Switching Architectures: Spanning Tree

Campus Network Design & Operations Workshop



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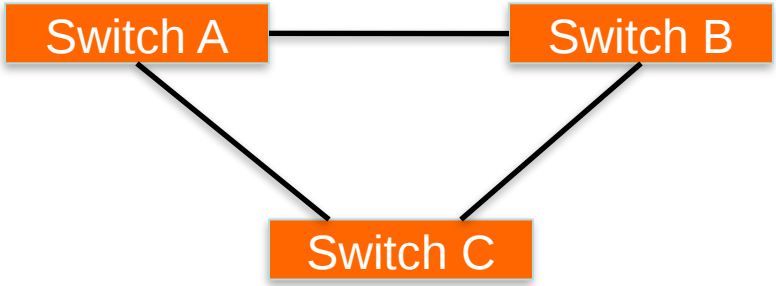


UNIVERSITY OF OREGON

Last updated 24th October 2022

NSRC
Network Startup Resource Center

Switching Loop



When there is more than one path between two switches

What are the potential problems?

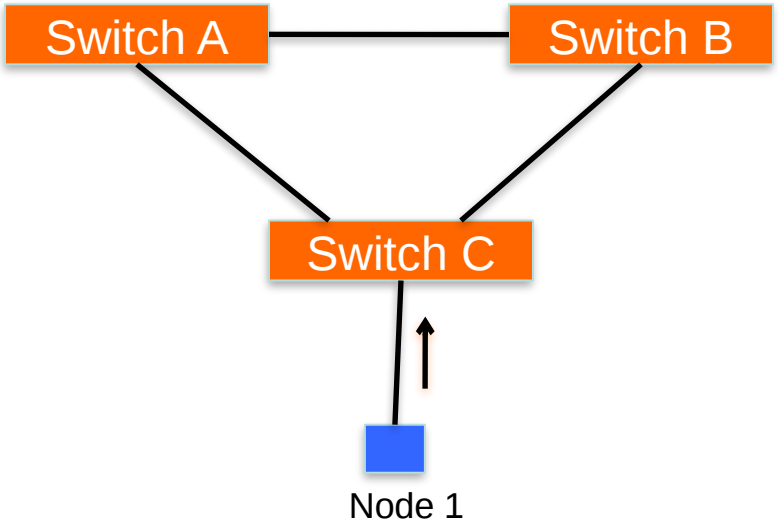
Switching Loop

- If there is more than one path between two switches:
  - Forwarding tables become unstable
    - Source MAC addresses are repeatedly seen coming from different ports

Switching Loop

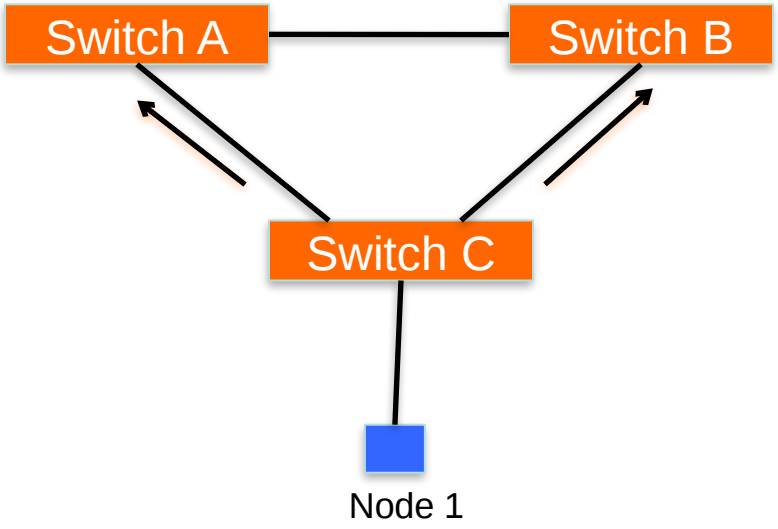
- If there is more than one path between two switches:
  - Forwarding tables become unstable
    - Source MAC addresses are repeatedly seen coming from different ports
  - Switches will broadcast each other's broadcasts
    - All available bandwidth is utilized
    - Switch processors cannot handle the load

Switching Loop



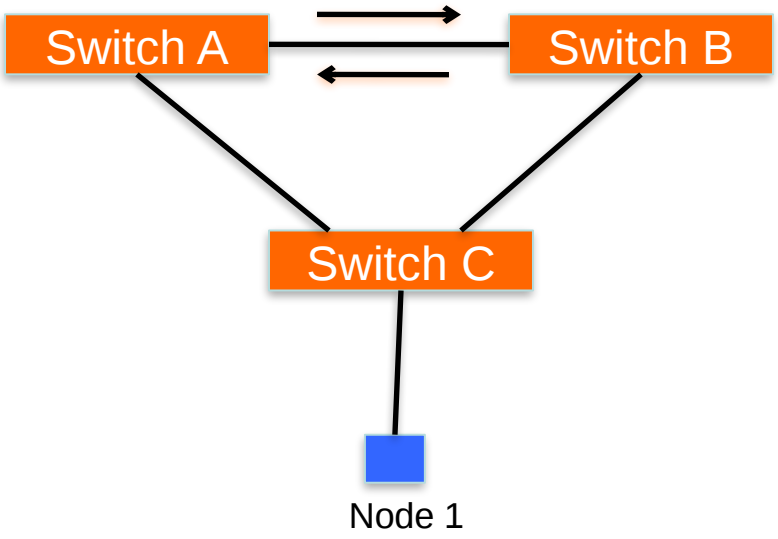
Node 1 sends a broadcast frame (e.g an ARP request)

Switching Loop



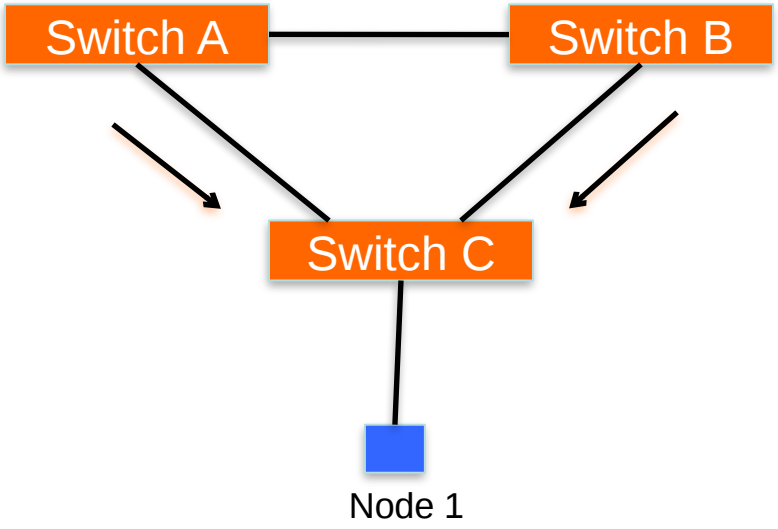
Switch C broadcasts node 1's frame out every port

Switching Loop



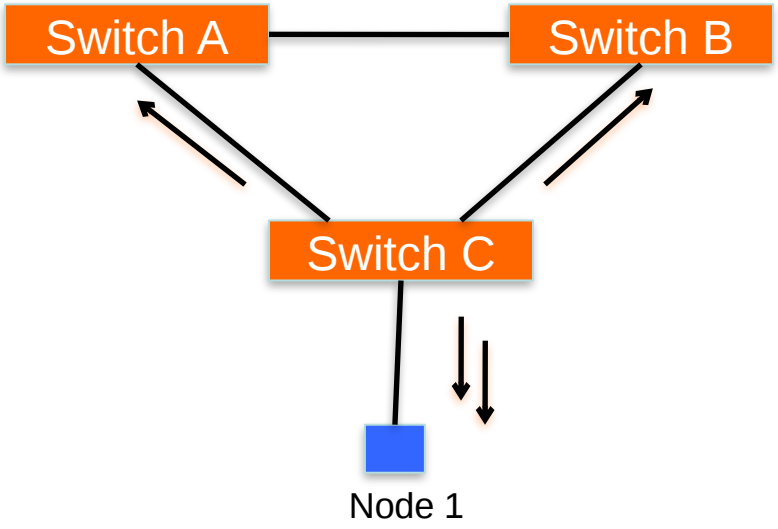
Switches A and B broadcast node 1's frame out every port

Switching Loop



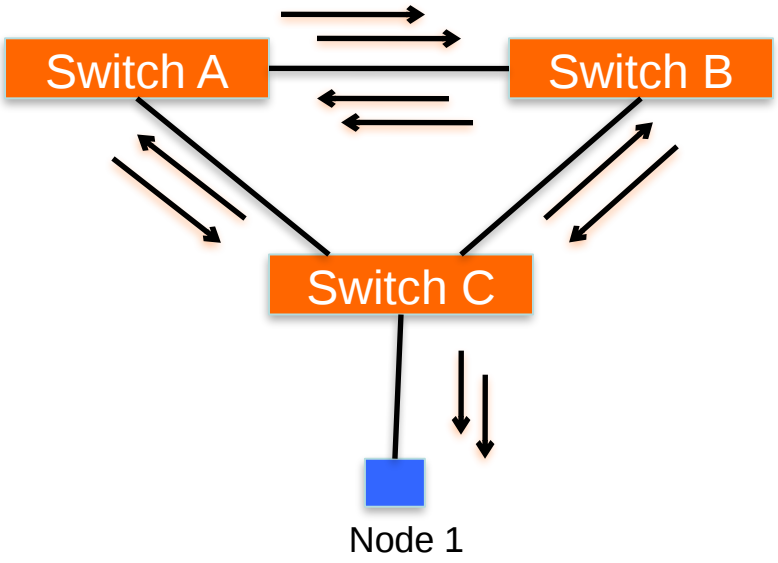
Switches A and B broadcast node 1's frame out every port

Switching Loop



Switch C broadcasts node 1's frame out every port

Switching Loop – End Result



They receive each other's broadcasts, which they then forward again out every port!

There is now an infinite loop of broadcasts

This creates what is known as a ***broadcast storm***

Good Switching Loops

- But you can take advantage of loops!
  - Redundant paths improve resilience when:
    - A switch fails
    - Wiring breaks

Good Switching Loops

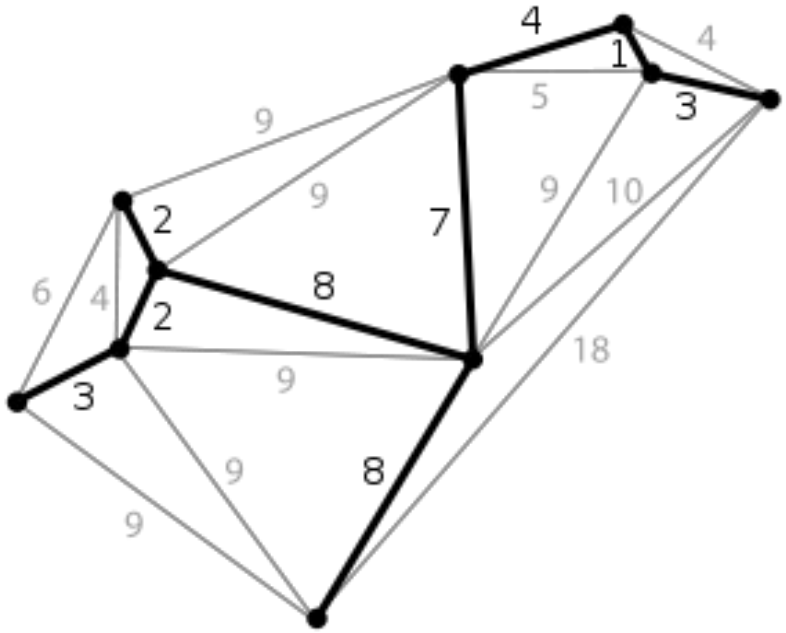
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    - A switch fails
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- How to achieve redundancy without creating dangerous traffic loops?

What is a Spanning Tree?

- “Given a connected, undirected graph, a *spanning tree* of that graph is a subgraph which is a tree and connects all the vertices together”.

- A single graph can have many different spanning trees.



Spanning Tree Protocol

- *The purpose of the protocol is to have bridges dynamically discover a subset of the topology that is loop-free (a tree) and yet has just enough connectivity so that where physically possible, there is a path between every switch*

Spanning Tree Protocol

- Several standard flavors:
  - Traditional Spanning Tree (IEEE 802.1d)
  - Rapid Spanning Tree or RSTP (IEEE 802.1w)
  - Multiple Spanning Tree or MSTP (IEEE 802.1s)

- Proprietary flavors:
  - Per-VLAN Spanning Tree or PVST (Cisco)
  - Rapid Per-VLAN Spanning Tree or RPVST+ (Cisco)

Traditional Spanning Tree (802.1d)

- Switches exchange messages that allow them to compute the Spanning Tree
  - These messages are called BPDUs (Bridge Protocol Data Units)

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- There are two types of BPDUs:
  - Configuration
  - Topology Change Notification (TCN)

Traditional Spanning Tree (802.1d)

- First Step:
  - Decide on a point of reference: the ***Root Bridge***

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  - Decide on a point of reference: the ***Root Bridge***
  - The election process is based on the Bridge ID
  - The Bridge ID is composed of:
    - The Bridge Priority: A two-byte value that is configurable
    - The MAC address: A unique, hardcoded address that cannot be changed.

Root Bridge Selection (802.1d)

- Each switch starts by sending out BPDUs with a Root Bridge ID equal to its own Bridge ID
  - *I am the root!*

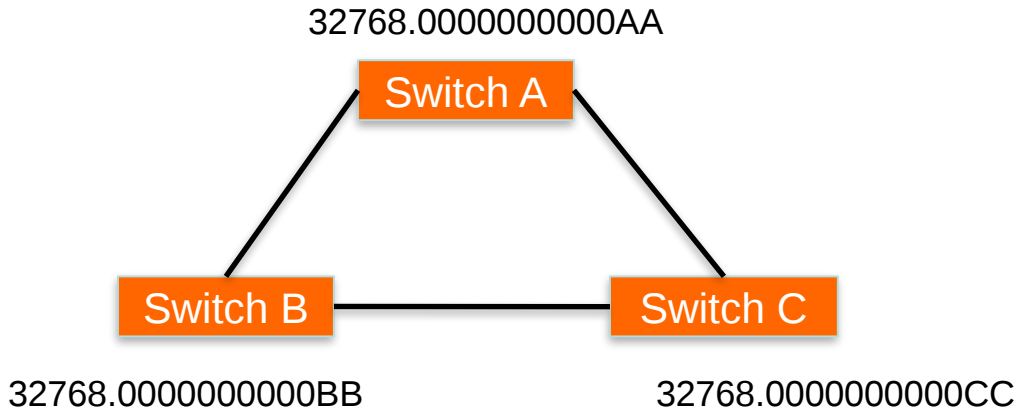
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  - If so, each switch replaces the value of the advertised Root Bridge ID with this new lower ID

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- Eventually, they all agree on who the Root Bridge is

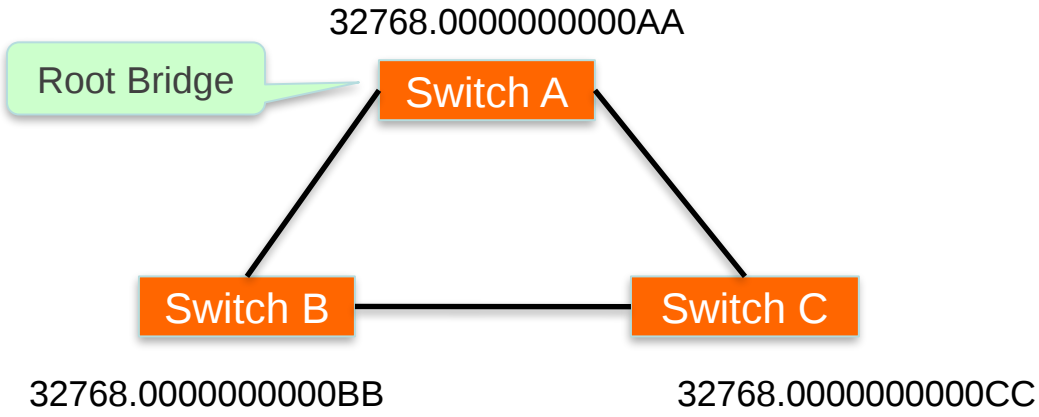
Root Bridge Selection (802.1d)



All switches have the same priority.

Which switch is the elected root bridge?

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Root Port Selection (802.1d)

- Now each switch needs to figure out where it is in relation to the Root Bridge
  - Each switch needs to determine its ***Root Port***

Root Port Selection (802.1d)

- Now each switch needs to figure out where it is in relation to the Root Bridge
  - Each switch needs to determine its ***Root Port***
  - The key is to find the port with the lowest ***Root Path Cost***
    - The cumulative cost of all the links leading to the Root Bridge

Root Port Selection (802.1d)

- Each link on a switch has a ***Path Cost***
  - Inversely proportional to the link speed
  - The faster the link, the lower the cost

Link Speed	STP Cost	RSTP Cost
10 Mbps	100	2,000,000
100 Mbps	19	200,000
1 Gbps	4	20,000
10 Gbps	2	2000
100 Gbps	N/A	200
1 Tbps	N/A	20

Root Port Selection (802.1d)

- ***Root Path Cost*** is the accumulation of a link's Path Cost and the Path Costs learned from neighboring Switches.
  - It answers the question: *How much does it cost to reach the Root Bridge through this port?*

Root Port Selection (802.1d)

1. Root Bridge sends out BPDUs with a Root Path Cost value of 0

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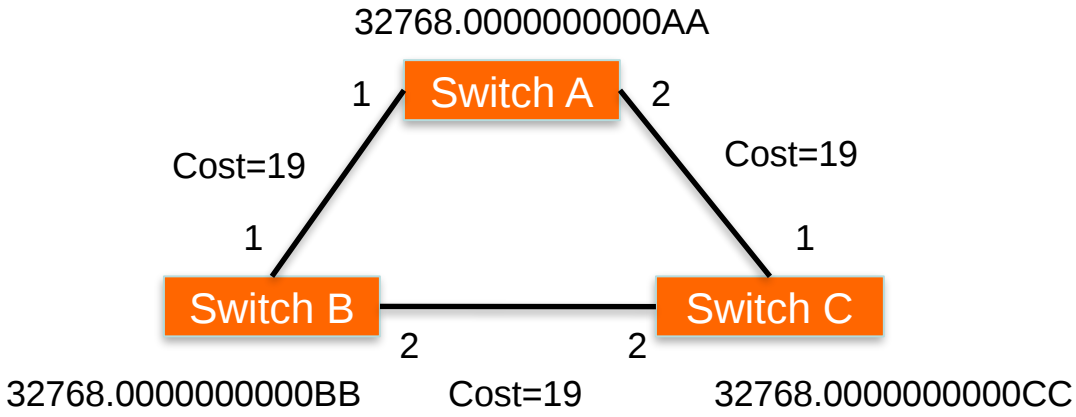
Root Port Selection (802.1d)

1. Root Bridge sends out BPDUs with a Root Path Cost value of 0
2. Neighbor receives BPDU and adds port's Path Cost to Root Path Cost received
3. Neighbor sends out BPDUs with new cumulative value as Root Path Cost
4. Other neighbors down the line keep adding in the same fashion

Root Port Selection (802.1d)

- On each switch, the port which has the lowest Root Path Cost becomes the ***Root Port***
  - This is the port with the best path to the Root Bridge

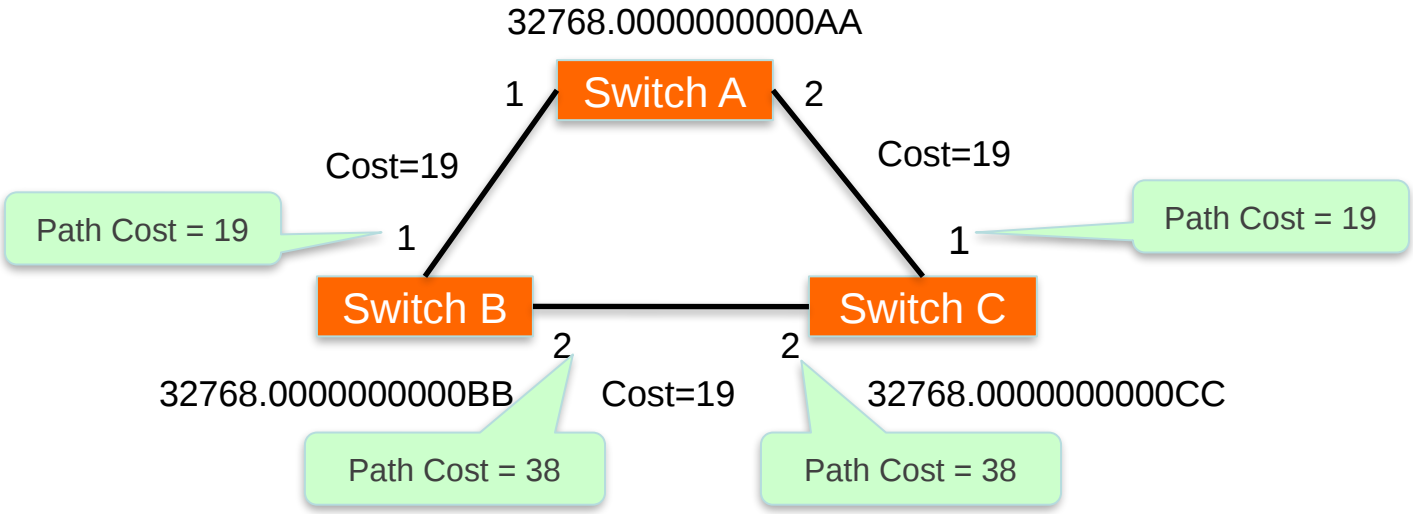
Root Port Selection (802.1d)



What is the Path Cost on each Port?

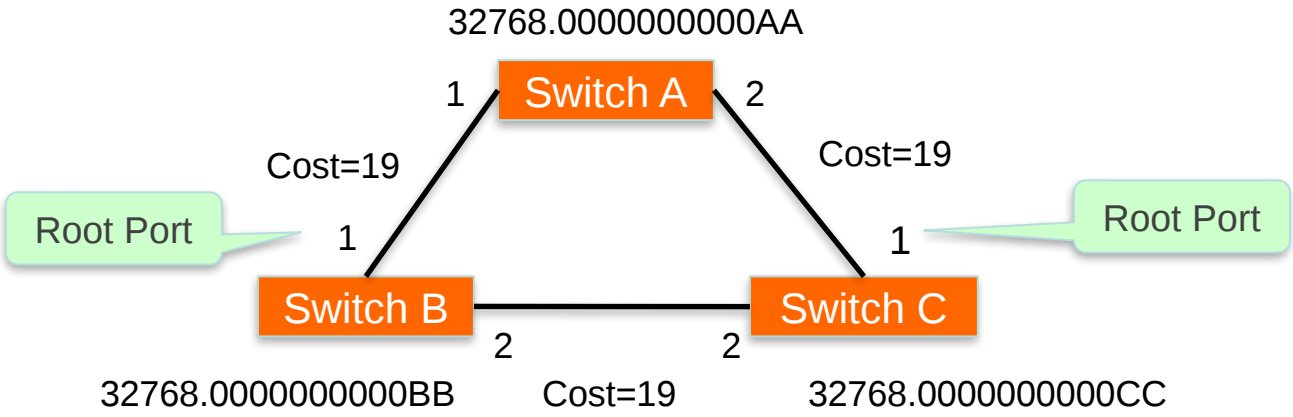
What is the Root Port on each switch?

Root Port Selection (802.1d)



Note: Path Cost is the sum of the value in the BPDU received from the neighbour plus the link cost

Root Port Selection (802.1d)



Electing Designated Ports (802.1d)

- OK, we now have selected the root ports, but we haven't solved the loop problem yet:
  - *The links are still active!*

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- Each network segment needs to have only one switch forwarding traffic to and from that segment

Electing Designated Ports (802.1d)

- OK, we now have selected the root ports, but we haven't solved the loop problem yet:
  - *The links are still active!*
- Each network segment needs to have only one switch forwarding traffic to and from that segment
- Switches then need to identify one **Designated Port** per network segment
  - The one with the lowest cumulative Root Path Cost to the Root Bridge

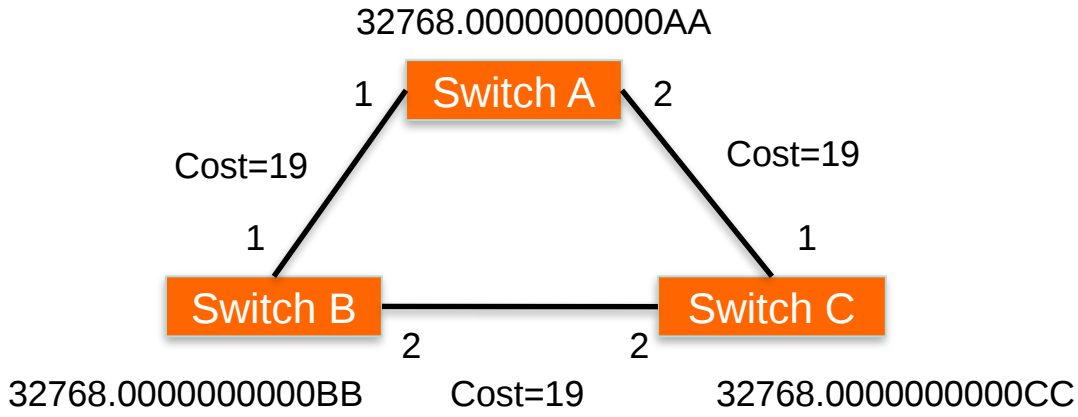
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- Two or more ports in a segment having identical Root Path Costs is possible, which results in a tie condition

Electing Designated Ports (802.1d)

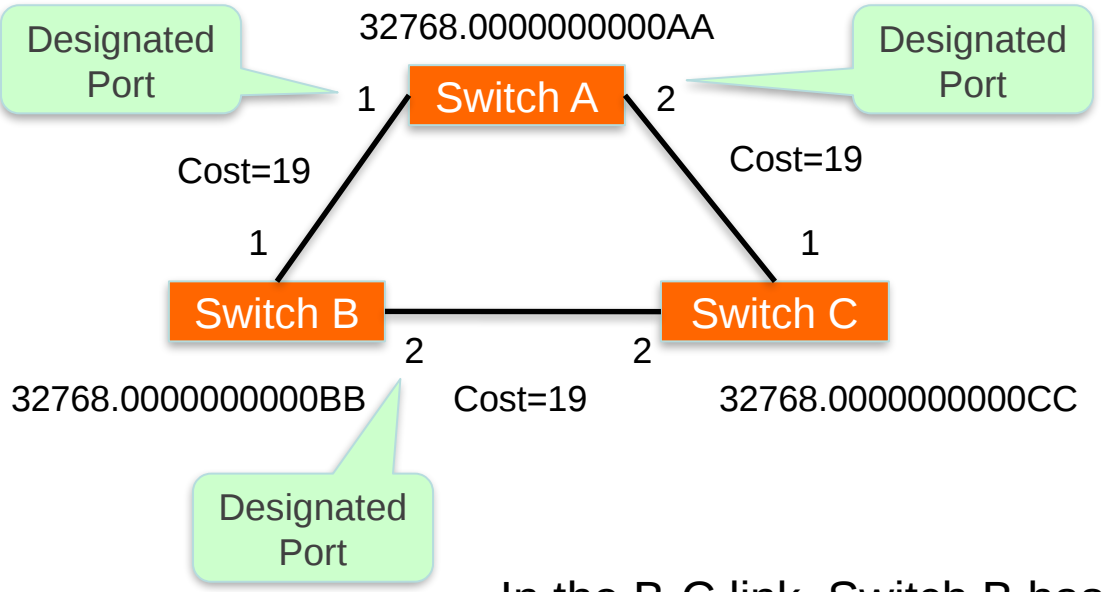
- Two or more ports in a segment having identical Root Path Costs is possible, which results in a tie condition
- All STP decisions are based on the following sequence of conditions:
  1. Lowest Root Bridge ID
  2. Lowest Root Path Cost to Root Bridge
  3. Lowest Sender Bridge ID
  4. Lowest Sender Port ID

Electing Designated Ports (802.1d)



Which port should be the Designated Port on each segment?

Electing Designated Ports (802.1d)

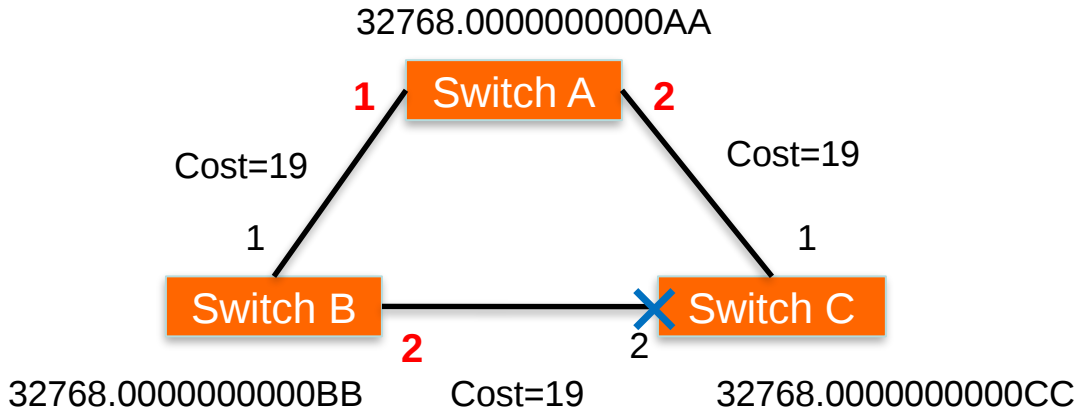


In the B-C link, Switch B has the lowest Bridge ID, so port 2 in Switch B is the Designated Port

Blocking a port

- Any port that is not elected as either a Root Port, nor a Designated Port is put into the **Blocking State**.
- This step effectively breaks the loop and completes the Spanning Tree.

Designated Ports on each segment (802.1d)



Port 2 in Switch C is then put into the ***Blocking State*** because it is ***neither a Root Port nor a Designated Port***

Spanning Tree Protocol States

- Disabled
  - Port is shut down
- Blocking
  - Not forwarding frames
  - Receiving BPDUs
- Listening
  - Not forwarding frames
  - Sending and receiving BPDUs

Spanning Tree Protocol States

- Learning
  - Not forwarding frames
  - Sending and receiving BPDUs
  - Learning new MAC addresses
- Forwarding
  - Forwarding frames
  - Sending and receiving BPDUs
  - Learning new MAC addresses
- *Once a link is detected on a port in a switch configured with spanning tree, it will typically go through all the states presented in order from disabled and stop at either* ***blocking*** *or* ***forwarding*** *depending on STP decisions.*

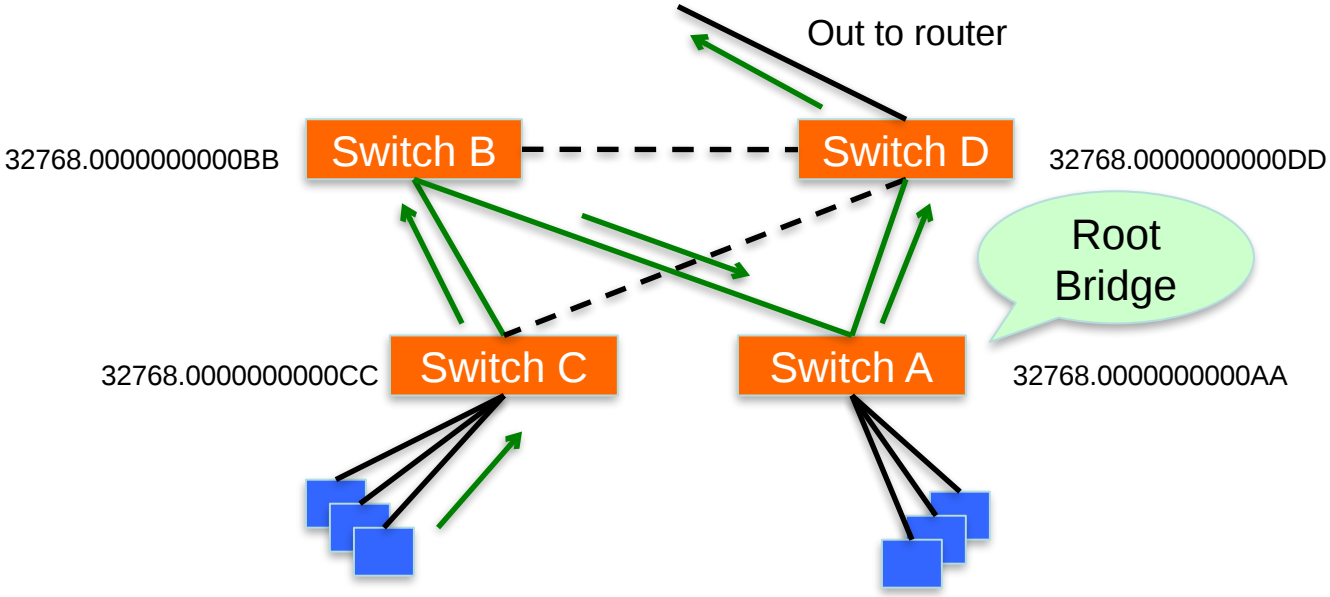
STP Topology Changes

- Switches will recalculate if:
  - A new switch is introduced
    - It could be the new Root Bridge!
  - A switch fails
  - A link fails
  - A link that failed comes back online
  - A new link is introduced

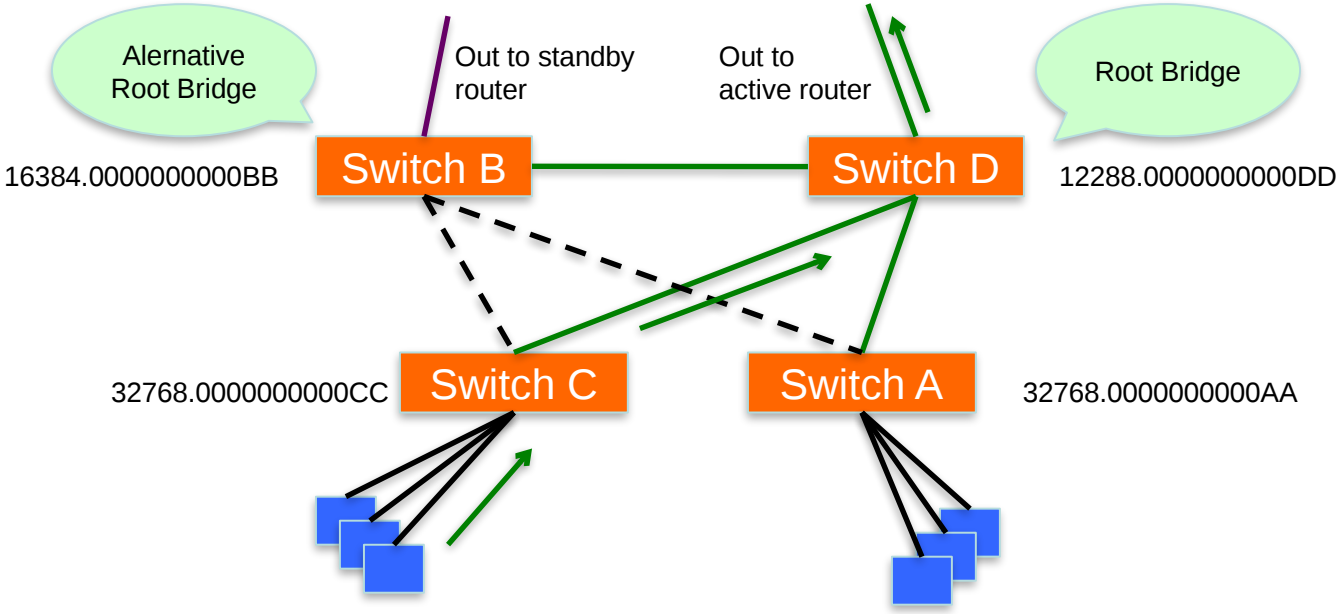
Root Bridge Placement

- Using default STP parameters might result in an undesired situation
  - Traffic will flow in non-optimal ways
  - An unstable or slow switch might become the root
- You need to plan your assignment of bridge priorities carefully

Bad Root Bridge Placement



Good Root Bridge Placement



Protecting the STP Topology

- Some vendors have included features that protect the STP topology:
  - Root Guard
  - BPDU Guard
  - Loop Guard
  - UDLD
  - Etc.
- These features will be discussed later

STP Design Guidelines

- Enable spanning tree even if you don’t have redundant paths
- Always plan and set bridge priorities
  - Make the root choice deterministic
  - Include an alternative root bridge
- If possible, do not accept BPDUs on end user ports
  - Apply BPDU Guard or similar where available

Bridge Priorities: Example Strategy

Priority	Description	Notes
0	Core Switch	
4096	Redundant Core Switch	For cases where there is a second core switch
8192	Reserved	
12288	Building Distribution Switch	
16384	Redundant Building Distribution Switch	For cases where buildings have redundant distribution switches
20480	Spare	
24576	Building Access Switch	
28672	Building Access Switch (Daisy Chain)	In rare cases where access devices have to be daisy-chained
32768	Default	No managed devices should have this priority

802.1d Convergence Speeds

- Moving from the Blocking state to the Forwarding State takes at least 2 x Forward Delay time units (~ 30 secs.)
  - This can be annoying when connecting end user stations
- Some vendors have added enhancements such as PortFast, which will reduce this time to a minimum for edge ports
  - Never use PortFast or similar in switch-to-switch links
- Topology changes typically take 30 seconds too
  - This can be unacceptable in a production network

Rapid Spanning Tree (802.1w)

- Backwards-compatible with 802.1d
- Provides faster convergence
  - You may notice alternate root ports, backup designated ports
- Configure which ports are edge ports
  - i.e. for end users, not connections to other switches

Multiple Spanning Tree (802.1s)

- Again, backwards-compatible
- Includes the fast convergence from RSTP
- Also lets you configure multiple trees (with different roots) for different groups of VLANs
  - So that load is shared between links
  - Usually not worth the complexity
  - Recommendation: stick with a single tree (the Common Spanning Tree, instance 0)

Configuration: Cisco

- STP enabled by default (PVST)
- Select standards-based STP *(recommended!)*

```
spanning-tree mode mst
```

- Set bridge priority:

```
spanning-tree mst 0 priority 12288
```

- For old switches which can only do PVST:

```
spanning-tree vlan 1 priority 12288
```

  - *Repeat for all vlans!*
- To enable portfast feature on all access ports:

```
spanning-tree portfast default
```

Configuration: HP

- Must enable STP explicitly!!

```
spanning-tree
```

- Set bridge priority:

```
spanning-tree priority 3
```

  - *Actual priority is 3 x 4096 = 12288*

- Disable portfast feature on each trunk port:

```
no spanning-tree <port> auto-edge-port
```

Configuration: Juniper

- Enable multiple spanning tree and set the bridge priority

```
set protocols mstp bridge-priority 12k
```

  - *(12k = 12x1024 = 12288)*

- Configure which ports participate in multiple spanning tree

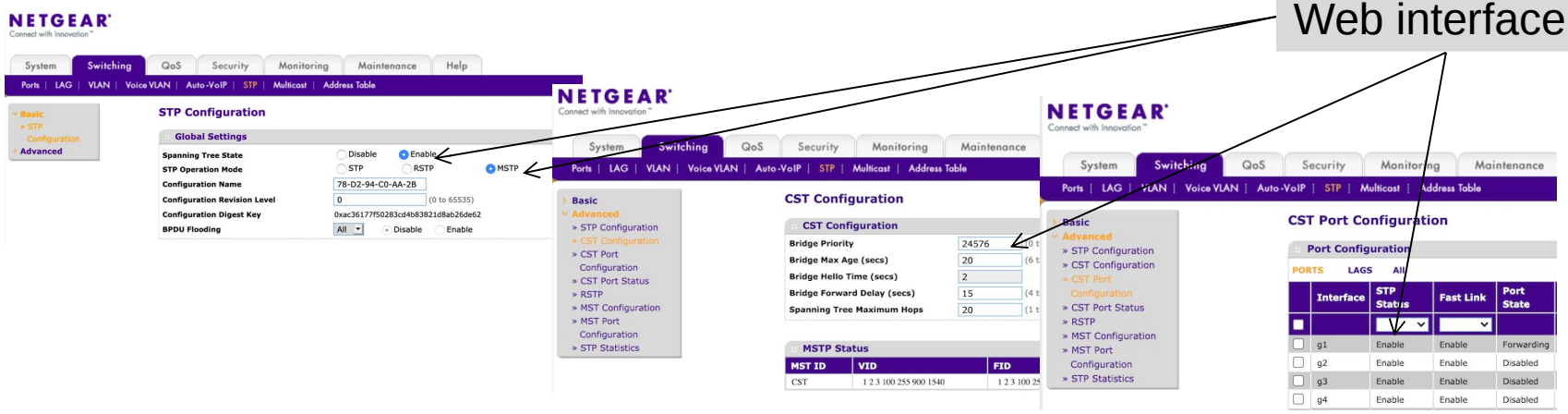
```
set protocols mstp interface ge-0/0/0
```

- *Alternatively for a group of ports:*

```
wildcard range set protocols mstp interface ge-0/0/[0-3]
```

Configuration: Netgear

- Must enable STP globally, *and* on each port!



Command line

```
spanning-tree
spanning-tree mst priority 0 24576
interface 0/1
  spanning-tree port mode
```

The End. Questions?

(Additional reference materials)

Rapid Spanning Tree (802.1w)

- Backwards-compatible with 802.1d
- Convergence is **much** faster
  - Communication between switches is more interactive
- Edge ports don’t participate
  - Edge ports transition to forwarding state immediately
  - If BPDUs are received on an edge port, it becomes a non-edge port to prevent loops

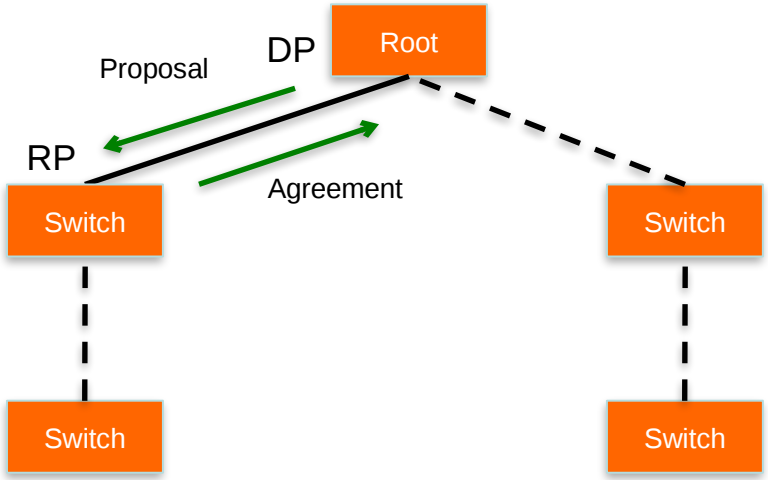
Rapid Spanning Tree (802.1w)

- Defines these port roles:
  - Root Port (same as with 802.1d)
  - Alternate Port
    - A port with an alternate path to the root
  - Designated Port (same as with 802.1d)
  - Backup Port
    - A backup/redundant path to a segment where another bridge port already connects.

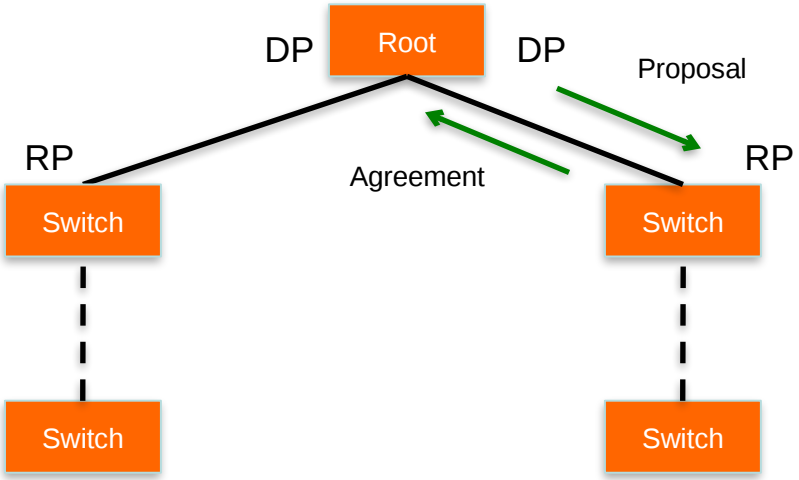
Rapid Spanning Tree (802.1w)

- Synchronization process uses a handshake method
  - After a root is elected, the topology is built in cascade, where each switch proposes to be the designated bridge for each point-to-point link
  - While this happens, all the downstream switch links are blocking

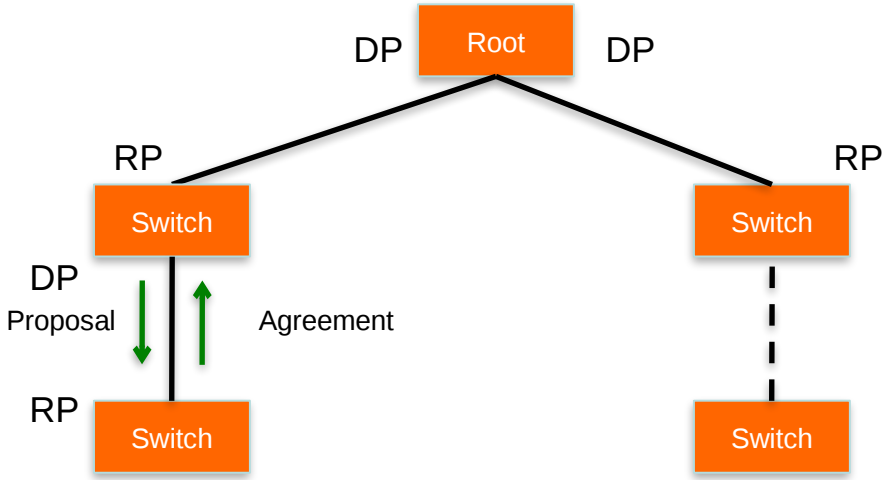
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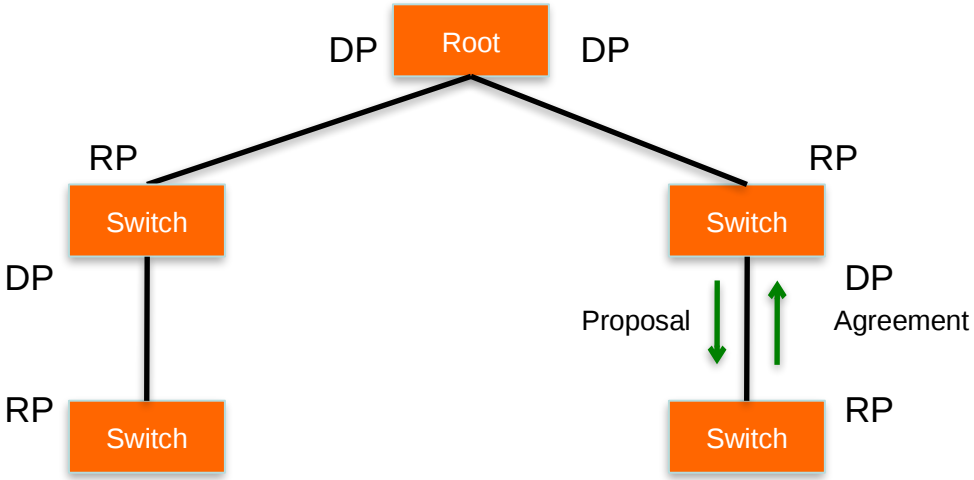
Rapid Spanning Tree (802.1w)



Rapid Spanning Tree (802.1w)



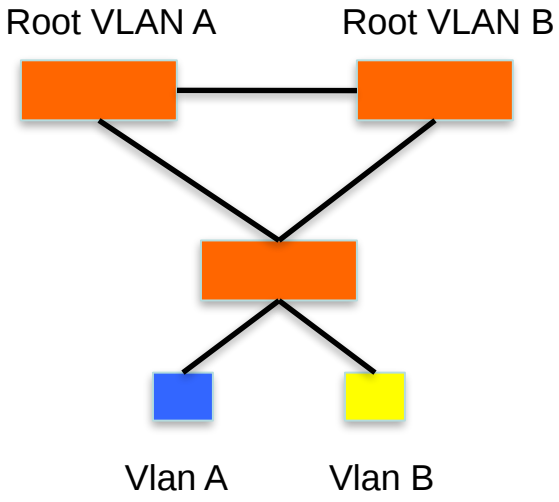
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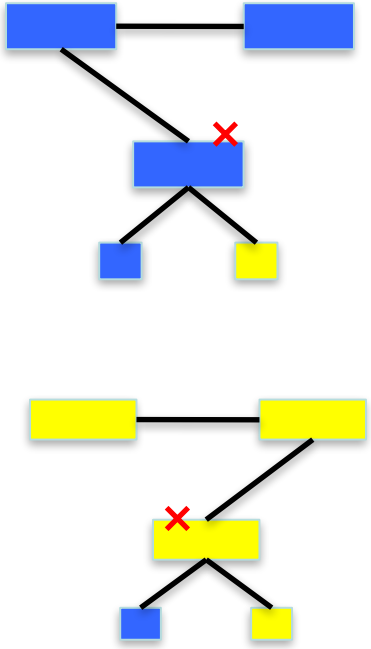


Multiple Spanning Tree (802.1s)

- Backwards-compatible with 802.1d
- Compatible with RSTP
- Allows separate spanning trees per VLAN group
  - Different topologies allow for load balancing between links
  - One or more VLANs are assigned (mapped) to an “instance” of MST (MSTI)
  - A particular VLAN can be mapped to only one MSTI

Multiple Spanning Tree (802.1s)





Multiple Spanning Tree (802.1s)

- MST Instances
  - Groups of VLANs are mapped to particular Spanning Tree instances
  - These instances will represent the alternative topologies, or forwarding paths
  - You specify a root and alternate root for each instance

Multiple Spanning Tree (802.1s)

- MST Region
  - Switches are members of a region if they have the same set of attributes:
    - MST configuration name
    - MST configuration revision
    - Instance-to-VLAN mapping
  - A digest of these attributes is sent inside the BPDUs for fast comparison by the switches
  - One region is usually sufficient

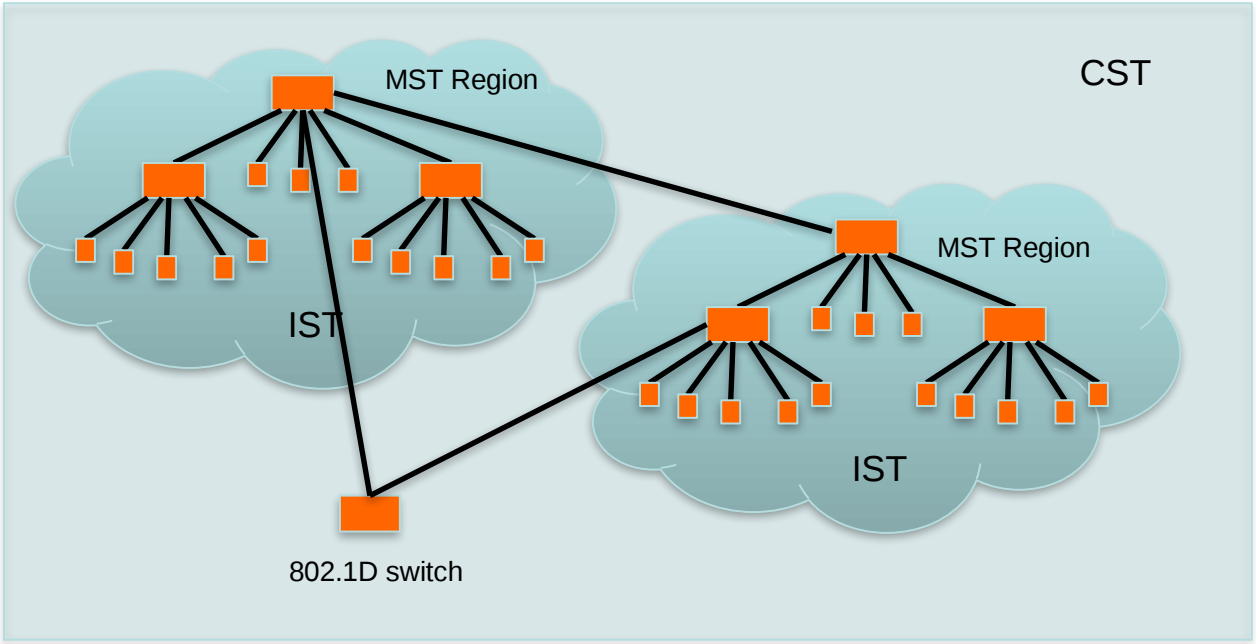
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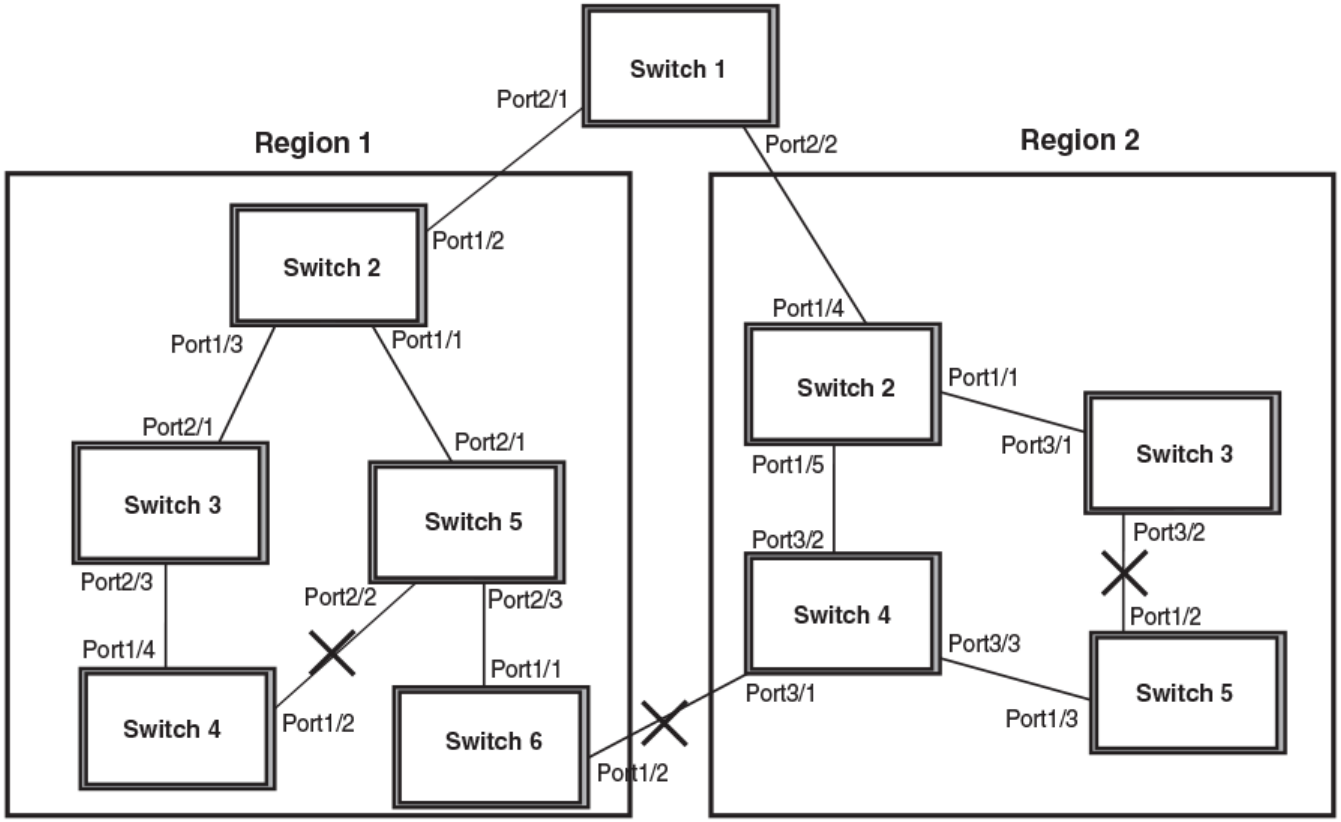
- CST = Common Spanning Tree
  - Defined in 802.1q standard (which also defines VLAN tagging)
  - In order to interoperate with other versions of Spanning Tree, MST needs a common tree that contains all the islands, including other MST regions
  - One spanning-tree instance for the entire bridged network regardless of the number of VLANs or regions

Multiple Spanning Tree (802.1s)

- IST = Internal Spanning Tree
  - Internal to the Region, that is
  - Within each MST region, the MSTP maintains multiple spanning-tree instances
  - Instance 0 is a special instance known as IST, which “extends” CST inside the MST region
  - MSTI instance 0 is always present if the switch is running MSTP
  - Presents the entire region as a single virtual bridge to the CST outside

Multiple Spanning Tree (802.1s)





Source: brocade.com L2 Switch configuration guide

Multiple Spanning Tree (802.1s)

- Design Guidelines
  - Determine relevant forwarding paths, and distribute your VLANs equally into instances matching these topologies
  - Assign different root and alternate root switches to each instance
  - Make sure all switches match region attributes
  - Do not assign VLANs to instance 0, as this is used by the IST