
# Layer 2 Spanning Tree Protocols

*Redes de Comunicações II*

Licenciatura em Engenharia de Computadores e Informática

Prof. Amaro de Sousa (asou@ua.pt)

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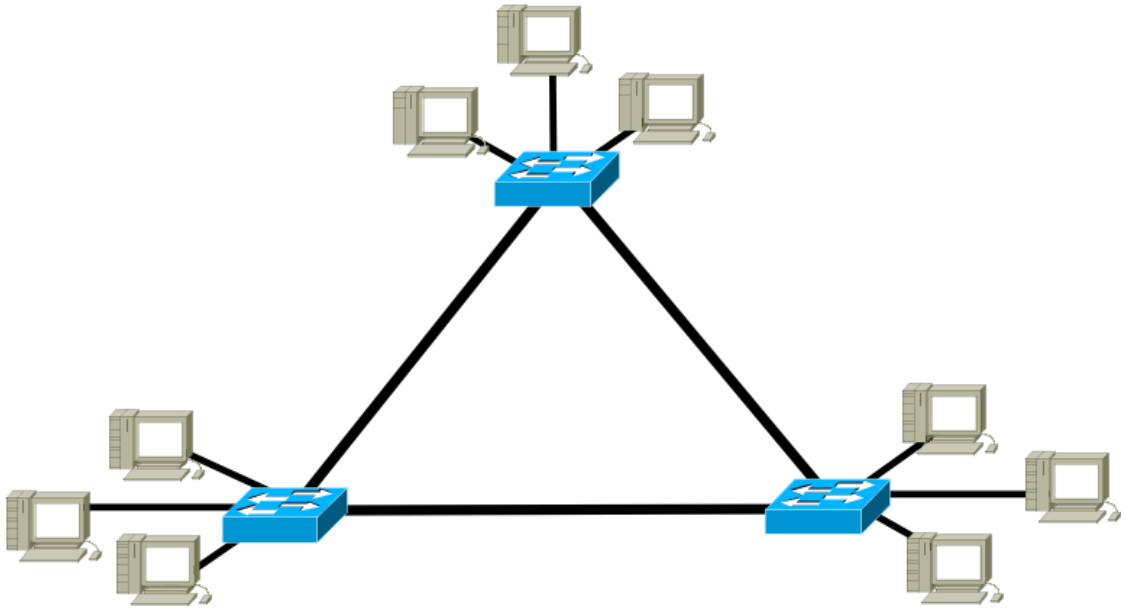
# Redundant Layer 2 network

**Objective:** To allow the network for dynamically recovery from network failures.

**Problem:** Link redundancy creates Layer 2 loops. Causes the collapse of communications when MAC frames with broadcast address are sent by any host due to infinite frame flooding.

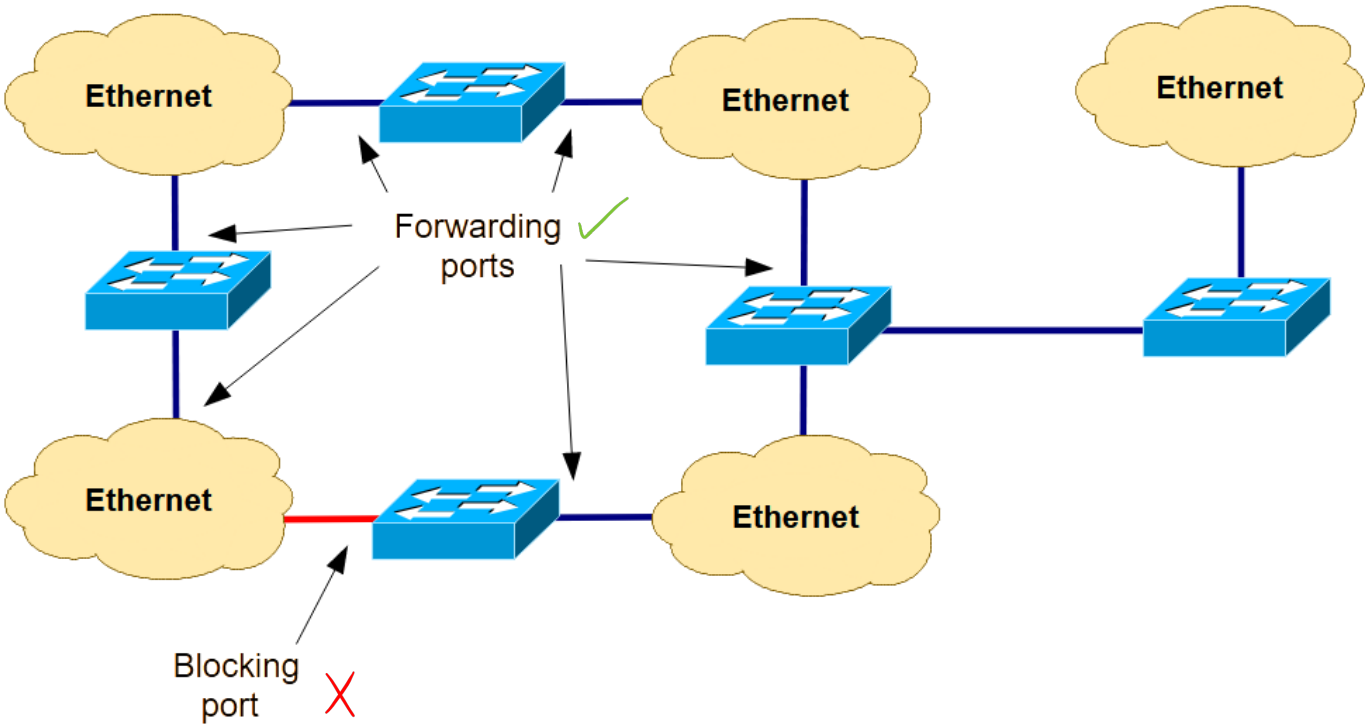


# Spanning Tree Protocol (SPT)

- STP enables the network to deterministically block ports and provide a fully connected loop-free topology in a network with redundant links.
- There are several STP Standards and Features:
  - STP is the original IEEE 802.1D version (802.1D-1998) that provides a loop-free topology in a network with redundant links.
  - RSTP, or IEEE 802.1W, is an evolution of STP that provides faster convergence of STP.
  - Multiple Spanning Tree (MST) is an IEEE standard. MST maps multiple VLANs into the same spanning-tree instance.
  - PVST+ (Per VLAN Spanning Tree Plus) is a Cisco enhancement of STP that provides a separate 802.1D spanning-tree instance for each VLAN configured in the network.
  - RPVST+ is a Cisco enhancement of RSTP that uses PVST+. It provides a separate instance of 802.1W per VLAN.

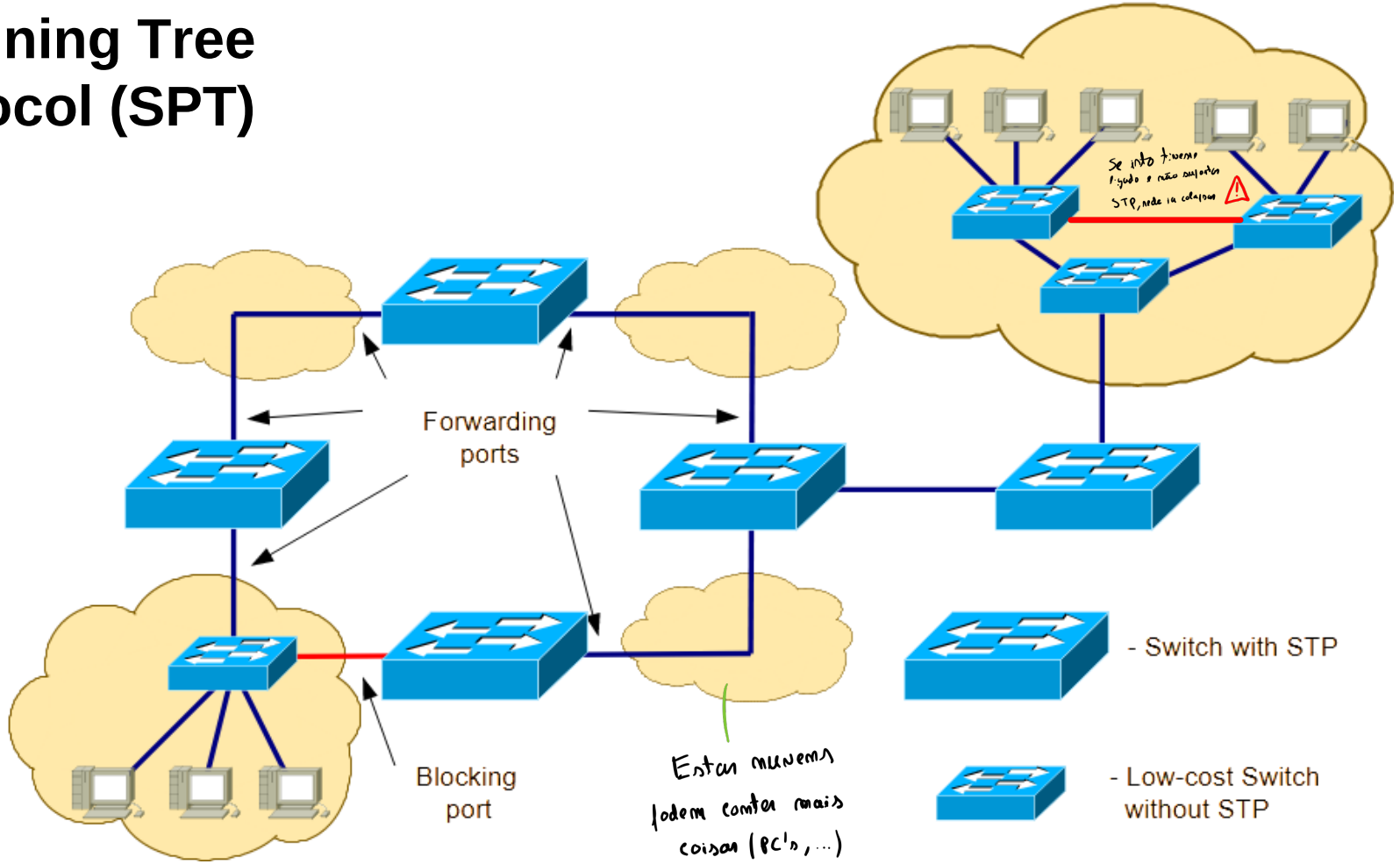
O STP, definido pelo padrão IEEE 802.1d, é um protocolo que funciona ao nível da camada 2 do modelo OSI e tem como como principal objetivo controlar ligações redundantes, garantindo o desempenho de uma rede.

# Spanning Tree Protocol (SPT)




- The switches running STP exchange protocol messages between them to decide which ports are forwarding and which ports are blocking data frames.
- In the resulting spanning tree, all pairs of network segments are connected by a single forwarding path (i.e., there are no forwarding loops).

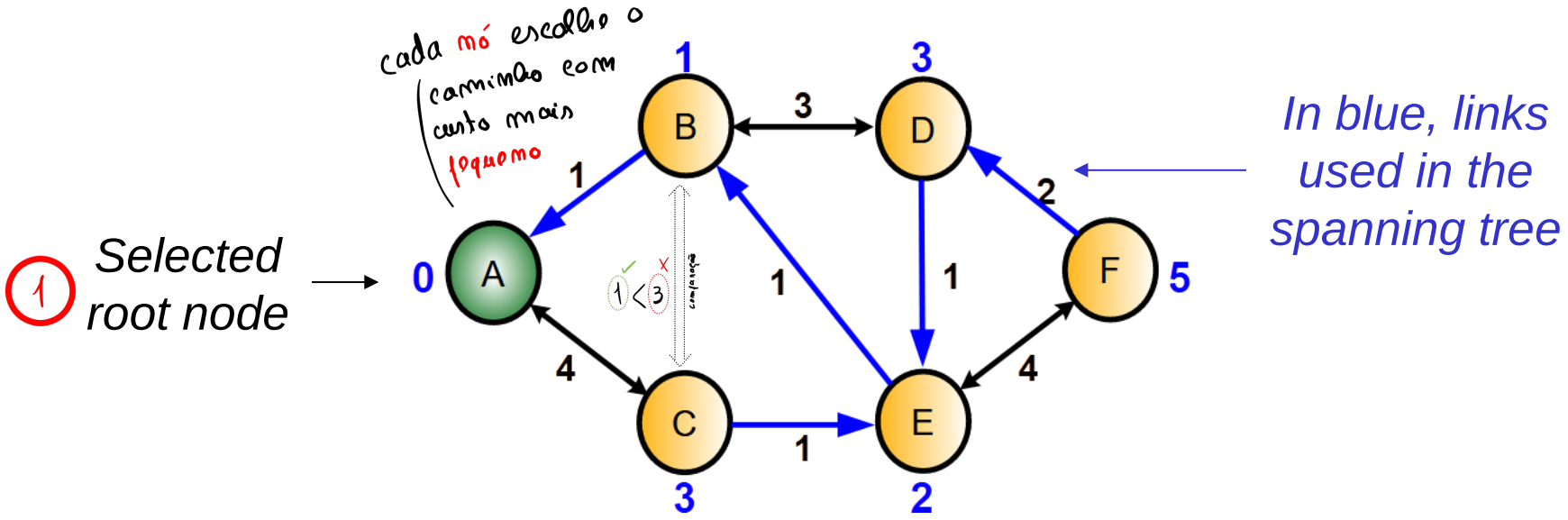
# Spanning Tree Protocol (SPT)




- The connections between Switches (supporting STP) might be:
  - Pont-to-point links
  - A network of switches (not supporting STP) with a loop-free topology

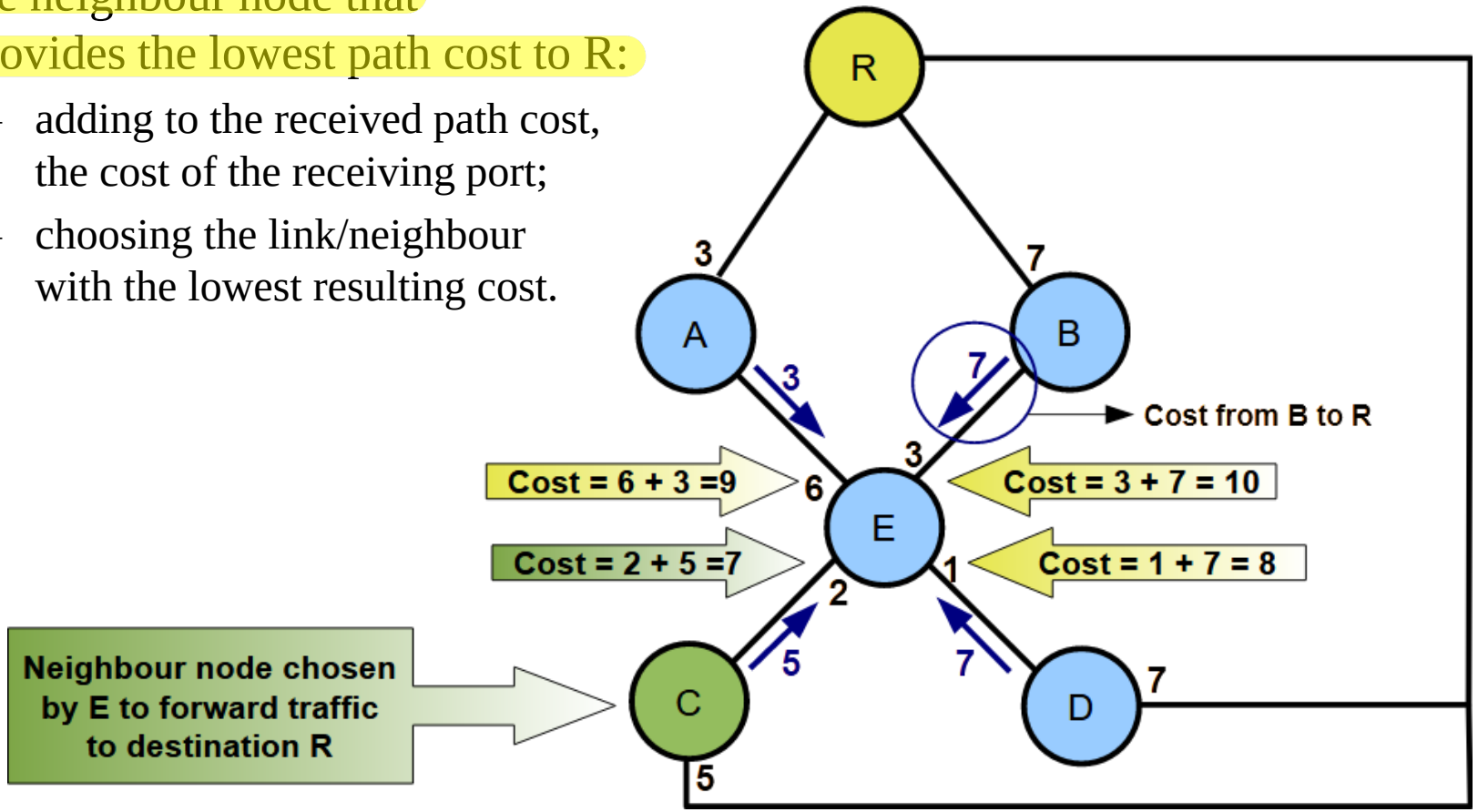
# Spanning trees based on shortest paths

- The active links are the ones that belong to the shortest path from each node to a node selected as the root node
  - All nodes use the **Bellman-Ford Distributed and Asynchronous Algorithm** to calculate the neighbour node that provides the smallest path cost to the root node.
  - The set of links belonging to a shortest path is called the **Spanning Tree.**
  - A criterion to solve ties is required (as will be seen later).



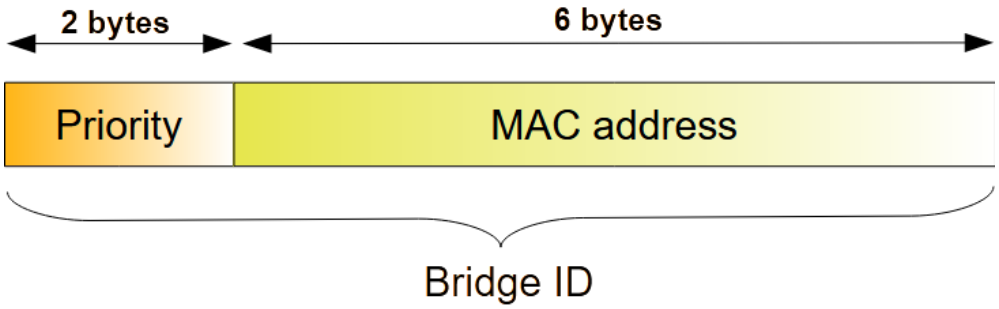
# Bellman-Ford Distributed and Asynchronous Algorithm

- Each node transmits periodically (to its neighbours) the estimation of the path cost from it to the destination R.
- Upon reception of a message from a neighbour node, each node recalculates the neighbour node that provides the lowest path cost to R:
  - adding to the received path cost, the cost of the receiving port;
  - choosing the link/neighbour with the lowest resulting cost.



# Spanning Tree Basic Concepts (1)

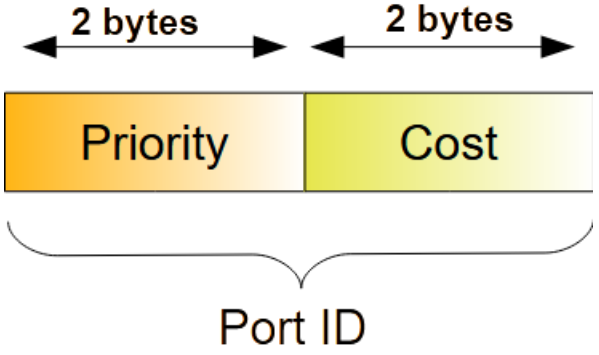
- **Bridge ID** – each switch is identified by an 8 bytes identifier:
  - **Priority** (2 bytes), configurable by the manager, default value: 32768 (8000h in hexadecimal)
  - **MAC address** (6 bytes), guaranteed by the manufacturer to be unique
  - **Priority** has precedence over the **MAC address**




- **Root ID** – the switch with the lowest Bridge ID is selected as the **Root Bridge** and its ID is the Root ID
  - By default, the **Priority** is the same for all switches: in this case the **Root Bridge** is the switch with the lowest **MAC address**
  - The manager can change the selected Root Bridge by configuration of different **Priority** values on different switches

# Spanning Tree Basic Concepts (2)

- **Port ID** – each interface is identified by a 4 bytes identifier:
  - **Priority** (2 bytes), configurable by the manager, default value: 128 (80h in hexadecimal)
  - **Cost** (2 bytes), configurable by the manager, default value depends on the interface speed
  - **Priority** has precedence over the **Cost**

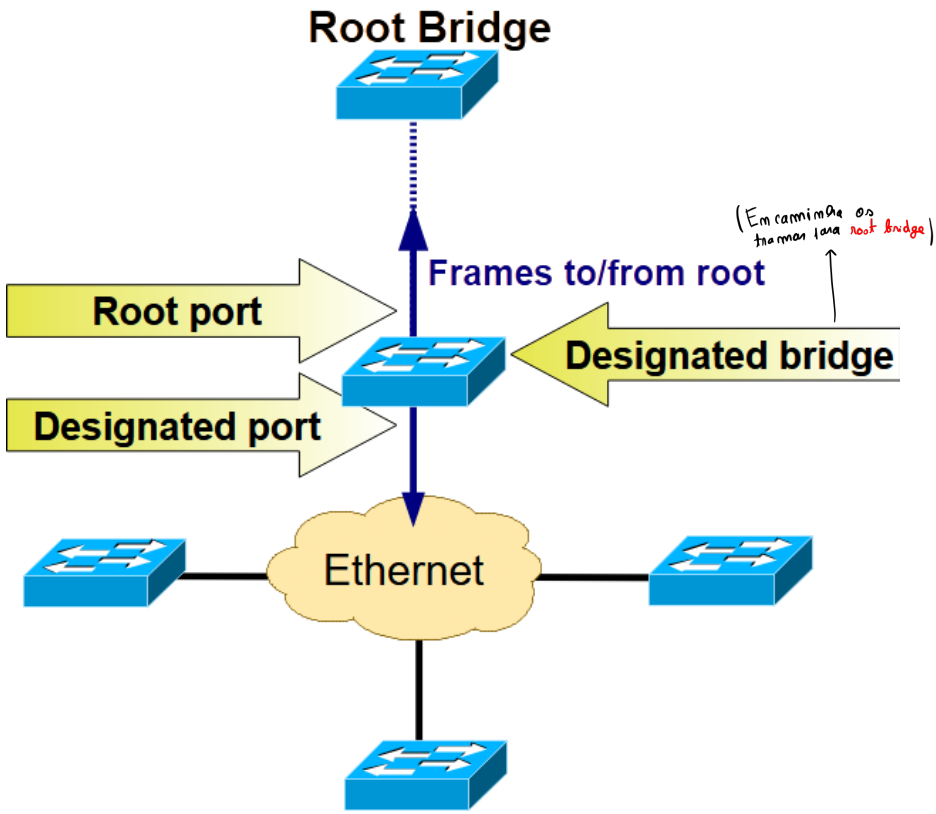



- The aim of the default **Cost** values is to include preferably the higher capacity links in the spanning tree
- The manager can change the **Cost** values in the different interfaces by configuration
- The need to change the **Priority** value of each interface is outside the scope of this course unit

| Interface Speed | Default Cost Value |
|---|---|
| 10 Mbps | 100 |
| 100 Mbps | 19 |
| 1 Gbps | 4 |
| 10 Gbps | 2 |
| 25 Gbps | 1 |
| 40 Gbps | 1 |
| 100 Gbps | 1 |

# Spanning Tree Basic Concepts (3)

- **Designated Bridge** – Switch responsible to forward the packets from an Ethernet segment to and from the **Root Bridge**.
  - The root bridge is the designated bridge to all Ethernet segments connected to it.
- **Designated Port** – Port of the designated bridge of the Ethernet segment.
- **Root Port** – Port of the switch that provides the shortest path to the **Root Bridge**.
  - The Root Bridge has no Root Port.



# Spanning Tree Basic Concepts (4)

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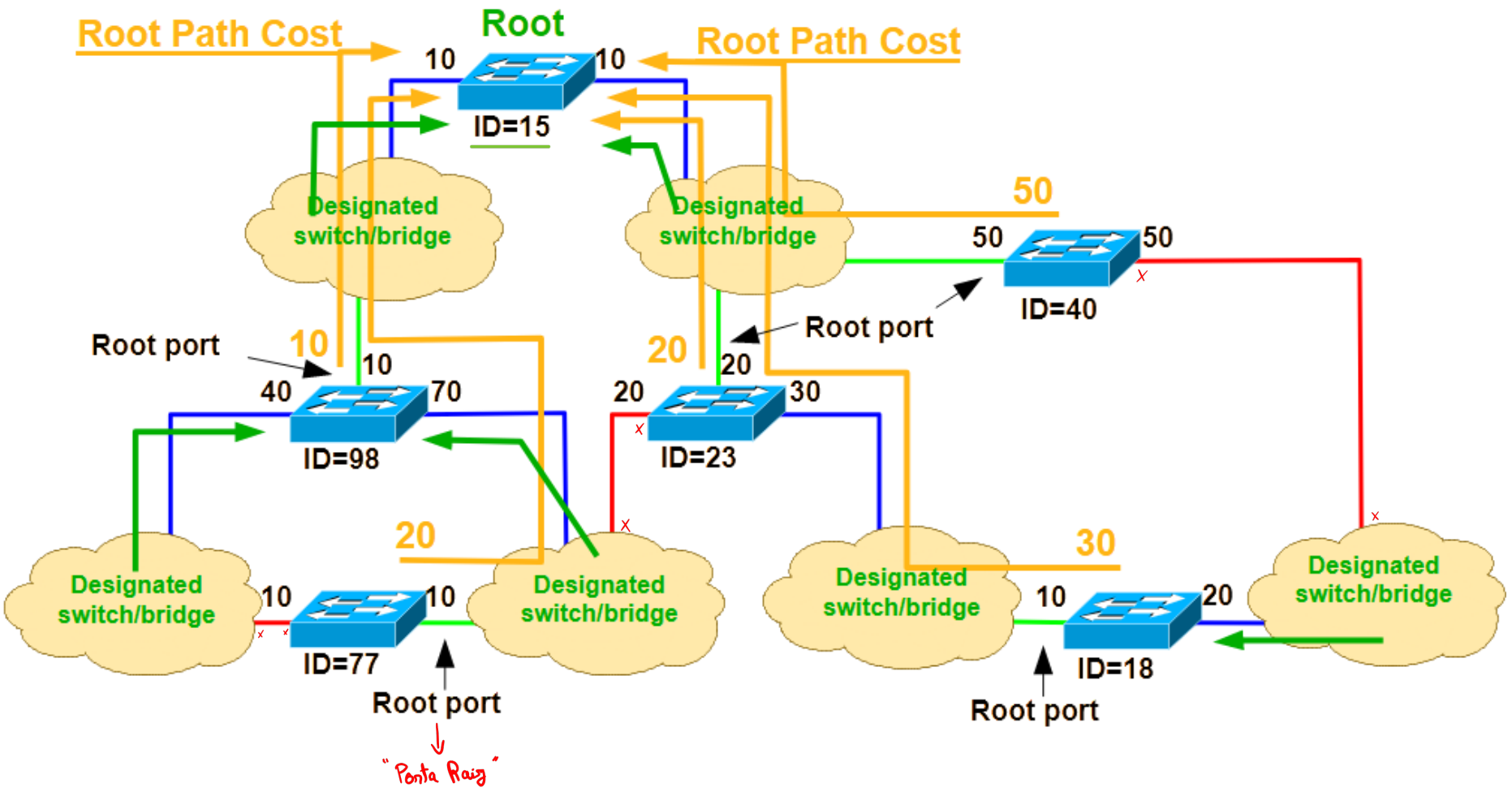
- Each switch has an associated cost of the shortest path to the root (**Root Path Cost**), given by the sum of the costs of all root ports along the path to the root.

- The **Root Port** in each switch is the port with the lowest Root Path Cost.
  - If multiple ports have the same lowest Root Path Cost, the port connected to the neighbour switch with the lowest Bridge ID is chosen as Root Port
- The **Designated Bridge** of each Ethernet segment, is the switch with the lowest Root Path Cost among all switches connected to the segment.
  - If multiple switches connected to an Ethernet segment have the same lowest Root Path Cost, the switch with the lowest Bridge ID becomes the Designated Bridge of the segment.
- The **Designated Port** of each Ethernet segment is the port of its Designated Bridge.

- The Root Ports and the Designated Ports are put in the **Forwarding state**.
- All other ports are put in **Blocking state**.

# Spanning Tree Basic Concepts Illustration



# Spanning tree info in a Cisco switch

Running the command `show spanning-tree brief`:

```
ESW1#show spanning-tree brief

VLAN1
  Spanning tree enabled protocol ieee
  Root ID     Priority    32768
              Address     c201.1a70.0000
              Cost        38
              Port        56 (FastEthernet1/15)
              Hello Time   2 sec  Max Age 20 sec  Forward Delay 15 sec

  Bridge ID   Priority    32768
              Address     c204.2dac.0000
              Hello Time   2 sec  Max Age 20 sec  Forward Delay 15 sec
              Aging Time 300

Interface                                      Designated
Name                 Port ID Prio Cost  Sts Cost  Bridge ID            Port ID
-------------------- ------- ---- ----- --- ----- -------------------- -------
FastEthernet1/14     128.55   128    19 BLK    19 32768 c203.24a4.0001 128.43
FastEthernet1/15     128.56   128    19 FWD    19 32768 c202.504c.0001 128.43
```

Root ID:
- 32768 - c201.1a70.0000

Root Path Cost: 38

Root Port:
- 56 (FastEthernet1/15)

Bridge ID:
- 32768 - c204.2dac.0000

Interface F1/14:
- Port priority: 128
- Port cost: 19
- State: Blocking

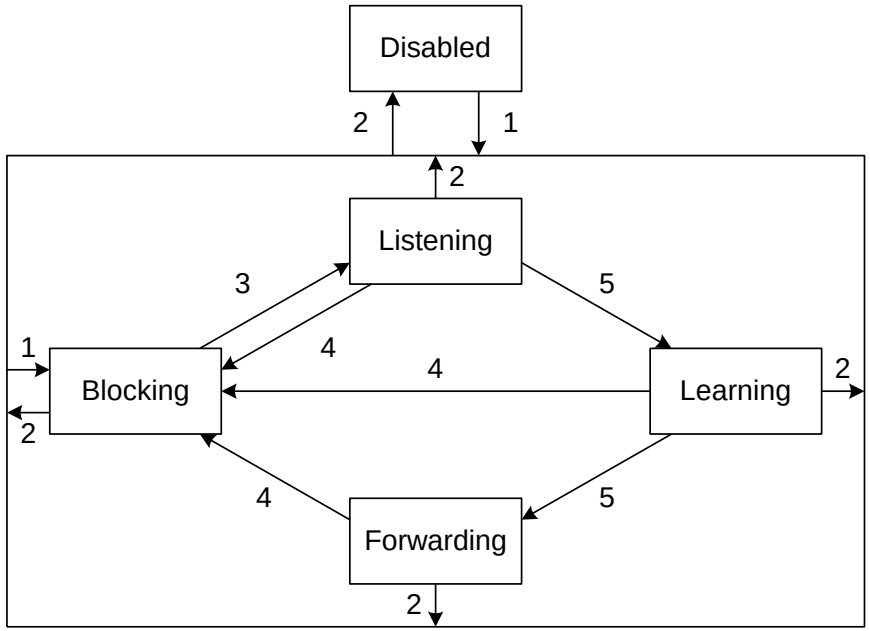
Interface F1/15:
- Port priority: 128
- Port cost: 19
- State: Forwarding

Designated Bridge on interface F1/14:
- 32768 - c203.24a4.0001 (with Port ID 128.43)

Designated Bridge on interface F1/15:
- 32768 - c202.504c.0001 (with Port ID 128.43)

# Possible Port States (to avoid temporary cycles)

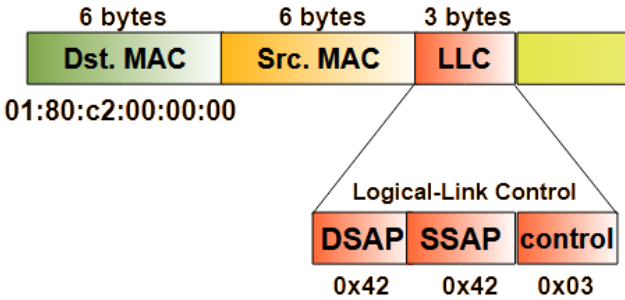
- Blocking state:
  - MAC address learning and packet forwarding are disabled
  - Receives and processes BPDU
- Listening state:
  - MAC address learning and packet forwarding are disabled
  - Receives and processes BPDU
  - When **Forward Delay** timer expires the port transits to Learning state
- Learning state:
  - MAC address is enabled but packet forwarding are disabled
  - Receives and processes BPDU
  - When **Forward Delay** timer expires the port transits to Forwarding state
- Forwarding state:
  - MAC address learning and packet forwarding are enabled
  - Receives and processes BPDU
- Disabled state:
  - MAC address learning and packet forwarding are disabled
  - Does not receive BPDU



# IEEE 802.1D Protocol
# BPDUs (Bridge Protocol Data Units)

- To build the spanning tree, switches exchange special messages between them called Bridge Protocol Data Units (BPDU).
  - There are two types: Configuration e TCN (Topology Change Notification).

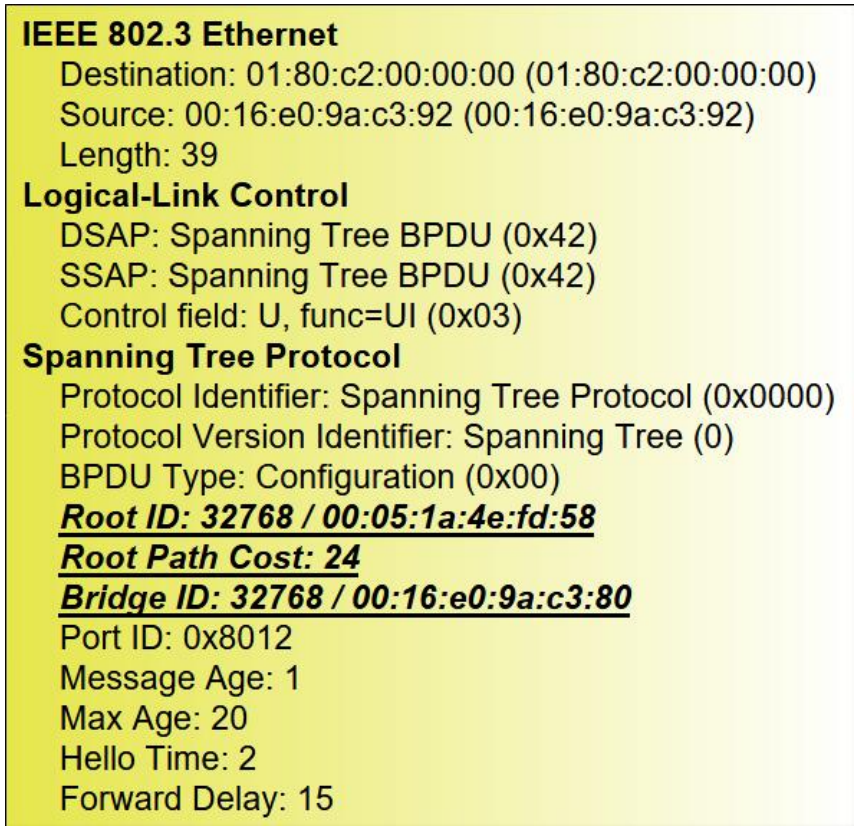
**IEEE 802.3 Ethernet**
Destination: 01:80:c2:00:00:00 (01:80:c2:00:00:00)
Source: 00:16:e0:9a:c3:92 (00:16:e0:9a:c3:92)
Length: 39
**Logical-Link Control**
DSAP: Spanning Tree BPDU (0x42)
SSAP: Spanning Tree BPDU (0x42)
Control field: U, func=UI (0x03)
**Spanning Tree Protocol**
Protocol Identifier: Spanning Tree Protocol (0x0000)
Protocol Version Identifier: Spanning Tree (0)
BPDU Type: Configuration (0x00)
Root ID: 32768 / 00:05:1a:4e:fd:58
Root Path Cost: 24
Bridge ID: 32768 / 00:16:e0:9a:c3:80
Port ID: 0x8012
Message Age: 1
Max Age: 20
Hello Time: 2
Forward Delay: 15




| protocol identifier | | |
|---|---|---|
| version | | |
| message type | | |
| TCA | reserved | TC |
| root ID | | |
| root path cost | | |
| bridge ID | | |
| port ID | | |
| message age | | |
| max age | | |
| hello time | | |
| forward delay | | |

# Set up of the Spanning Tree

- The setup of the Spanning Tree is done using the Configuration BPDU messages.

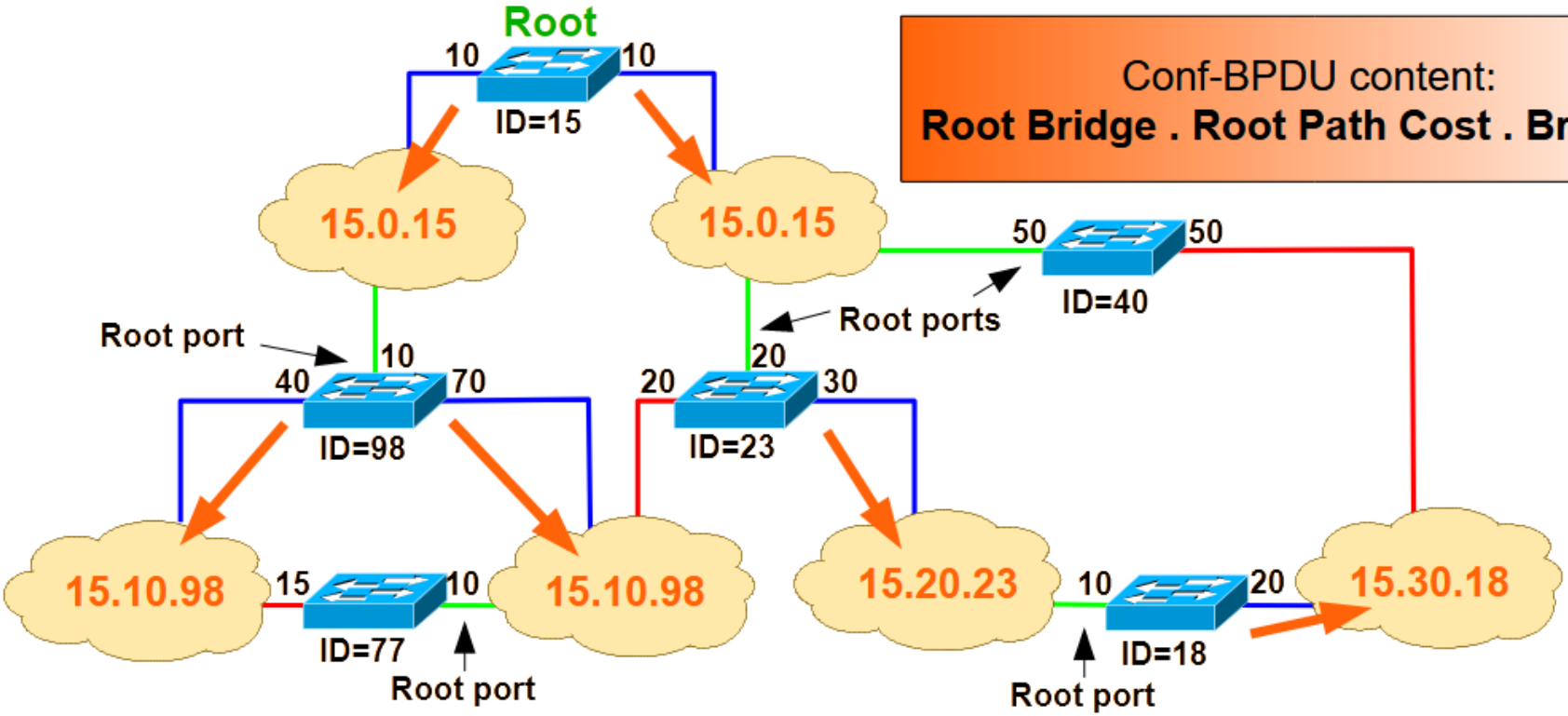



More relevant fields:

- **Root ID** of the current Root Bridge known by the sending switch.
- **Root Path Cost** of the sending switch.
- **Bridge ID** of the sending switch.

# Spanning Tree maintenance

- Switches send periodically Conf-BPDUs by their Designated Ports in accordance with the Bellman-Ford Algorithm.
  - Periodicity of Conf-BPDU messages = Hello Time
  - Recommended Hello time: 2 seconds.
  - Defined at the Root Bridge.



# Lifetime of MAC Address Table

Recall how MAC Address Tables are managed:

- A new MAC address is automatically inserted when a frame is received
- An existing MAC address is deleted when the **Lifetime** is reached without receiving any other frame from it

In general, the **Lifetime** value is a trade-off:

- Long Lifetime values – many frames will be lost when network is changing topology.
- Short Lifetime values – generate too much traffic due to frequent flooding.

There are two lifetime values:

- **Long Lifetime**: used by default (recommended value = 300 seconds)
- **Short Lifetime**: used when the Spanning Tree changes (recommended value = 15 seconds)

# TCN (Topology Change Notification) BPDUs

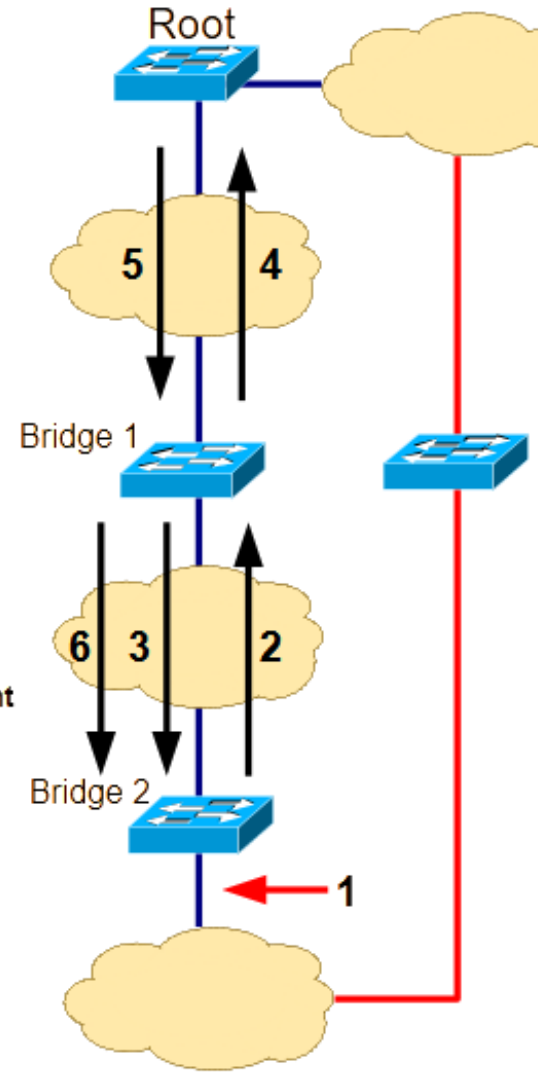
**Conf (Configuration) BPDU**

| protocol identifier | | |
|---|---|---|
| version | | |
| message type = 0 | | |
| TCA | reserved | TC |
| root ID | | |
| root path cost | | |
| bridge ID | | |
| port ID | | |
| message age | | |
| max age | | |
| hello time | | |
| forward delay | | |

TCA - flag Topology Change Acknowledgment
TC - flag Topology Change

**TCN (Topology Change Notification) BPDU**

| protocol identifier |
|---|
| version |
| message type = 1 |




1. Port changes state to disabled or blocking
2. Sends TCN-BPDU (periodicity = hello time)
3. Sends Conf-BPDU with TCA = 1 while receiving TCN-BPDU
4. Sends TCN-BPDU (periodicity = hello time)
5. Sends Conf-BPDU with TCA = 1 while receiving TCN-BPDU and with TC=1 for a period of time equal to *ForwardDelay* + *MaxAge*

   Root bridge uses the forwarding table short lifetime during this period
6. Sends Conf-BPDU with TC=1

   Bridge 1 uses the forwarding table short lifetime while receiving Conf-BPDU with TC=1

   Bridge 2 uses the forwarding table short lifetime while receiving Conf-BPDU with TC=1

# Other protocols: PVST+

- Cisco's proprietary versions of the SPT.
- It create a different spanning tree for each VLAN:
  - By default, the default spanning tree parameters are used in all spanning trees (i.e., all spanning trees are equal)
  - Configuring different parameters on the different VLANs, different spanning trees be obtained
  - The spanning tree of each VLAN runs only on the links belonging to the VLAN

Example of a (PVST+) BPDU:

- Dest. MAC: 01:00:0c:cc:cc:cd
- 802.1Q tag: VLAN 2

```
> Frame 4: 68 bytes on wire (544 bits), 68 bytes captured (544 bits) on interface -, id 0
> Ethernet II, Src: c2:02:4b:4c:f1:02 (c2:02:4b:4c:f1:02), Dst: PVST+ (01:00:0c:cc:cc:cd)
v 802.1Q Virtual LAN, PRI: 0, DEI: 0, ID: 2
    000. .... .... .... = Priority: Best Effort (default) (0)
    ...0 .... .... .... = DEI: Ineligible
    .... 0000 0000 0010 = ID: 2
    Length: 50
> Logical-Link Control
v Spanning Tree Protocol
    Protocol Identifier: Spanning Tree Protocol (0x0000)
    Protocol Version Identifier: Spanning Tree (0)
    BPDU Type: Configuration (0x00)
  > BPDU flags: 0x00
  > Root Identifier: 32768 / 0 / c2:01:1a:70:00:01
    Root Path Cost: 5
  > Bridge Identifier: 32768 / 0 / c2:02:50:4c:00:00
    Port identifier: 0x802b
    Message Age: 1
    Max Age: 20
    Hello Time: 2
    Forward Delay: 15
  v Originating VLAN (PVID): 2
      Type: Originating VLAN (0x0000)
      Length: 2
      Originating VLAN: 2
```

# Other protocols: RSTP

- IEEE 802.1w Rapid Spanning Tree Protocol
  - Extension of IEEE 802.1D
  - Speeds up the convergence time of the Spanning Tree in case of topology changes
    - There are only three port states in RSTP that correspond to the three possible operational states.
    - Adds two additional port roles to a port when in blocking state
      - Alternate port: possible alternative Root port.
      - Backup port: possible alternative Designated port.
  - Adds a negotiated mechanism between switches.
    - Uses the reserved bits in the Conf-BPDU.

**Conf (Configuration) BPDU**