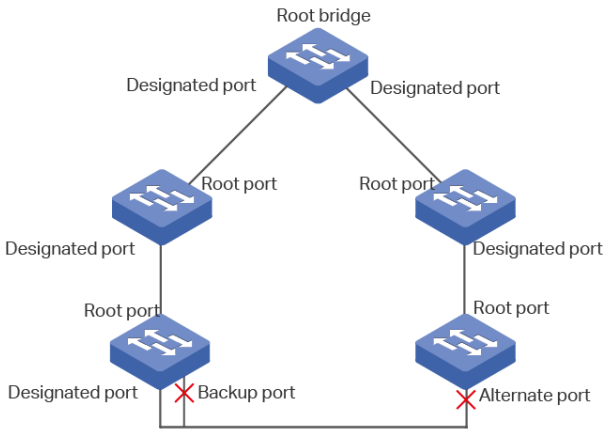
Types of Non-Designated Ports

1. Alternate Port

- An **alternate path** to the Root Bridge.
- Receives a **superior BPDU** on a non-root port.
- The superior BPDU comes from a **different switch (different Bridge-ID)**.
- If the current Root Port fails, the Alternate Port can quickly transition to become the new Root Port.

Example:

- Switch has two uplinks toward the Root Bridge.
- One link is elected as the Root Port.
- The other becomes an **Alternate Port**, sitting in discarding state but ready as backup.



2. Backup Port

- A **backup path** to the same Designated Port on the same switch.
- Receives a **superior BPDU** on a non-root port.
- This BPDU comes from the **same switch (same Bridge-ID)**.
- Backup Ports are usually seen when multiple ports of the same switch connect to the same shared segment (e.g., a hub).

Example:

- Two ports of the same switch connect into the same collision domain.
- One port becomes Designated, the other becomes a **Backup Port** in discarding state.

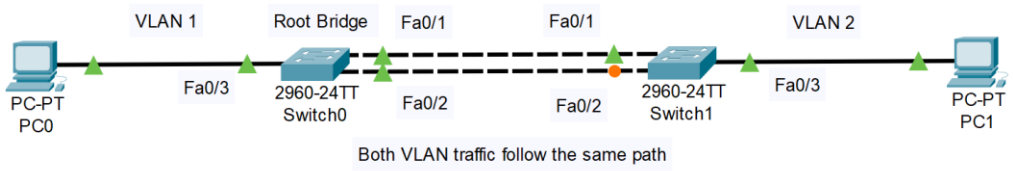
Load Balancing with Rapid-PVST

1. Multiple VLANs and Trunks

- In many switched topologies, there are **multiple VLANs**.
- Typically, **all VLANs are allowed on trunk links** between switches.
- **Rapid-PVST+** creates a **separate RSTP instance for each VLAN**.

2. Problem

- By default, all VLANs may **elect the same Root Bridge**.
- This causes **all VLAN traffic to follow the same path**, which can lead to **congested links**.



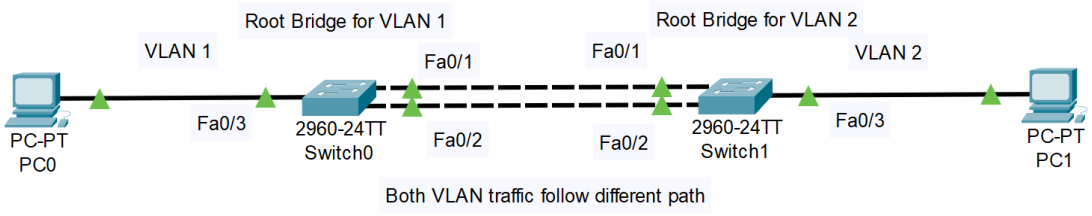
3. Solution: Load Balancing by Root Bridge Manipulation

We can manually influence the **Spanning-Tree topology per VLAN** so different VLANs use different paths:

Method 1: Change Root Bridge

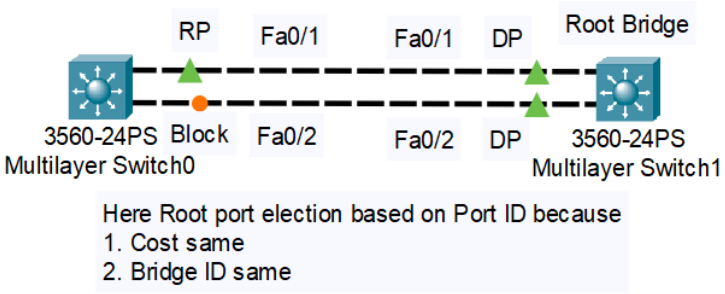
- Set different switches as Root Bridge for different VLANs.
- Example:

  spanning-tree vlan 1 priority 0 Make Switch 0 Root for VLAN 1
  spanning-tree vlan 2 priority 0 Make Switch 1 Root for VLAN 2
- This ensures VLAN 1 and VLAN 2 take **different paths**.

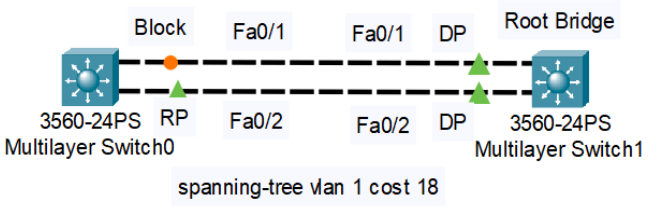


Method 2: Adjust Port Cost

- If we want a **blocked port to become the Root Port**, we can **lower its path cost**.
- Example:
  spanning-tree vlan 1 cost 18
- If the default was **19**, lowering to **18** will make this port more favorable.
- **Caution:** This changes the cost calculation for **all connected devices on that link**, not just one switch.



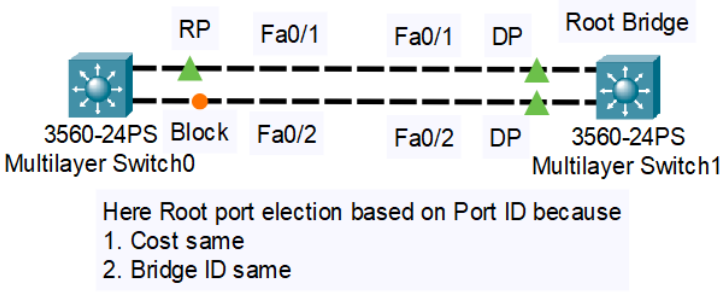
To (Switch0)



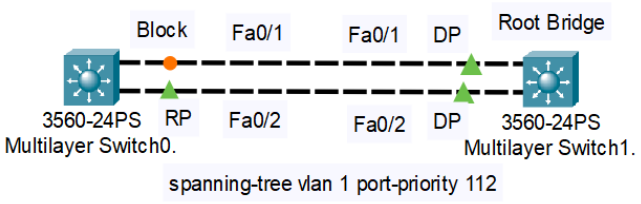

```
Switch#conf t
Enter configuration commands, one per line.  End with CNTL/Z.
Switch(config)#int fa0/2
Switch(config-if)#s
Switch(config-if)#sp
Switch(config-if)#span
Switch(config-if)#spanning-tree v
Switch(config-if)#spanning-tree vlan 1
Switch(config-if)#spanning-tree vlan 1 c
Switch(config-if)#spanning-tree vlan 1 cost 18
```

Method 3: Adjust Port Priority (Port ID)

- Another way is to lower the **port priority** so it wins during the tie-breaker.
- Example:
  spanning-tree vlan 1 port-priority 112



To (Switch1)




```
Switch(config)#int fa0/2
Switch(config-if)#spa
Switch(config-if)#spanning-tree v
Switch(config-if)#spanning-tree vlan 1
Switch(config-if)#spanning-tree vlan 1 p
Switch(config-if)#spanning-tree vlan 1 port-priority 112
Switch(config-if)#
```

Why 112?

- Port ID = **Port Priority (4 bits)** + **Port Number (12 bits)**.
- Port Priority values must be in increments of **16** (0, 16, 32 … 240).
- Default = **128**. Lowering to **112** makes this port preferred in case of a tie.

RSTP Synchronization Process

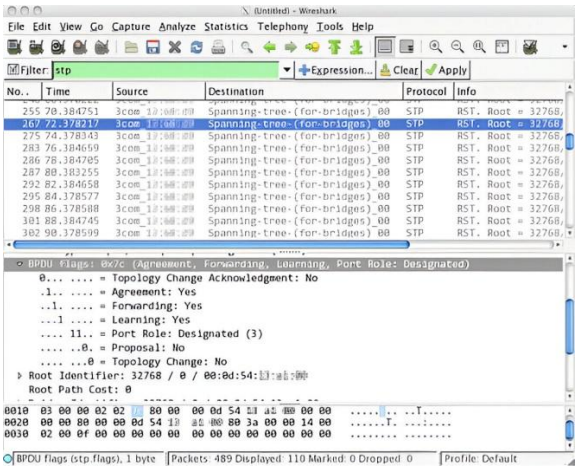
1. Goal

- The main goal of **RSTP (Rapid Spanning Tree Protocol)** is to **synchronize a new port with the existing topology as quickly as possible**.
- Unlike legacy STP (802.1D), which can take **30–50 seconds** (Listening + Learning), RSTP converges in **a few milliseconds to a couple of seconds**.

2. New BPDU Flags

RSTP introduces two new flags in the BPDU:

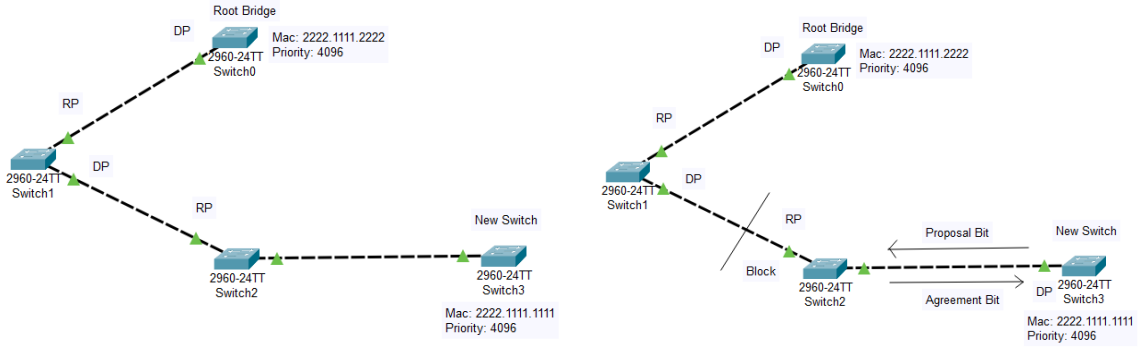
- **Proposal**
- **Agreement**
  - These are only used on **point-to-point links** (normally full-duplex).
  - On **shared links** (half-duplex), RSTP falls back to **classic STP behavior**.

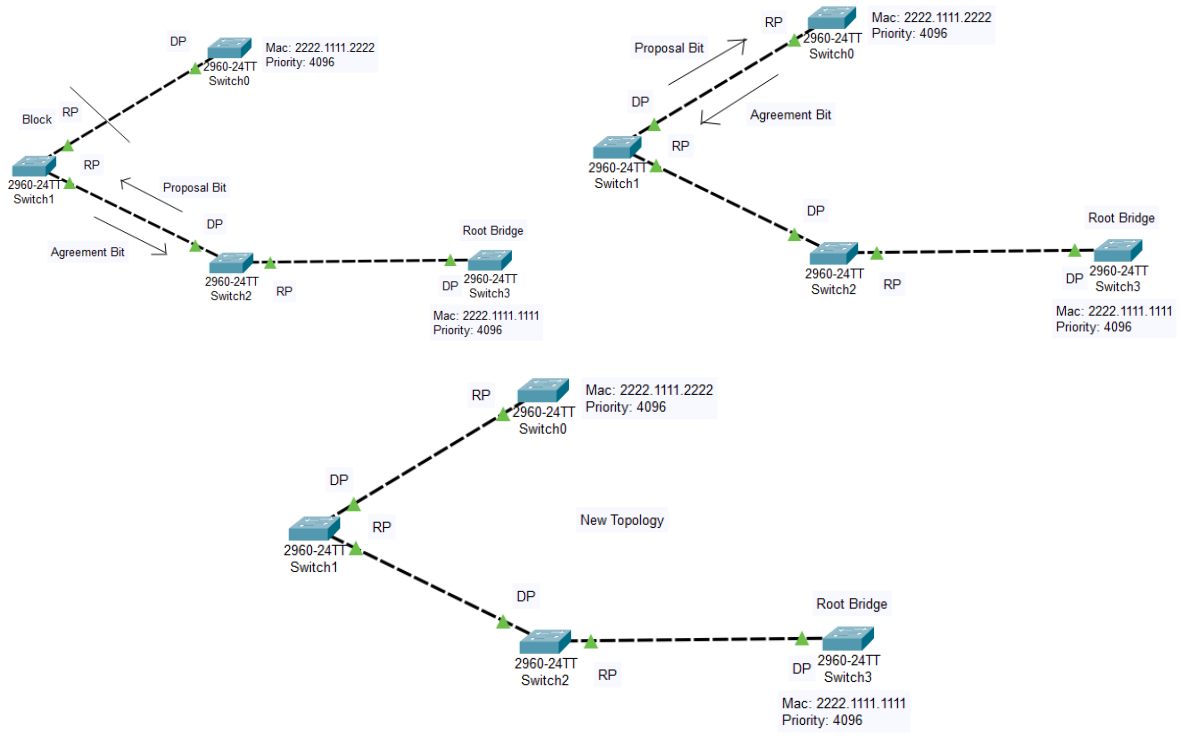


3. How Proposal–Agreement Works (Simple Flow)

When a **new connection** is made between two switches:

- **Proposal**
  - One switch sends a **Proposal BPDU**.
  - If the Proposal is from a **new switch** → it carries **its own BID**.
  - If the Proposal is from an **already connected switch** → it carries the **Root Bridge BID** it already knows.
- **Comparison of BIDs**
  - If the **new switch's BID is lower** → it becomes the **Root Bridge**. The other switch then sends an **Agreement** back.
  - If the **new switch's BID is higher** → the existing Root Bridge remains.
    The new switch sends an **Agreement** back.
- **Result**
  - After the Proposal–Agreement exchange, ports move **immediately to Forwarding**.
  - Convergence happens **very fast** (no 30-second delay like classic STP).





4. Faster Root Port (RP) Selection in RSTP

In **legacy STP**:

- If the Root Port fails, a backup port becomes the new RP.
- But it must go through **Listening (15 sec) + Learning (15 sec) → 30 seconds total** before forwarding.

In **RSTP**:

- Alternate or Backup ports can take over **immediately** when the RP fails.
- No need for 30 seconds of waiting.

RSTP Timers

Hello Timer

- **Purpose:** Controls the frequency of **BPDU generation**.
- **Default: 2 seconds**.
- **Configurable:** Can only be changed on the **Root Bridge** (all other bridges inherit this value).

- **STP (802.1D):** Only the **Root Bridge** generates BPDUs every Hello Time, others forward them.
- **RSTP (802.1w):** Every **switch** generates BPDUs as **keepalives**, not just the Root.
- **Command:**

  Switch(config)# spanning-tree vlan <vlan-id> hello-time <1-10>

Forwarding Delay

- **Purpose:** Controls transition delay for **non-edge ports**.
- **Default: 15 seconds**.
- **Range: 4–30 seconds**.
- **STP (802.1D):**
  A non-edge port must go through:
  Listening (15s) + **Learning (15s)** = **30 seconds** total.
  Used to prevent temporary loops.
- **RSTP (802.1w):**
  Edge (PortFast) ports: Skip delays → move **immediately to forwarding**.
  Non-edge ports: Forwarding Delay only applies on **half-duplex/shared links** (since RSTP falls back to STP behavior there).
- **Command:**

  Switch(config)# spanning-tree vlan <vlan-id> forward-time <4-30>

Max Age Timer

- **Default: 20 seconds** (range 6–40 seconds).
- **STP (802.1D):**
  BPDUs are generated only by the **Root Bridge** and relayed by Designated Ports.
  If a switch does not receive a BPDU from the Root within **Max Age (20s)**, it assumes the path to the Root has failed.
- **RSTP (802.1w):**
  Not actively used as a timer.
  Every Designated Port generates its own BPDUs (keepalives).
  Instead of waiting **20 seconds**, RSTP considers a port lost after **3 missed BPDUs (≈ 6 seconds by default)** → much faster failure detection.
- **Command:**

  Switch(config)# spanning-tree vlan <vlan-id> max-age <6-40>

Message Age

- **Purpose:** Works like a **hop count** for BPDUs.
- **Operation:**
  Starts at **0** at the Root Bridge.
  Incremented by **1** each time the BPDU passes through a bridge.
  Prevents loops where BPDUs could circulate endlessly.
- **Discard rule:**
  If a switch receives a BPDU where **Message Age = Max Age**, that BPDU is **discarded**.

Topology Change BPDUs (TC-BPDUs) in RSTP

STP (802.1D – Classic)

When Generated:

- A switch generates a **Topology Change Notification (TCN BPDU)** whenever a port changes state (e.g., **forwarding → blocking**, **blocking → forwarding**, or port goes **down**).

Process:

- The switch experiencing the change sends **TCN BPDUs** toward the Root Bridge (on its Root Port).
- Each upstream switch acknowledges and forwards the TCN until it reaches the **Root Bridge**.
- The Root Bridge then sends out **TC flags** in its **configuration BPDUs** to notify the entire topology.

Drawback:

- **Slow propagation** → notification must travel all the way to the Root and then back out.
- Causes **long convergence times (30–50s)**.

RSTP (802.1w – Rapid)

When Generated:

- A **TC BPDU** is generated **immediately** when a **non-edge port** transitions **to Forwarding state**.

Who Sends It:

- The switch that detects the change (the **initiator**), not just the Root Bridge.

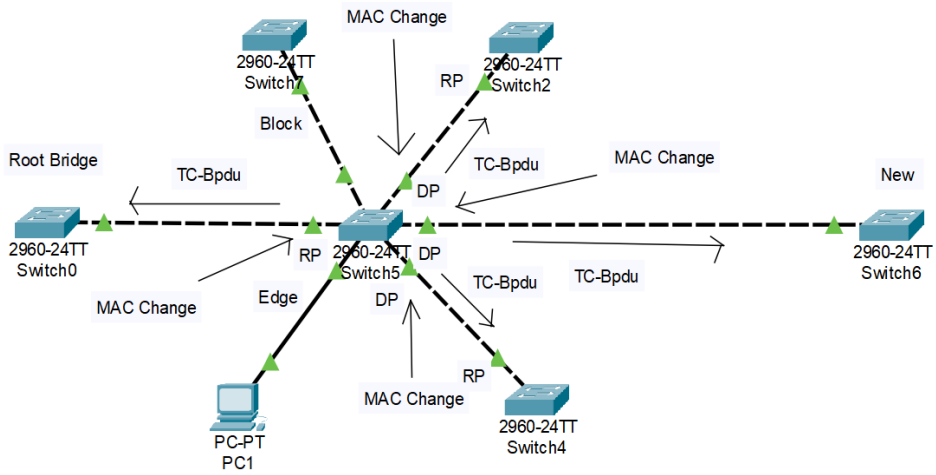
Where Sent:

- On **all Root Ports**.

- On **all Designated Ports that are non-edge**.

Effect:

- Causes **MAC address table flushing** to speed up reconvergence.



MAC Address Flushing in RSTP

Why Flush?

- When a port goes into Forwarding, the path to certain MAC addresses may have **changed**.
- If old MAC entries remain, traffic could be forwarded to the **wrong port**, causing loops or blackholes.

What Gets Flushed:

- **Most MAC entries** are flushed immediately.

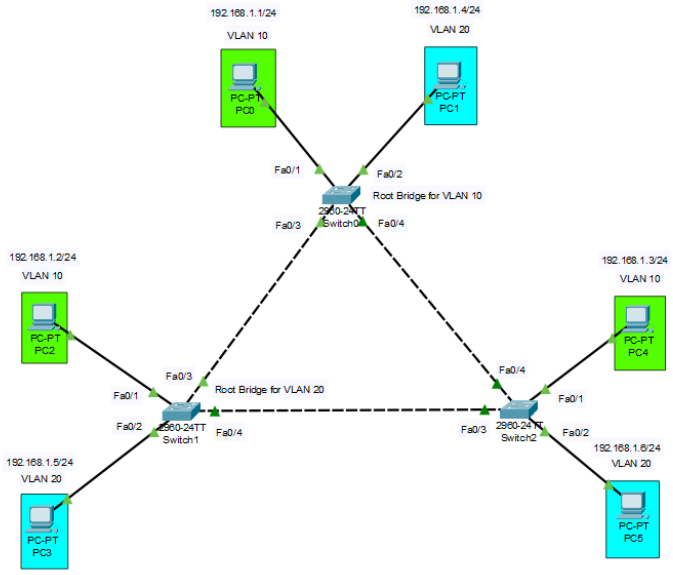
What Does NOT Get Flushed:

- **Edge Ports (PortFast)** → unaffected (end-host connections).
- **MACs on ports receiving the TC-BPDU** → not flushed (since they are still valid).

What IS Flushed:

- **MACs learned on ports that sent the TC-BPDU** → cleared, because connectivity behind that port has changed.

Small Network (Cisco Packet Tracer)



VLAN Configuration

On each Switch:

```
Switch>en
Switch#conf t
Enter configuration commands, one per line.  End with CNTL/Z.
Switch(config)#vlan 10
Switch(config-vlan)#vlan 20
Switch(config-vlan)#int fa0/1
Switch(config-if)#switchport mode access
Switch(config-if)#switchport access vlan 10
Switch(config-if)#int fa0/2
Switch(config-if)#switchport mode access
Switch(config-if)#switchport access vlan 20
```

Configure Trunk Port between Switches and Disable Auto negotiation

On each Switch:

```
Switch(config)#int range fa0/3-4
Switch(config-if-range)#switchport mode trunk
Switch(config-if-range)#switchport nonegotiate
Switch(config-if-range)#
```

Enabling Rapid-pvst mode

On each Switch:

```
Switch#CONF T
Enter configuration commands, one per line.  End with CNTL/Z.
Switch(config)#!
Switch(config)#spanning-tree mode rapid-pvst
Switch(config)#
```

Enable Portfast

On each Switch: (int range fa0/1-2)

```
Switch(config-if-range)#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
```

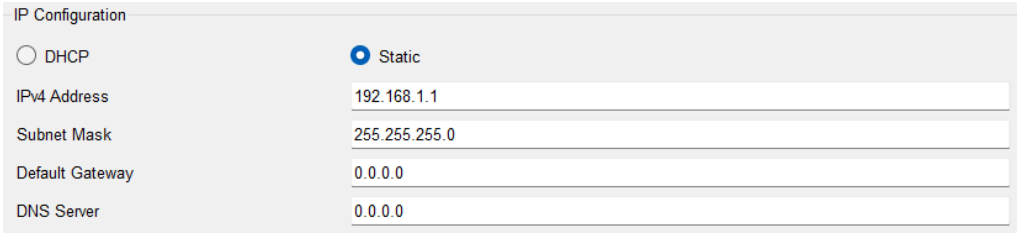
Making Switch0, The Root Bridge for VLAN 10

```
Switch#conf t
Enter configuration commands, one per line.  End with CNTL/Z.
Switch(config)#spanning-tree vlan 10 priority 0
Switch(config)#end
Switch#
%SYS-5-CONFIG_I: Configured from console by console

Switch#show span
Switch#show spanning-tree v
Switch#show spanning-tree vlan 10
VLAN0010
  Spanning tree enabled protocol rstp
  Root ID     Priority    10
              Address     0060.3E99.55DE
              This bridge is the root
              Hello Time  2 sec  Max Age 20 sec  Forward Delay 15 sec

  Bridge ID   Priority    10  (priority 0 sys-id-ext 10)
              Address     0060.3E99.55DE
              Hello Time  2 sec  Max Age 20 sec  Forward Delay 15 sec
              Aging Time  20

Interface        Role Sts Cost      Prio.Nbr Type
---------------- ---- --- --------- -------- --------------------------------
Fa0/1            Desg FWD 19        128.1    P2p
Fa0/4            Desg FWD 19        128.4    P2p
Fa0/3            Desg FWD 19        128.3    P2p
```

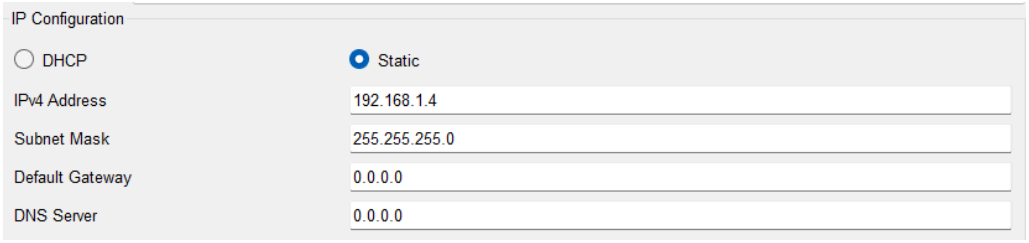
Making Switch1, The Root Bridge for VLAN 20

```
Switch#conf t
Enter configuration commands, one per line.  End with CNTL/Z.
Switch(config)#spanning-tree vlan 20 priority 0
Switch(config)#end
Switch#
%SYS-5-CONFIG_I: Configured from console by console
show spanning-tree vlan 29

No spanning tree instance exists.

Switch#show spanning-tree vlan 20
VLAN0020
  Spanning tree enabled protocol rstp
  Root ID     Priority    20
              Address     0060.474D.A326
              This bridge is the root
              Hello Time  2 sec  Max Age 20 sec  Forward Delay 15 sec

  Bridge ID   Priority    20  (priority 0 sys-id-ext 20)
              Address     0060.474D.A326
              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
Fa0/2            Desg FWD 19        128.2    P2p
Fa0/3            Desg FWD 19        128.3    P2p
```

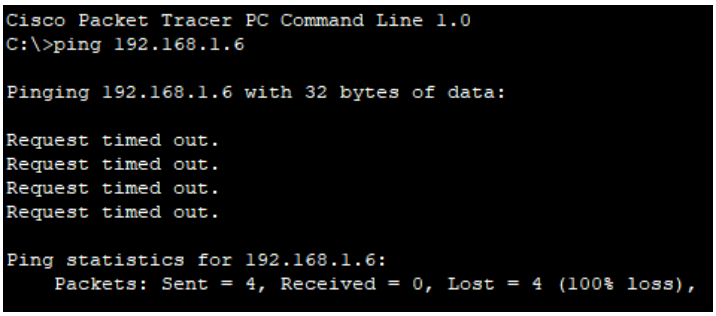
Assigning IPs to PCs
PC1:



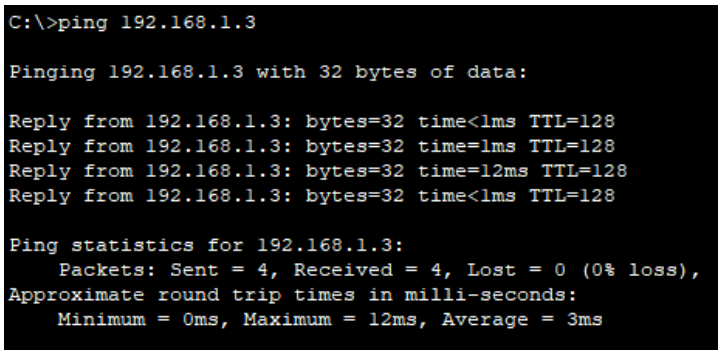
PC4:



Pinging (From PC0 to PC5) (Different VLAN)



Pinging (From PC0 to PC4)



Pinging (From PC3 to PC1)

```
C:\>ping 192.168.1.4

Pinging 192.168.1.4 with 32 bytes of data:

Reply from 192.168.1.4: bytes=32 time<1ms TTL=128
Reply from 192.168.1.4: bytes=32 time<1ms TTL=128
Reply from 192.168.1.4: bytes=32 time<1ms TTL=128
Reply from 192.168.1.4: bytes=32 time<1ms TTL=128

Ping statistics for 192.168.1.4:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 0ms, Maximum = 0ms, Average = 0ms
```

EtherChannel

Why EtherChannel?

- In **RSTP/STP**, if multiple physical links exist between switches, only **one link is active**, while the others are **blocked** to prevent loops.
- This creates **bottlenecks** and underutilization of available links.
- **EtherChannel solves this problem** by bundling multiple physical links into **one logical link (channel)**.

Benefits of EtherChannel

- **Aggregated Bandwidth:** Multiple links combined into one high-capacity link.
- **Load Balancing:** Distributes traffic across member links using algorithms (e.g., based on source MAC, destination MAC, IP, or port).
- **Redundancy:** If one link fails, traffic continues over the remaining links in the bundle.
- **STP Friendly:** STP sees the entire bundle as **one logical link**, preventing blocking of extra links.
- **Scalability:** Up to **8 ports** can be bundled together.

Requirements

All bundled ports must have:

- Same **speed**.
- Same **duplex mode**.
- Same **VLAN membership** (if trunking).
- Same **switchport mode** (access/trunk).

EtherChannel Protocols

1. PAgP (Port Aggregation Protocol) – *Cisco Proprietary*
Modes:

- **On:** No negotiation, forces EtherChannel.
- **Desirable:** Actively sends PAgP messages to form a channel.
- **Auto:** Passively waits/listens for PAgP messages (does not initiate).

Note: EtherChannel forms if **one side is Desirable and the other is Auto/Desirable**.

2. LACP (Link Aggregation Control Protocol) – *IEEE 802.3ad Standard*
Modes:

- **On:** No negotiation, forces EtherChannel.
- **Active:** Actively sends LACP messages to initiate bundling.
- **Passive:** Waits for LACP requests, does not initiate.

Note: EtherChannel forms if **one side is Active and the other is Active/Passive**.

Configuration Commands

- Enter the interface range:

Switch(config)# interface range fa0/1 - 4

- Assign the interfaces to an EtherChannel:

Switch(config-if-range)# channel-group <number> mode <mode>

<number> = EtherChannel group (1–6 typical).
<mode> = on | auto | desirable | active | passive.

- Verify:

Switch# show etherchannel summary

Switch0

```
Switch>EN
Switch#CONF T
Enter configuration commands, one per line.  End with CNTL/Z.
Switch(config)#int range fa0/1-3
Switch(config-if-range)#channel-group 1 mode desirable
Switch(config-if-range)#int pol
Switch(config-if)#switchport mode trunk
Switch(config-if)#end
```

Switch1

```
Switch>EN
Switch#CONF T
Enter configuration commands, one per line.  End with CNTL/Z.
Switch(config)#int range fa0/1-3
Switch(config-if-range)#channel-group 1 mode desirable
Switch(config-if-range)#int pol
Switch(config-if)#switchport mode trunk
Switch(config-if)#end
Switch#!
Switch#show etherchannel summary
Creating a port-channel interface Port-channel 1
Flags:  D - down        P - in port-channel
        I - stand-alone s - suspended
        H - Hot-standby (LACP only)
        R - Layer3      S - Layer2
        U - in use      f - failed to allocate aggregator
        u - unsuitable for bundling
        w - waiting to be aggregated
        d - default port


Number of channel-groups in use: 1
Number of aggregators:           1

Group  Port-channel  Protocol    Ports
------+-------------+-----------+-----------------------------------------------

1      Pol(SU)           PAgP    Fa0/1(P) Fa0/2(P) Fa0/3(P)
```


```
Cisco Packet Tracer PC Command Line 1.0
C:\>ping 192.168.1.20

Pinging 192.168.1.20 with 32 bytes of data:

Reply from 192.168.1.20: bytes=32 time=2ms TTL=128
Reply from 192.168.1.20: bytes=32 time<1ms TTL=128
Reply from 192.168.1.20: bytes=32 time=11ms TTL=128
Reply from 192.168.1.20: bytes=32 time<1ms TTL=128

Ping statistics for 192.168.1.20:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 0ms, Maximum = 11ms, Average = 3ms
```

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