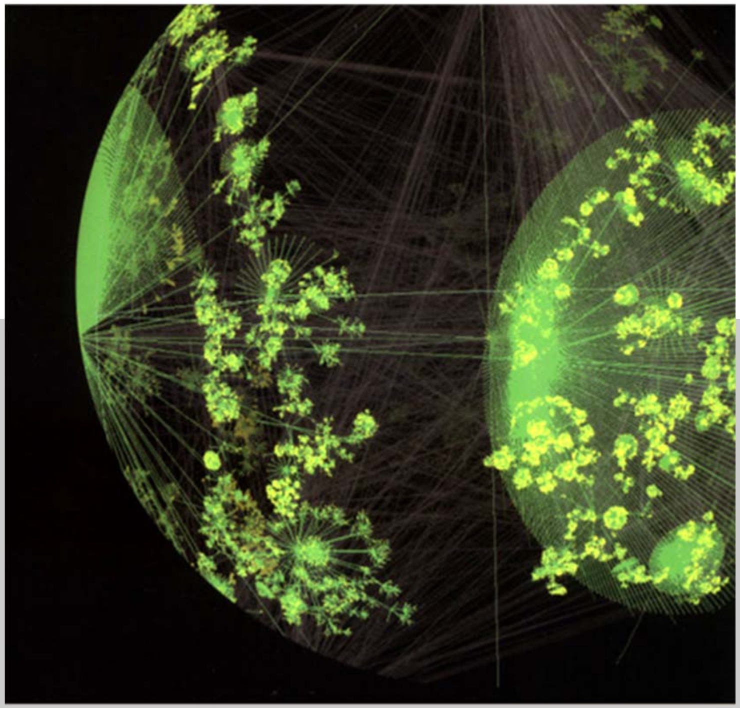
Chapter 3
Bridges, LANs, and the Cisco IOS



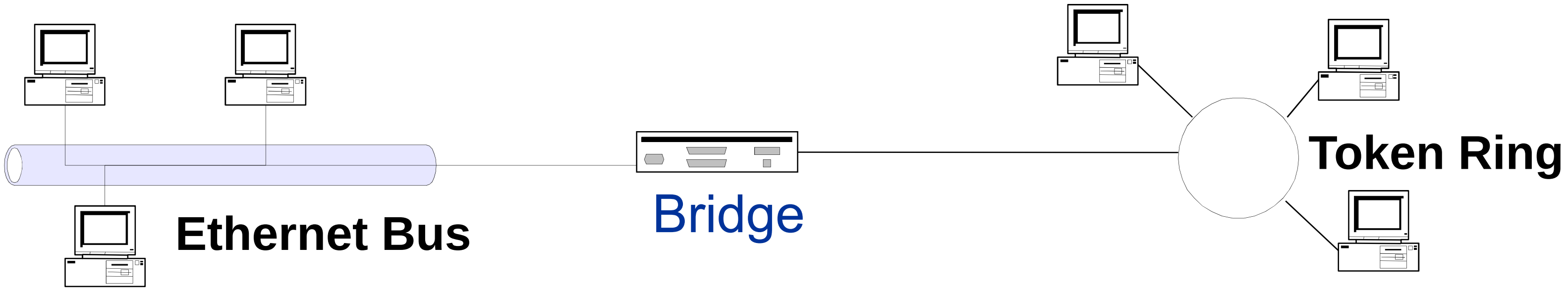
TCP/IP Essentials

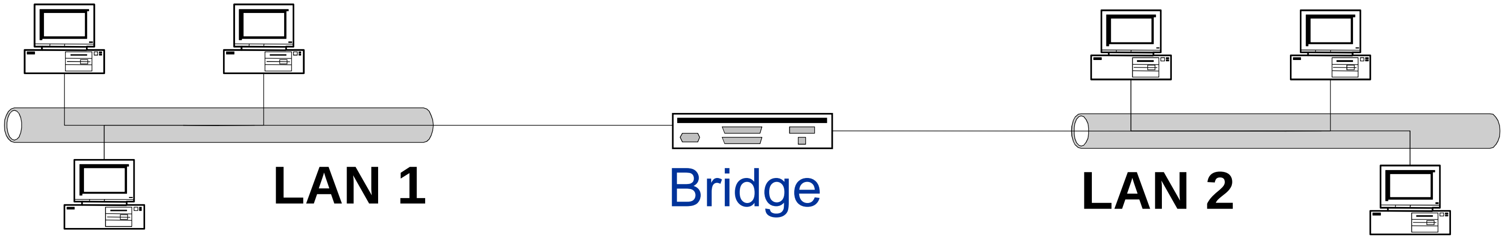
A Lab-Based Approach

Spring 2017

Bridges

- Interconnect multiple LANs, possibly of different types
- Bridges operate at the Data Link Layer (Layer 2)
- Pass frames to a different LAN if the destination is not on the local LAN.





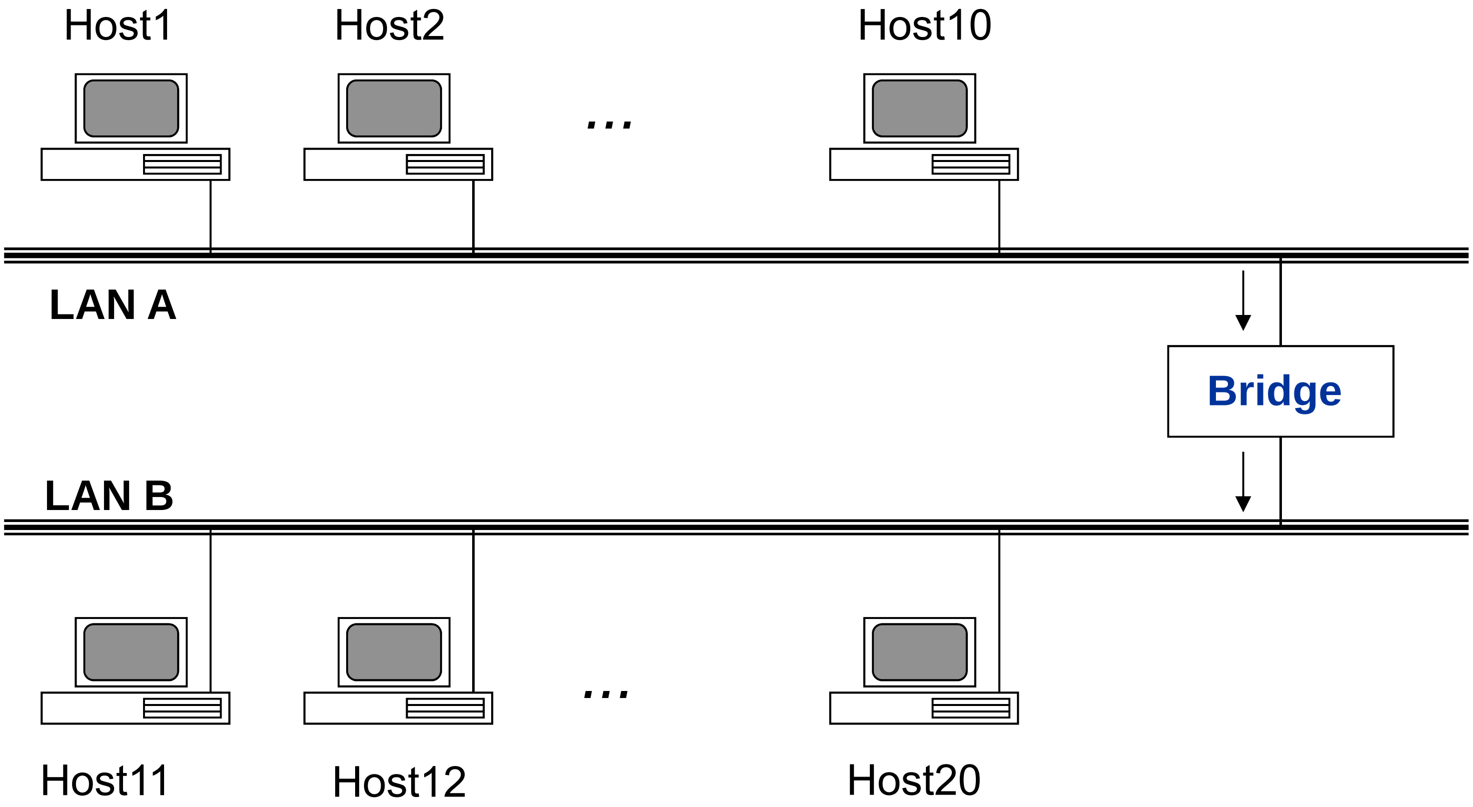
Why & What Bridges

- Bridges allow to build a local area network with multiple small LANs instead of one single LAN, which increases
  - reliability
  - throughput
  - security
  - geography
- *Transparent bridges* are not seen by hosts IF they connect same type of LANs.
  - Most frames are simply copied to the respective destination network ← not flooding to all networks/segments
  - No change in the header and data section.
- *Source Route bridges* , another form of bridging, use a field in frame header, ex. the Routing Information Field (RIF) in token ring header, to indicate the series of bridges along the routing path

Bridge Function – an Example

For frames from Host 1

- Those to Host 2 … Host 10 are forwarded on LAN A
- Those to Host 11 … Host 20 are forwarded on LAN A, accepted and repeated further on LAN B

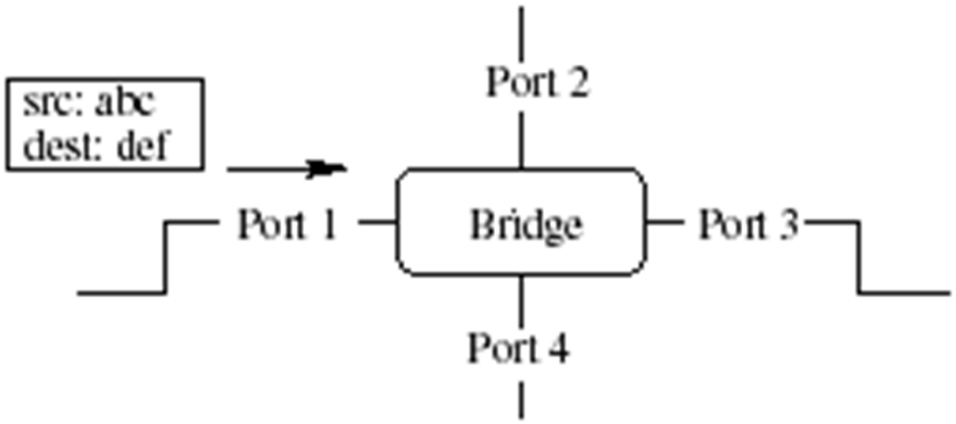


Filtering Database of a Bridge

- MAC addresses of the hosts are stored in a Filtering Database in the bridge.
- Elements of each entry of the filtering database
  - The destination MAC address
  - The bridge port where frames for this destination MAC address should be forwarded to
  - The age of this entry
- The filtering database could be set statically.
- In an IEEE 802.1d bridge, the filtering database is maintained automatically by a MAC Address Learning process.

Address Learning Process

- When a frame is received, its source MAC address and the incoming port are updated in the bridge's filtering database.
- The default age of a new entry is 300 sec.



The original filtering database:

Dest.	Port	Age

The new filtering database:

Dest.	Port	Age
abc	1	300s

Address Learning – an Example

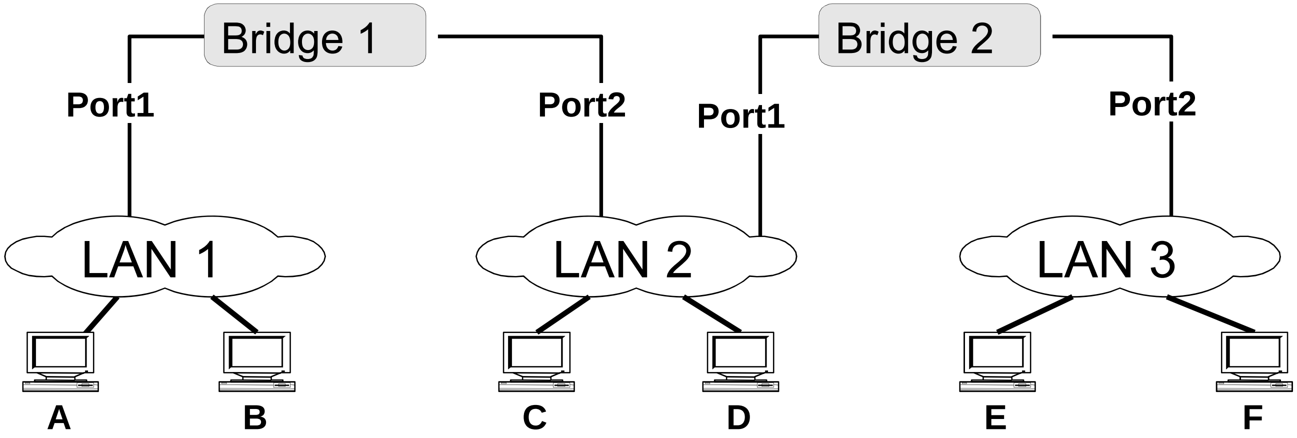
- Consider the following three packets:

  <Src=A, Dest=F>, <Src=C, Dest=A>, <Src=E, Dest=C>

- What have the bridges learned?

Dest.	Port	Age
A	1	…
C	2	…
E	2	…

Dest.	Port	Age
A	1	…
C	1	…
E	2	…

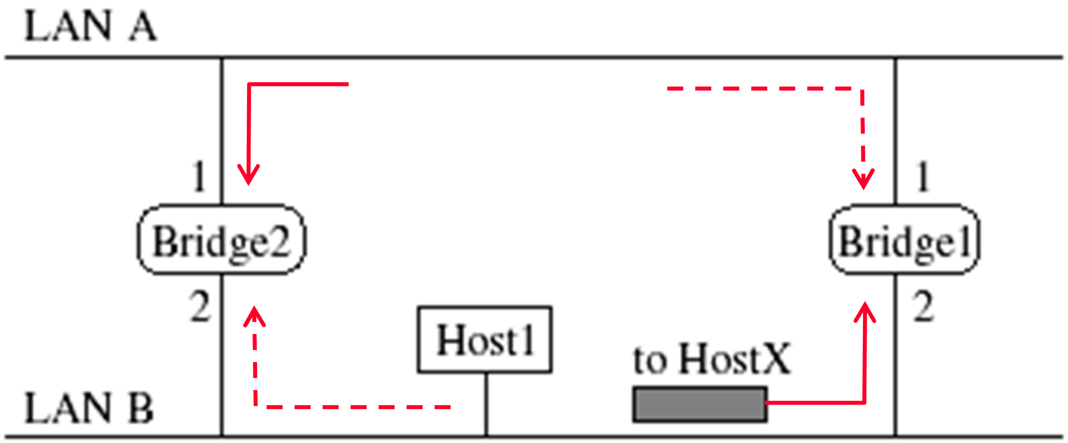


Bridge Operations

- A bridge makes forwarding decisions by filtering database lookups.
  - If an entry is found, the bridge forwards the frame to the network segment indicated by the entry.
  - Otherwise, Flooding is used. The frame is copied to all active ports except the incoming port.

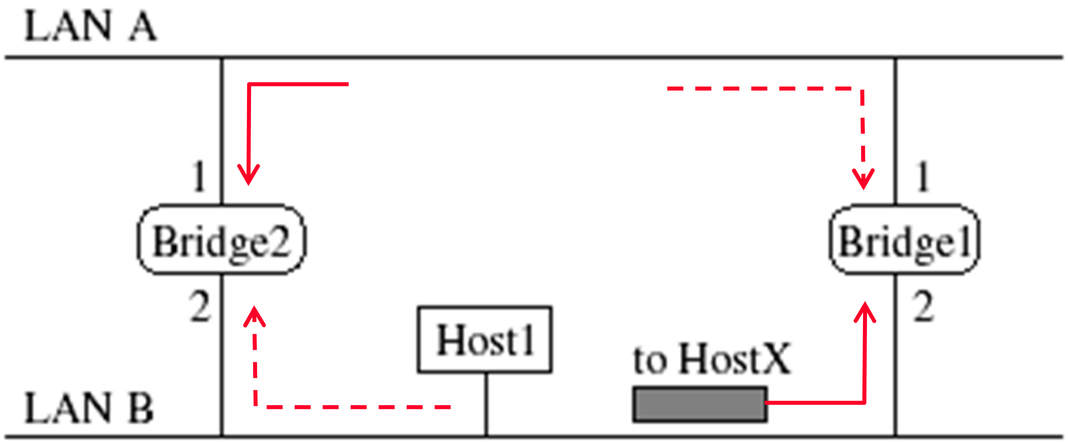
Danger of Loops

- Address learning and forwarding scheme may cause serious problems when there is a loop.
- Assume
  - Host 1 sends a frame to Host X (not shown in the picture below).
  - There is no entry about Host X in Bridge 1 and Bridge 2's filtering database.
- Bridges 1 and 2 both
  - receive the frame on LAN B, and learn that host 1 is on LAN B,
  - correctly add the entry for Host 1 in their filtering database, and
  - Forward the frame to LAN A using flooding since there is no entry for Host X.



Danger of Loops (cont'd)

- Then, each bridge
  - will receive the same frame forwarded by the other bridge, and
  - will incorrectly change the filtering database entry to indicate that Host 1 is on LAN A.
- This process will repeat indefinitely, which leads to a *broadcast storm*.
- Other traffic can be blocked, resulting in a network meltdown.

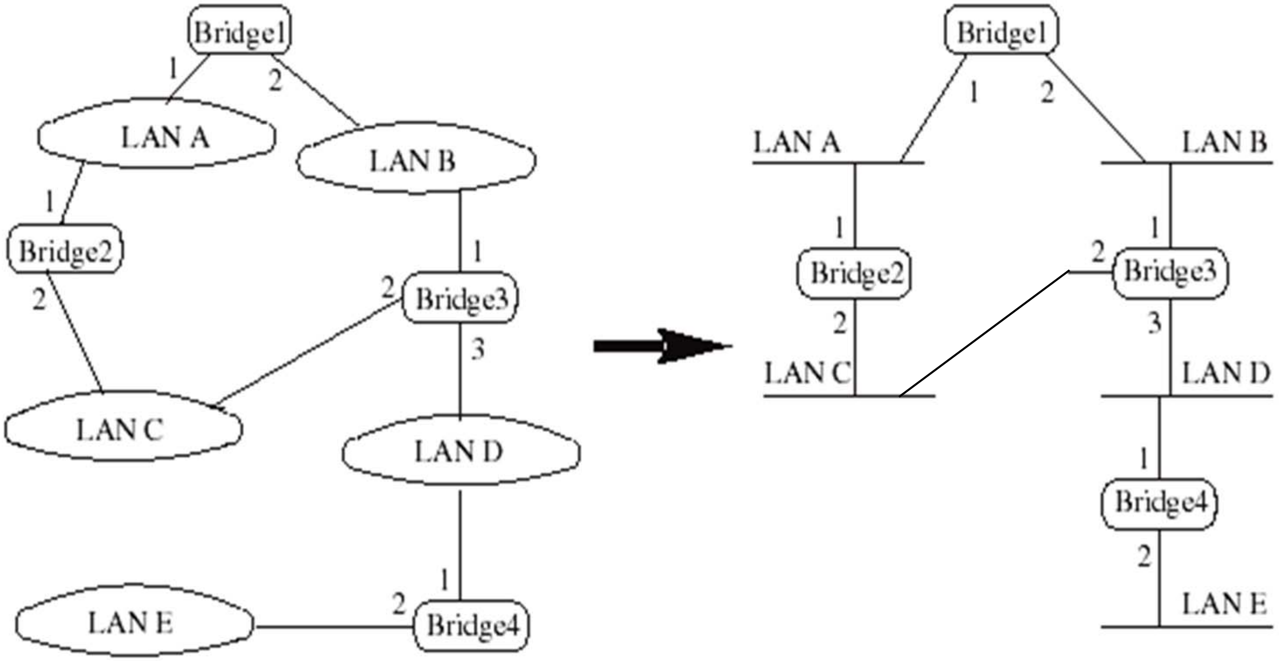


Removing Loops

- The solution to the loop problem is to remove loops.
- IEEE 802.1 has an algorithm, Spanning Tree Protocol (STP), that builds and maintains a Spanning Tree in a dynamic environment.
- Bridges exchange messages, Configuration Bridge Protocol Data Units (Configuration BPDUs), to configure the bridge and build the tree.

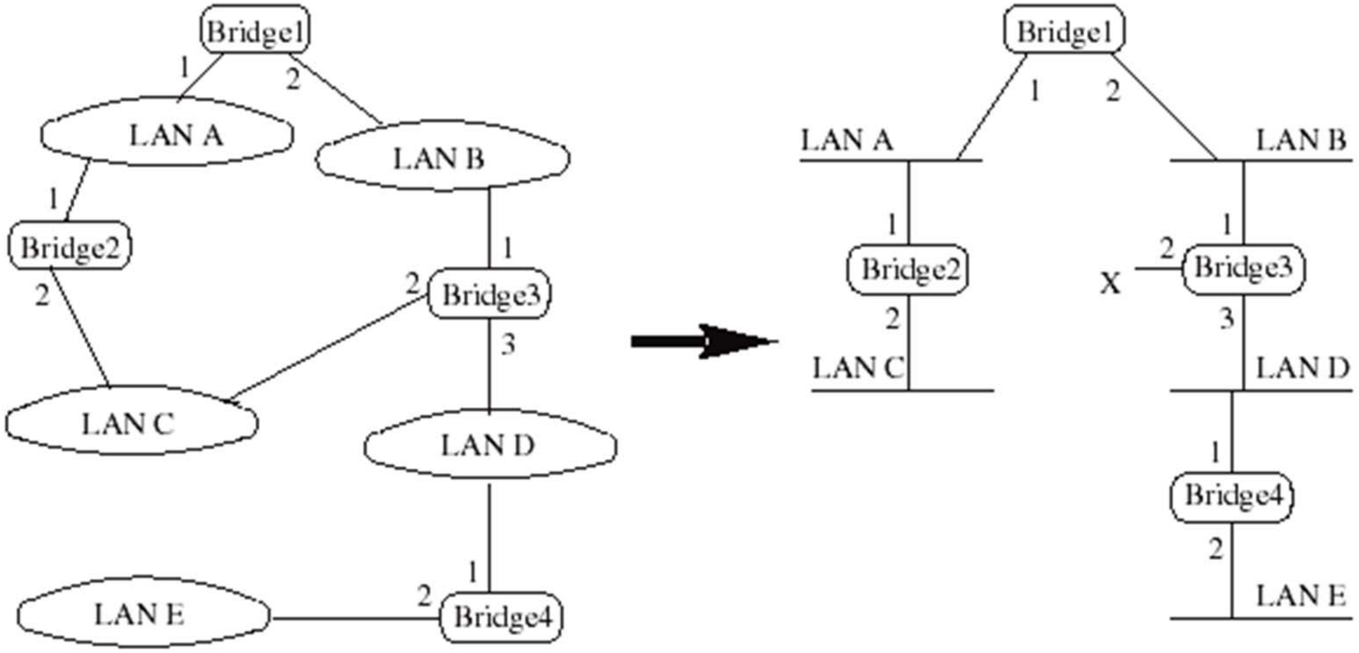
A Graph of a Network

- A bridged network can be viewed as a graph
  - The bridges are nodes
  - The LAN segments are edges



A Tree of a Network

- A tree is a graph with no loops
- Disable some bridge ports to remove loops
  - e.g., port 2 of Bridge 3 in the figure
- In a tree, there is only a single path between any two hosts

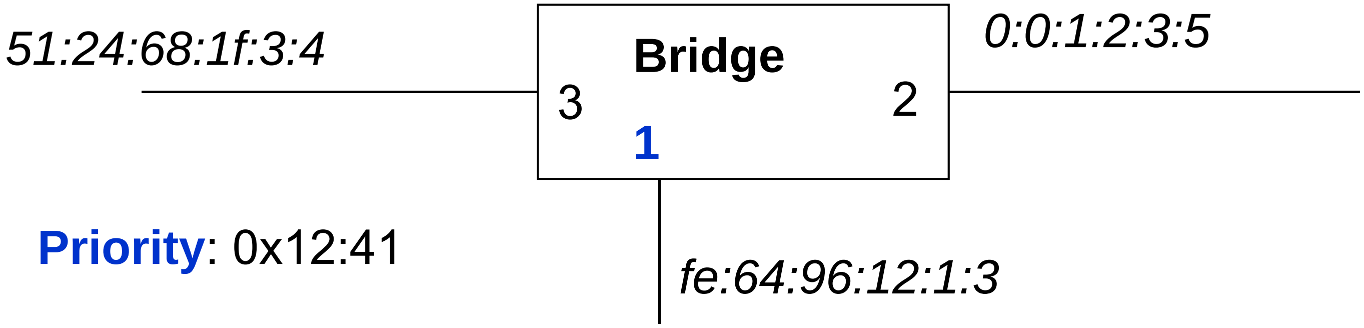


Building a Spanning Tree (1/6)
– Bridge ID

Each bridge has a unique identifier (8 bytes) defined:

- Bridge ID = <bridge Priority Level + MAC address>
- Priority Level has 2 bytes that can be configured
- A bridge has several MAC addresses (one for each port), but the Bridge ID uses only the MAC address of the lowest numbered bridge port (port 1)

Each port within a bridge has a unique identifier (port ID).



51:24:68:1f:3:4

Bridge

3

2

1

0:0:1:2:3:5

Priority: 0x12:41

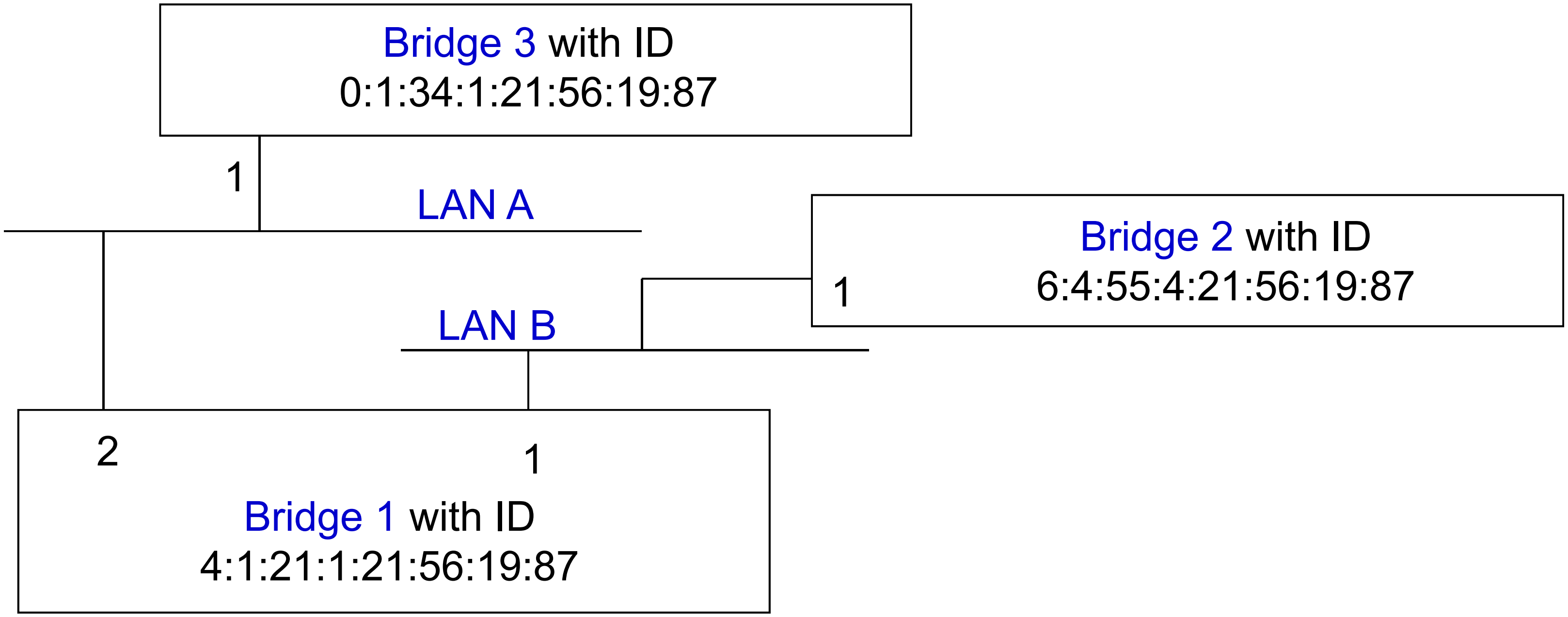
fe:64:96:12:1:3

Bridge ID = 12:41:*fe:64:96:12:1:3*

Building a Spanning Tree (2/6) – Root Bridge of a Network

A spanning tree can be "built" from its logical root – a Root Bridge

Root Bridge: The bridge with the lowest identifier is the root of the spanning tree.



The Root Bridge is Bridge 3, since it has the smallest ID.

Building a Spanning Tree (3/6) – For Each Bridge

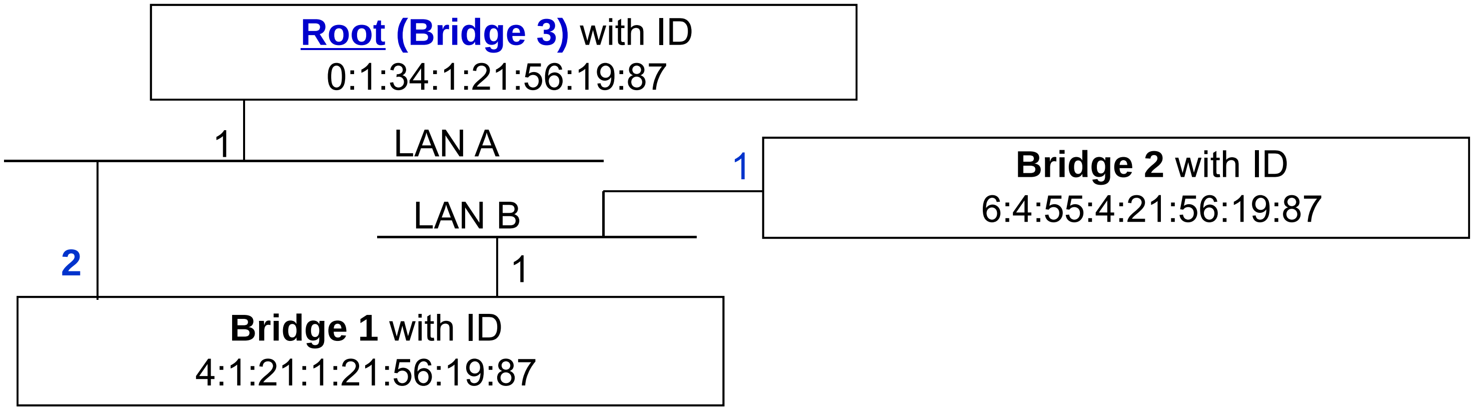
Root Port: Each bridge has a root port which identifies the next hop from a bridge to the root.

Root Path Cost: the cost of the min-cost path to the root.

For Bridge 1:

- The root port is port 2 since it leads to the Root Bridge (Bridge 3)
- The root path cost is 1 since bridge 1 is one hop away from the Root Bridge (i.e., Bridge 3).

Note: We assume that "cost" of a path is the number of "hops". This "cost" can take the value per IEEE 802.1D based on the port speed or be set to different values when designing the network.

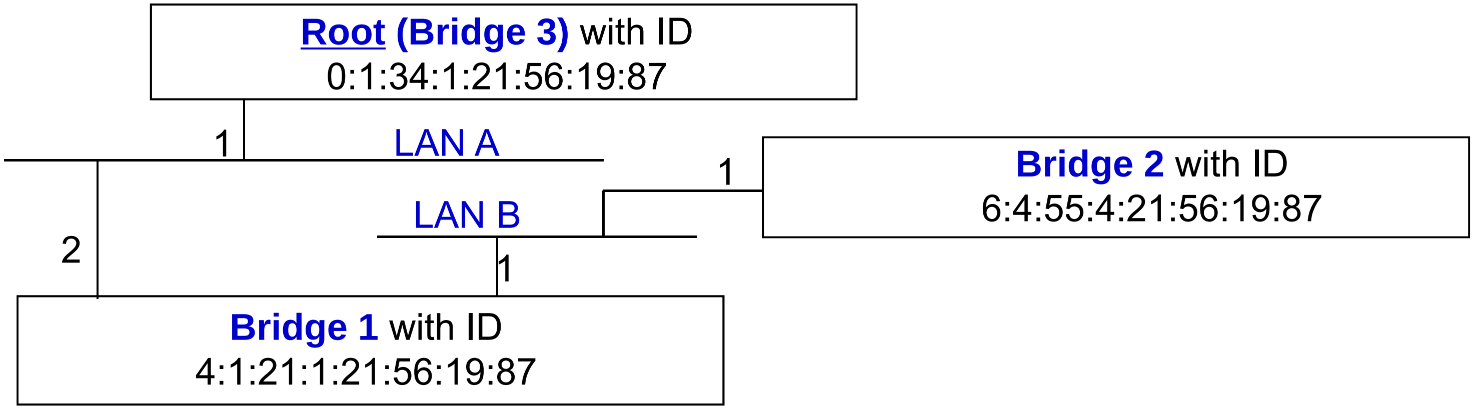


Building a Spanning Tree (4/6)
– For Each LAN

- Designated Bridge: single bridge on a LAN that provides the minimal cost path to the root for this LAN
- Designated Port: the port on this minimal cost path.
- If two bridges have the same cost, select the one with highest priority (lower bridge ID)
- If the min-cost bridge has two or more ports on the LAN, select the port with the lowest identifier

Building a Spanning Tree (5/6)
– For Each LAN Segment

- For LAN A, the designated bridge is Bridge 3 since it is the Root Bridge itself; the designated port is port 1.
- For LAN B, the designated bridge is Bridge 1 since this is closer to the root bridge than bridge 2. The designated port is port 1.



Building a Spanning Tree (6/6)
– Designated Bridge and Designated Port

- Even though each LAN is the entity that has a designated bridge/designated port, it is each bridge that determines whether or not it is the designated bridge for the LAN on each of its ports, because a LAN is a group of hosts, there is no centralized control over a LAN.
- Example: Bridge 1 in the example on slide 18 determines whether it is the designated bridge for LAN A (to which its port 2 is connected) and for LAN B (to which its port 1 is connected).

Spanning Tree Algorithm

Step 1: Each bridge is assigned a unique identifier, and each port of a bridge is assigned an identifier unique to the bridge.

Step 2: Determine the root bridge of the whole network.

Step 3: For all other bridges determine root ports.

Step 4: For all bridges, determine which of their bridge ports are respective designated ports for the corresponding LANs.

Step 5: Only the root ports and designated ports of bridges are allowed to forward frames.

- These ports are all set to the “forwarding state,” while all other ports are in a “blocked state.”
- The spanning tree consists of all the root ports and the designated ports.

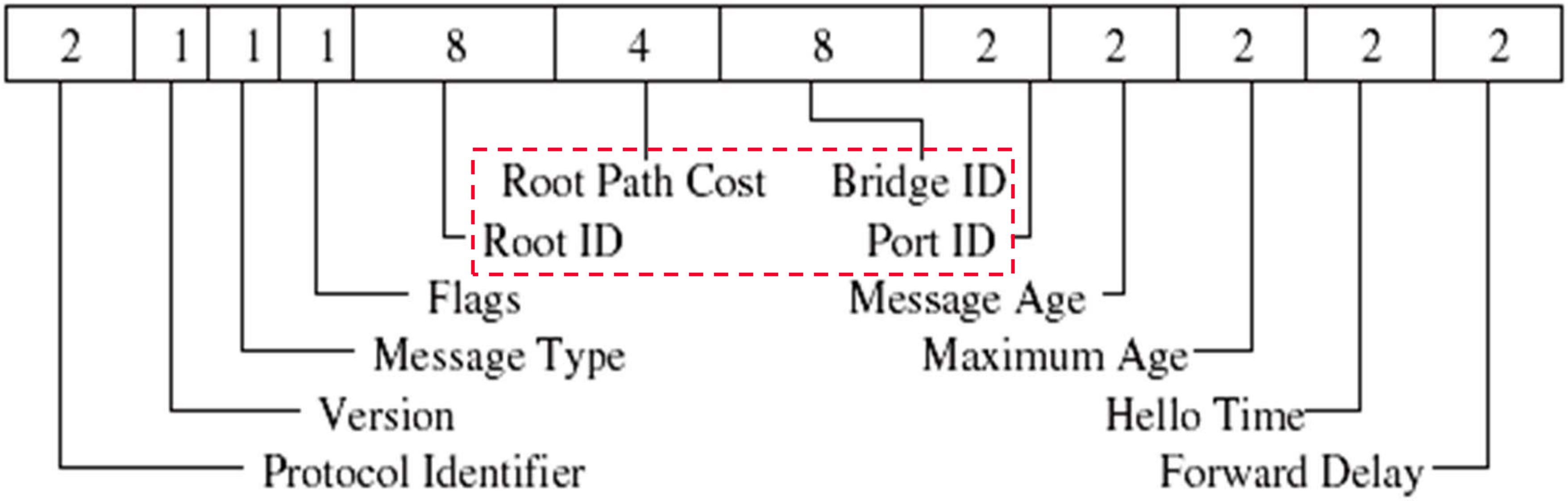
Step 6: Repeat steps 1 to 5 whenever the network topology changes.

Determine the Spanning Tree

Bridges determines the spanning tree in a "distributed manner" by using exchanged BPDUs.

- Elect a single bridge as the root bridge.
- Each bridge can determine:
  - a root port, the port that gives the best path to the root bridge.
  - and the corresponding root path cost
- Each bridge determines whether it is a designated bridge, for the LANs connected to each of its ports. The designated bridge will forward packets the corresponding LANs towards the root bridge.
- Select ports to be included in the spanning tree.
  - Root ports and designated ports
- It takes some time for a network to converge.

Configuration BPDUs

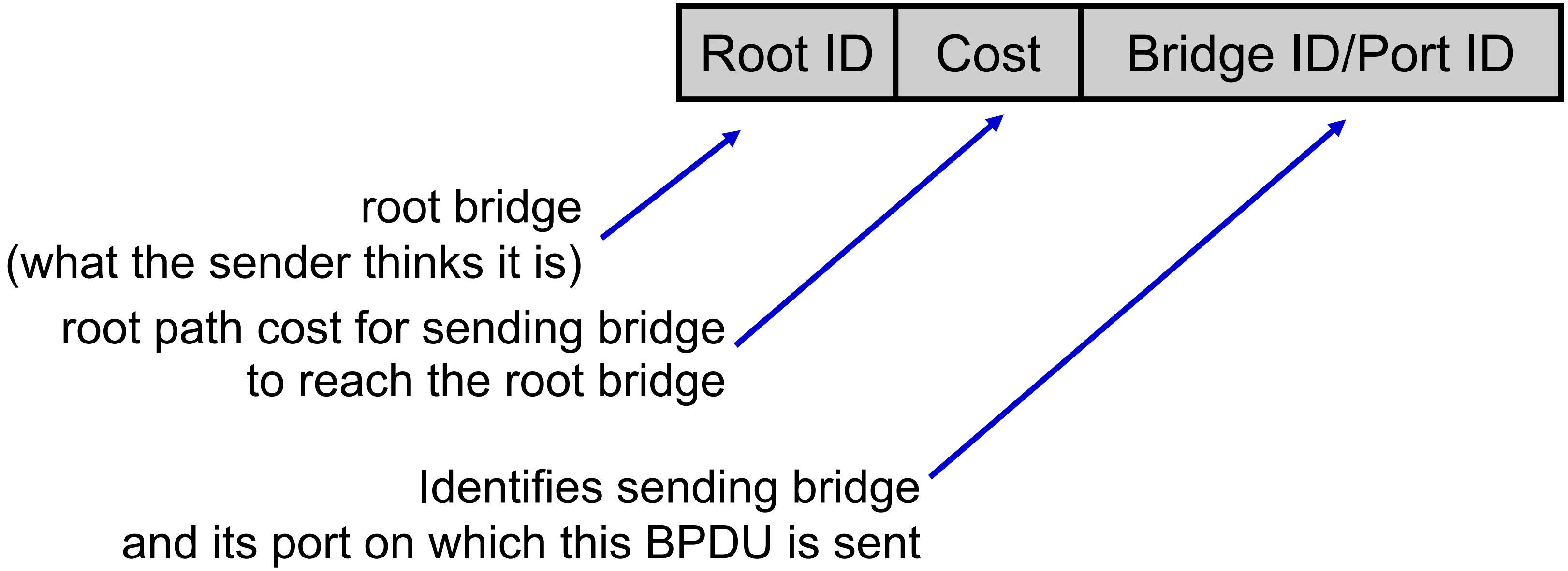


Note –

- Shown format above used for building single spanning tree
- New format introduced to support Multiple Spanning Tree Protocol (MSTP) for Virtual LANs (VLANs)

Short Form Notation for BPDUs

- Each bridge sends out BPDUs
  - With Bridge Group Address starting like 01:80:C2:00:00:00
  - Containing the following information:



Root ID	Cost	Bridge ID/Port ID

root bridge
(what the sender thinks it is)

root path cost for sending bridge
to reach the root bridge

Identifies sending bridge
and its port on which this BPDU is sent

Ordering of BPDU Messages

We can order BPDU messages with the following ordering relation “⬋”:

M1	ID R1	C1	ID B1/P1	⬋	ID R2	C2	ID B2/P1	M2

a.k.a. M1 can be used to form a superior bridge configuration → new BPDU

```
If (R1 < R2)
    M1 ⬋ M2
elseif ((R1 == R2) and (C1 < C2))
    M1 ⬋ M2
elseif ((R1 == R2) and (C1 == C2) and (B1 < B2))
    M1 ⬋ M2
elseif ((R1 == R2) and (C1 == C2) and (B1 == B2) and (P1<P2))
    M1 ⬋ M2
```

Determine the Root Bridge

- Initially, each bridge assumes itself is the root bridge.
- Each bridge B sends BPDUs of this form on its LANs:

B	0	B/p

note p changes its value as the sending port ID

- Each bridge looks at the BPDUs received on all its ports and its own transmitted BPDUs.
- Root Bridge is the smallest received root ID that has been received so far (Whenever a smaller ID arrives, the root is updated).

Calculate the Root Path Cost
Determine the Root Port

At this time: Bridge B has a belief of who the root is, say R.

Bridge B determines the Root Path Cost (Cost) as follows:

- *If $B = R$:* Cost = 0.
- *If $B \neq R$:* Cost = {Smallest Cost in any of BPDUs that were received from R} + 1 (hop, as the additional cost)

B's root port is the port from which B received the lowest cost path to R

Knowing R and Cost, B/p can generate its BPDU (but will not necessarily send it out):

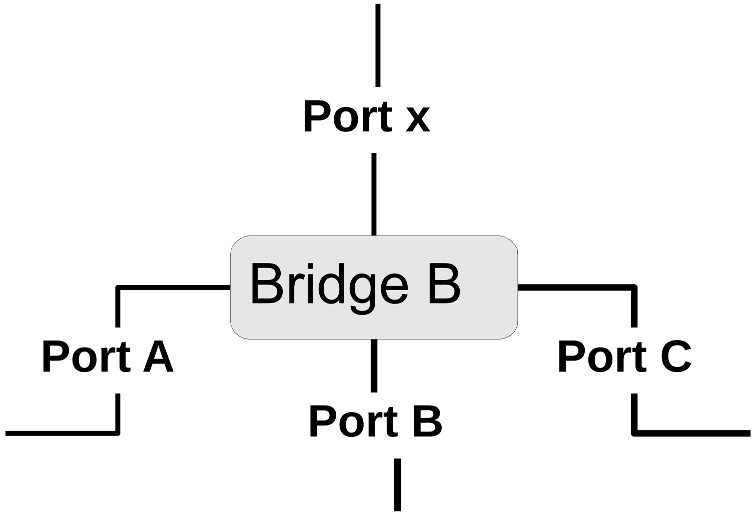
R	**Cost**	**B/p**

Determine if the bridge is the designated bridge for any of the LANs connected to its ports

B has generated its BPDU. B will send this BPDU on one of its ports, say port x, only if its BPDU is lower than any BPDU that B received from port x. Then the BPDU sent from port x is

R	**Cost**	**B/x**

In this case, B also assumes that it is the designated bridge for the LAN to which port x connects.



Select Ports for the Spanning Tree

- Bridge B has calculated the root bridge for the network, its root port, root path cost, and whether it is the designated bridge for each of its LANs.
- Now B can decide which ports are in the spanning tree:
  - B's root port is part of the spanning tree
  - All ports for which B is the designated bridge are part of the spanning tree.
- B's ports that are in the spanning tree will forward packets (forwarding state)
- B's ports that are not in the spanning tree will block packets (blocking state) except BPDUs and other needed control protocol frames

Adapt to Changes

- Bridges continually exchange BPDU’s according to the rules we just discussed.
- This allows the bridges to adapt to changes to the topology.
- Whenever a BPDU arrives on a port, say port x, bridge B determines:
  - Can B become the designated bridge for the LAN that port x is attached to?
  - Can port x become the root port?

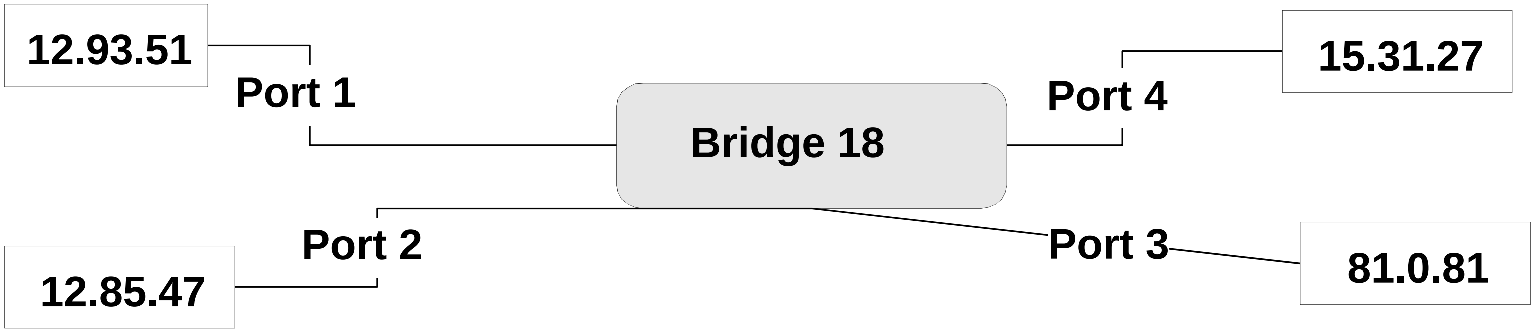
Example 1

A Bridge with ID 18

The lowest messages received on its 4 ports are shown in the figure (*ignore the corresponding sending port IDs here*).

After Bridge 18 checks all four messages, then

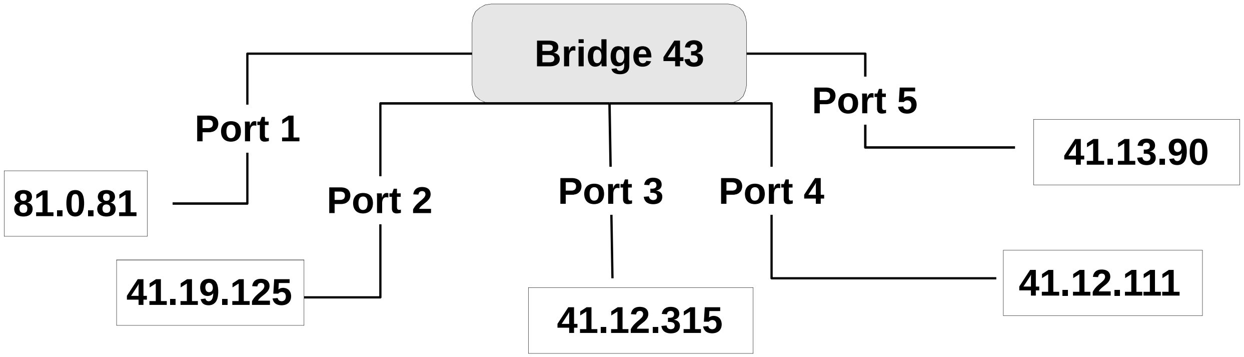
- What is the root? -- the bridge with ID12
- What is the Root Path Cost? – 85 +1 = 86
- What is the root port? – Port 2
- What is 18's configuration BPDU? – 12.86.18
- For which LAN (through which port), if any, is B the designated bridge? – Ports 1,3, 4



Example 2

A bridge with ID 43, the lowest messages received on its five ports are shown.

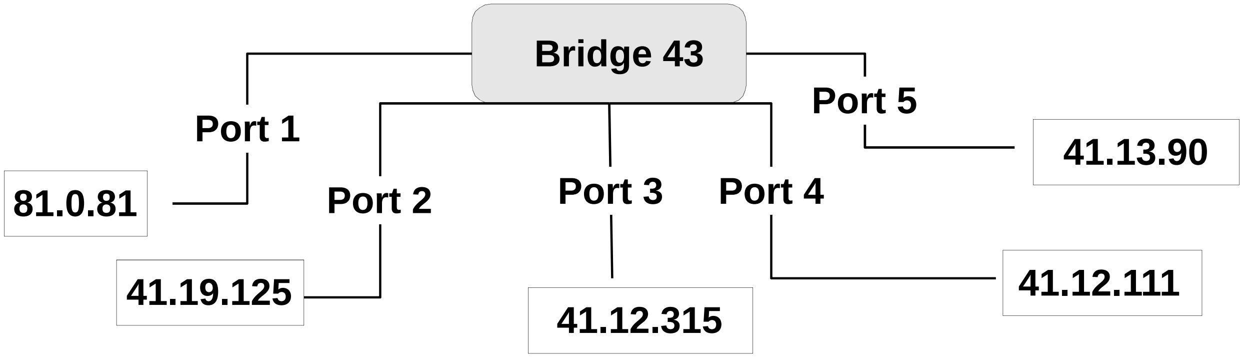
- What is the root?
- What is the Root Path Cost?
- What is the root port ?
- What is Bridge 43's configuration BPDU?
- Which ports, if any, are designated ports on Bridge 43?



Example 2 (Solution)

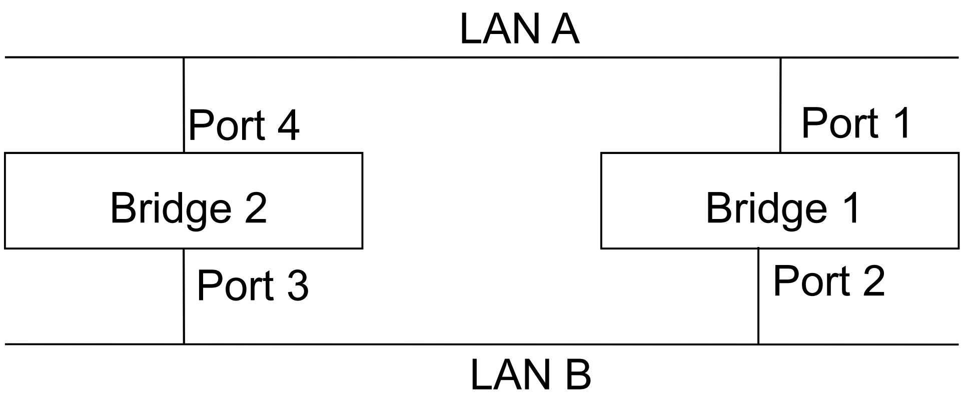
A bridge with ID 43, the lowest messages received on its five ports are shown.

- What is the root? Bridge 41
- What is the Root Path Cost? 13
- What is the root port ? Port 4
- What is Bridge 43's configuration BPDU? 41.13.43
- Which ports, if any, are designated ports on Bridge 43? 1,2,5



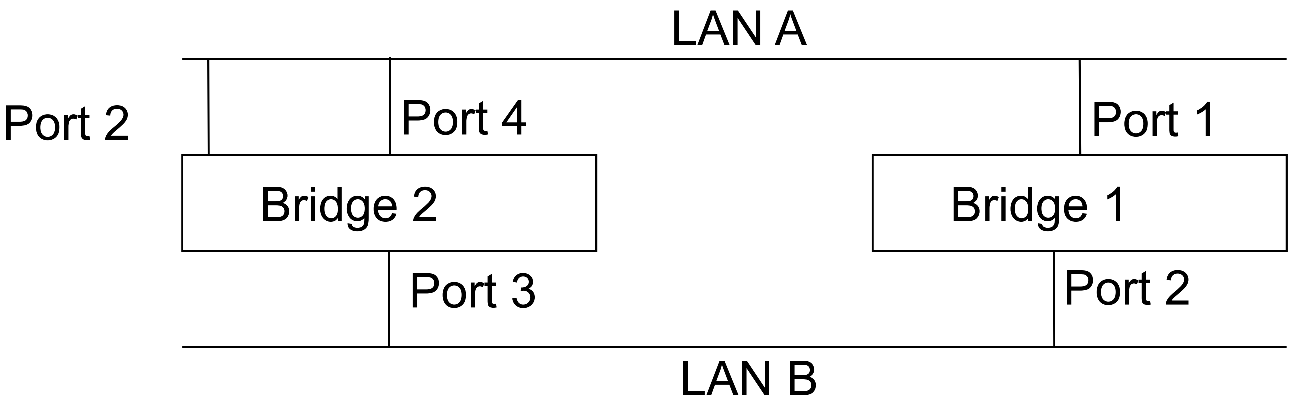
Interesting Case One

- Bridge 2 receives two BPDUs [1,0,1] on both its port 3, e.g. [1,0,1/2], and port 4, e.g. [1,0,1/1]
- The designated port for LAN A is port 1 on Bridge 1
- The designated port for LAN B is port 2 on Bridge 1
- Since the port 1 on Bridge 1 is lower than the port 2, it has higher priority.
- Hence port 4 is the root port on Bridge 2.



Interesting Case Two

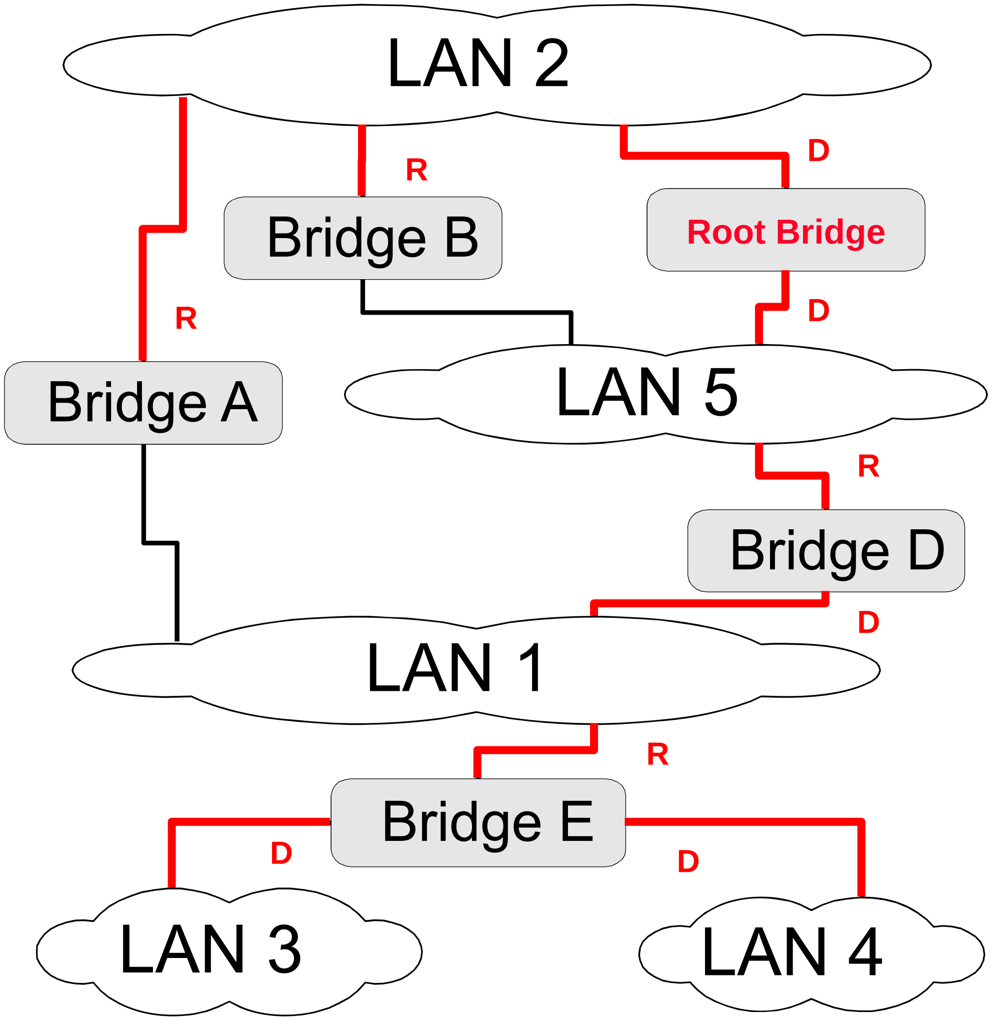
- Ports 4 and 2 of Bridge 2 are both on LAN A. They will both receive BPDU [1,0,1/1] from Bridge 1.
- The designated port for LAN A is port 1 on Bridge 1. So even the designated ports are the same.
- Hence choose between ports 2 and 4 by selecting the lower one, which makes port 2 as the root port on Bridge 2.



Building the Spanning Tree

Consider the network on the right.

Assume that the bridges have calculated the designated ports (D) and the root ports (R) as indicated.



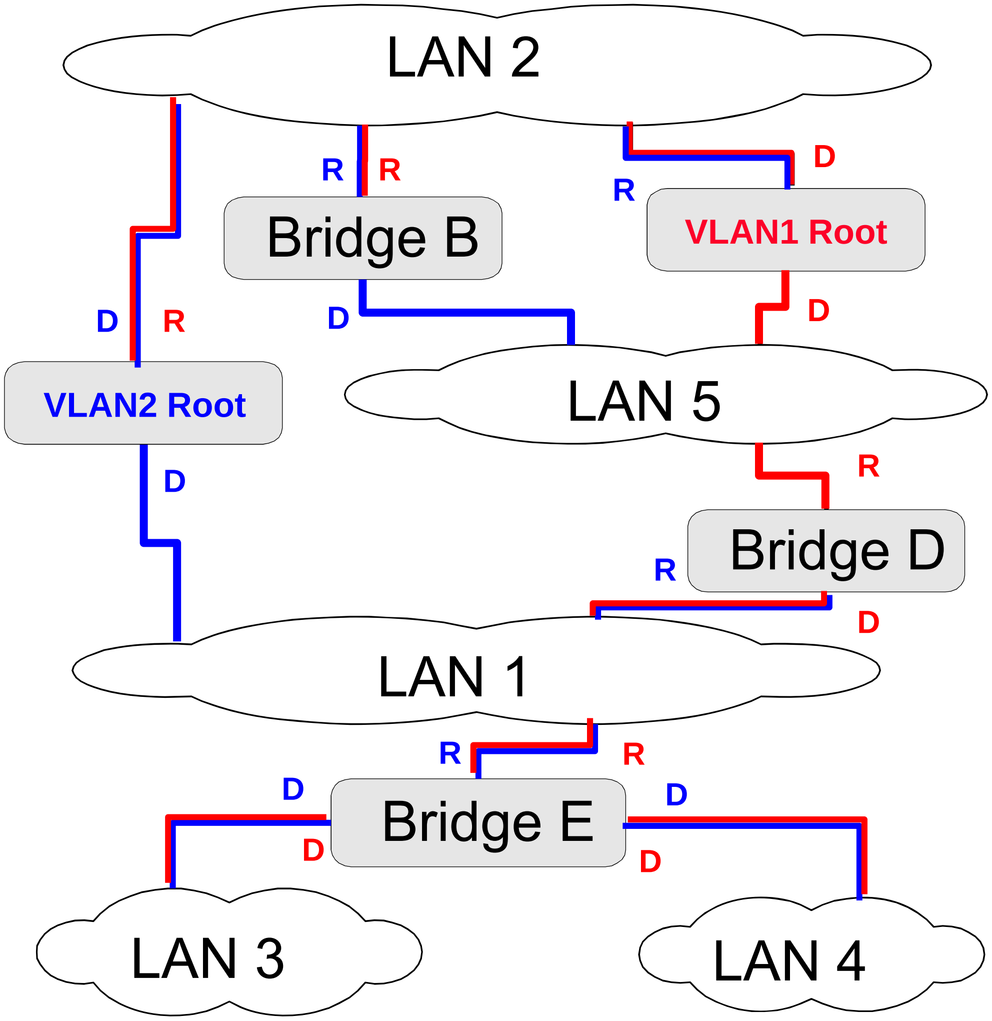
- Which bridge is the Root Bridge?
- Where is the spanning tree?

802.1Q Virtual LANs (VLAN)

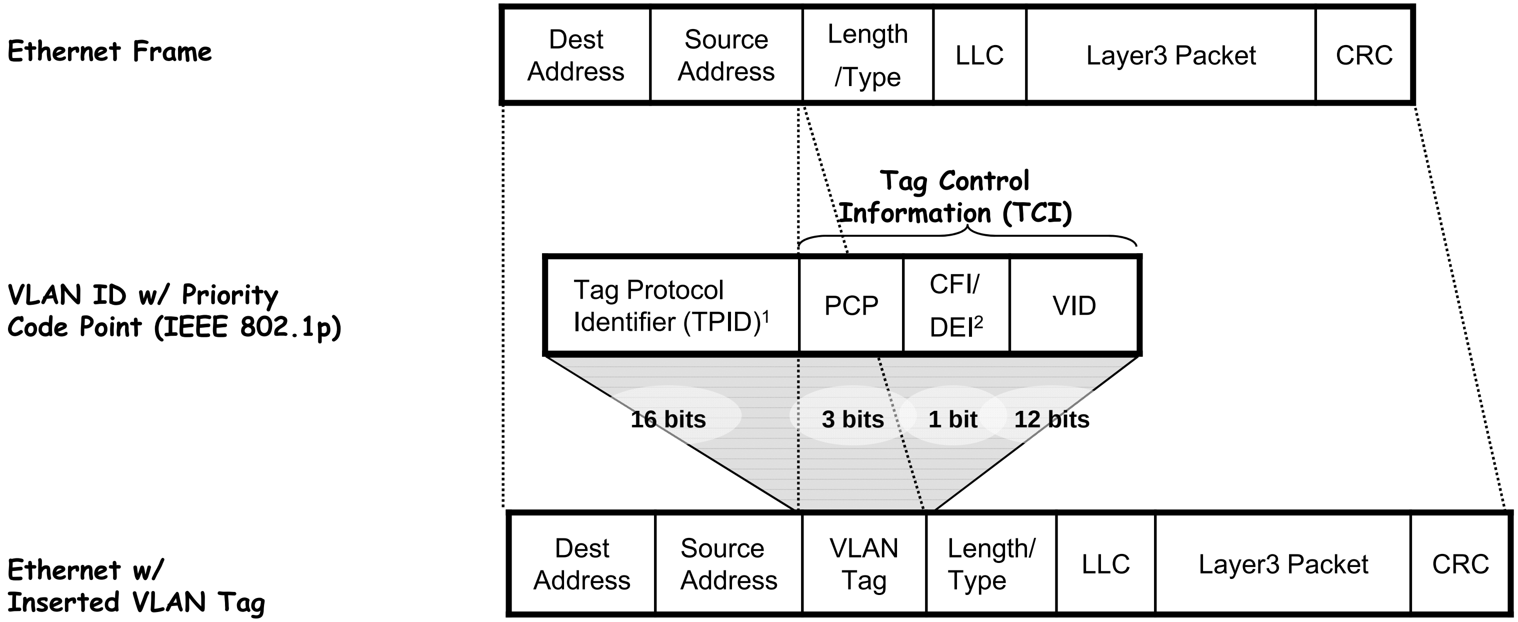
- IEEE 802.1Q defines the operation of VLAN Bridges to partition a LAN
  - Hosts are assigned to logical groups (VLANs) to communicate within each group in Layer2
  - Each bridge port is configured to support one or more VLANs
  - Bridges filter destination addresses and forward VLAN frames only to ports that serve the VLAN to which the traffic belongs
- Applications:
  - Enterprise customers to segregate traffic for different communities of interest, ex. financing, engineering, customer service, …
  - Broadcast control to avoid traffic flooding to entire L2 network
  - Service providers to isolate different customers' traffic from each other

Example: Building Spanning Trees for two VLANs

- Design two VLANs, VLAN1 and VLAN2 in a bridged network
- Each bridge has two distinct Bridge IDs, one for each VLAN
  - Configured with different priority levels
- Each bridge port is configured with two port IDs
- Multiple Spanning Tree Protocol (MSTP) forms two spanning trees, one for each VALN



IEEE 802.1Q/p VLAN and Priority Tagging



Maximum frame size w/ VLAN tag becomes 1518 + 4 = 1522 bytes

- TPID (Tag Protocol IDentifier) sets to 81:00 for Ethernet, other protocols include Token Ring, FDDI, … 802.1ad assigns TPID 88:a8 for Ethernet in S-VLAN tag.
- 3 bits Priority Code Point (PCP) for p0 to p7 eight priority levels
- CFI (Canonical Format Indicator) sets if this is a Token Ring frame encapsulated in an Ethernet format; see 802.ad slides for DEI definition
- **12 bits VLAN IDentifier (VID) supports 4096 unique VLAN tags**

IEEE 802.11 Wireless LANs

Alternative to the wired Ethernet:

- Wireless channel
- Frequency band: unlicensed radio spectrums

Protocols:

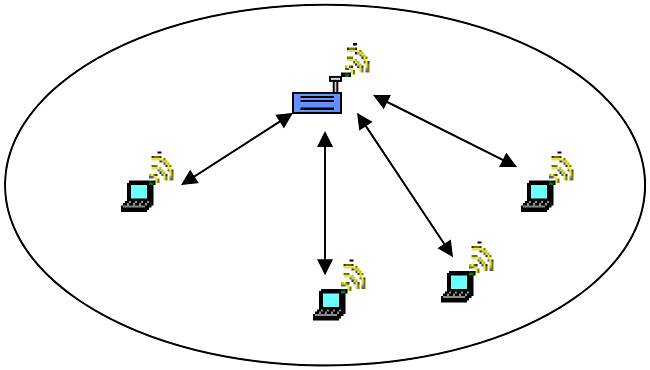
- IEEE 802.11b: 5, 11Mbps channel speed, 2.4GHz frequency band
- IEEE 802.11a: 6, 9, 12, 18, 24, 36, 48, 54Mbps, 5GHz frequency band
- IEEE 802.11g: 54 Mbps, 2.4GHz band
- IEEE 802.11i: security
- IEEE 802.11f: Inter Access Point Protocol
- IEEE 802.11e: Quality of Service enhancement, …, video optimized
- IEEE 802.11n: data rate great than 100 Mbps using MIMO, 2.4G and/or 5GHz bands
- IEEE 802.11ac: single stream up to 433 Mbps, more spatial streams, 5GHz band

Range: Transmission power up to 100mW

- Indoor: 20 - 25 meters
- Outdoor: 50 - 100 meters

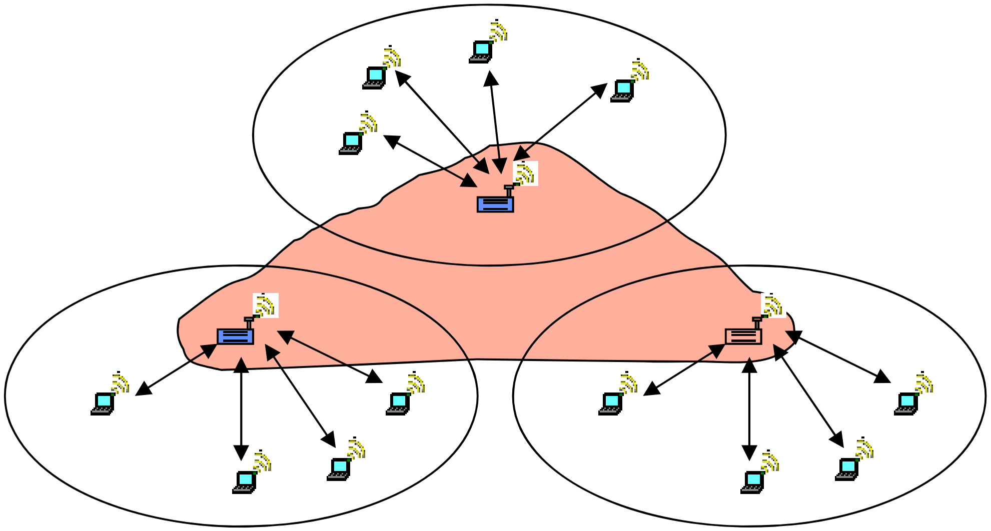
IEEE 802.11 Architecture

Basic Service Set (BSS)



Extended Service Set (ESS)

a.k.a. Infrastructure Mode



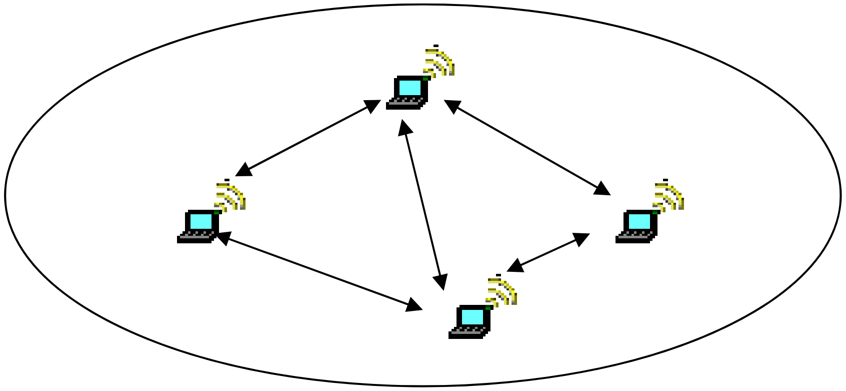
Infrastructure mode

- Fixed Access Point (AP) provides:
  - Connection to wireline network
  - Relay function
- Handoff, an active host moves from one access point to another.

IEEE 802.11 Architecture (cont'd)

The ad hoc mode, a.k.a. Independent BSS

- No access point.
- Hosts communicate with each other directly.



IEEE 802.11 Frame Format

Frame Control	Duration	MAC Address 1	MAC Address 2	BSS ID	Sequence Control	MAC Address 4	Data	CRC
2	2	6	6	6	2	6	0 ~ 2312	4

- More fields than other data-link protocols
- High overhead:
  - 30 byte header
  - Four Address fields: BSSID, Source Address, Destination Address, Receiving Station Address, Transmitting station Address depend on Frame Control setting
- Different frame types for different tasks:
  - Some fields are not presented in all types of frames

802.11 MAC Addresses

MAC header contains up to 4 MAC addresses:

- MAC addresses are globally unique IDs assigned by manufacturer to any network interface card (NIC).
- Several IEEE formats: MAC-48, EUI-48, EUI-64

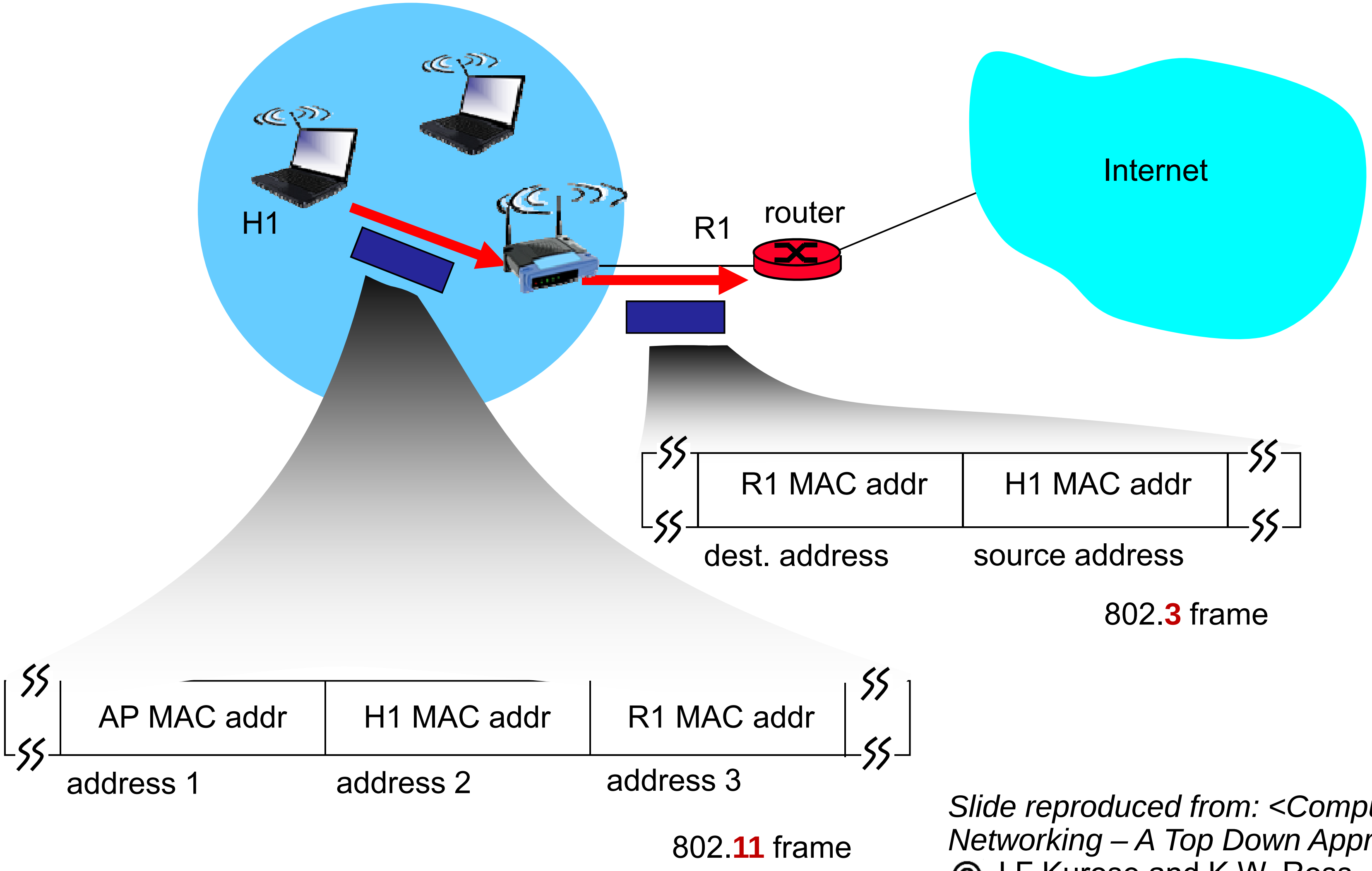
Addresses:

- RA, TA = receiving, transmitting MAC addresses
- BSSID = ID of basic service set of the transmission
- DA, SA = end-to-end destination, source MAC address (wired or wireless)
  - –May be different from RA, TA in multi-hop wireless transmission, rarely used.

2 bits in the header Frame Control field

Scenario		To DS	From DS	Addr 1	Addr 2	Addr 3	Addr 4
IBSS (Ad Hoc network)		0	0	RA=DA	TA=SA	BSSID	N/A
Infrastructure network	AP to STA	0	1	RA=DA	TA=BSSID	SA	N/A
	STA to AP	1	0	RA=BSSID	TA=SA	DA	N/A
	AP to AP	1	1	RA	TA	DA	SA

802.11 frame: addressing



Internet

router

R1

H1

R1 MAC addr	H1 MAC addr
dest. address	source address

802.3 frame

AP MAC addr	H1 MAC addr	R1 MAC addr
address 1	address 2	address 3

802.11 frame

Slide reproduced from: <Computer Networking – A Top Down Approach>, © J.F Kurose and K.W. Ross

IEEE 802.11: multiple access

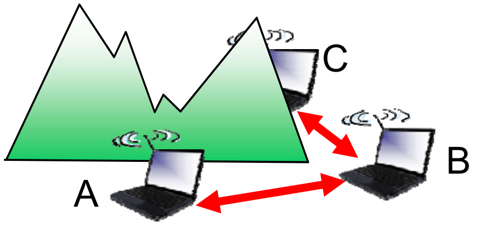
Collisions: 2$^+$ nodes transmitting at same time

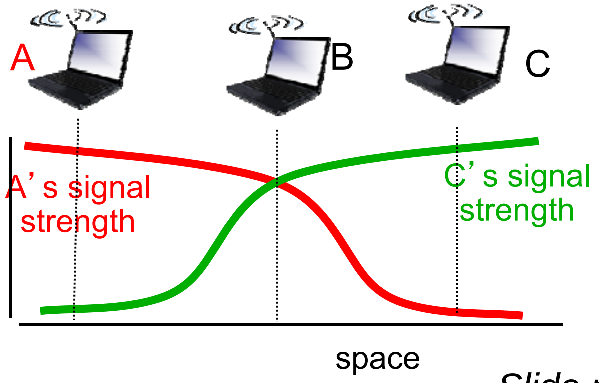
802.11: CSMA - sense before transmitting

- don't collide with ongoing transmission by other node

802.11: *no* collision detection (CD)!

- difficult to receive (sense collisions) when transmitting due to weak received signals (fading)
- can't sense all collisions in any case: hidden terminal, fading
- goal: *avoid collisions:* CSMA/C(ollision)A(voidance)





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CSMA/CA

CSMA/CA:

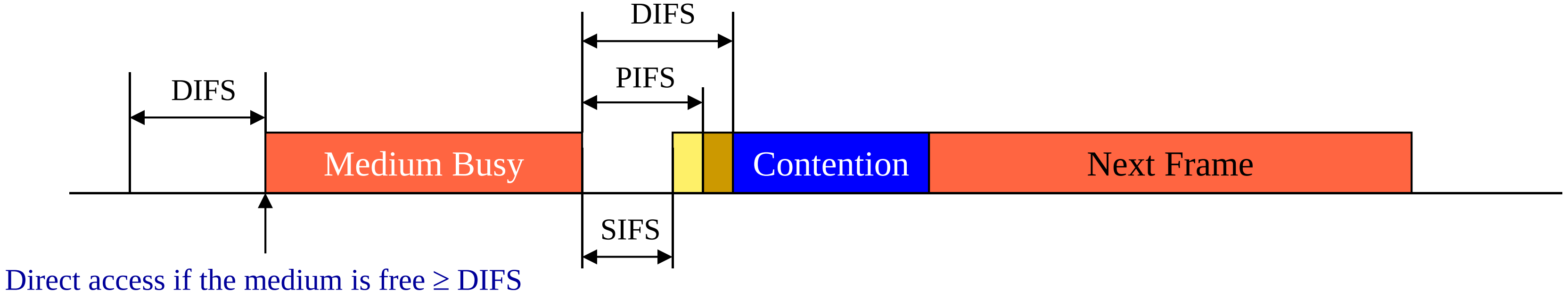
- CSMA: carrier sensing
  - Carrier: don't send
  - No carrier: send
  - Needs to be enhanced in wireless networks
- CA: collision avoidance
  - random backoff
  - priority ack protocol
- Media Access Control coordination function:
  - Distributed Coordination Function (DCF) for multiple access
  - Point Coordination Function (PCF) for polling-based priority
  - Hybrid Coordination Function (HCF) per 802.11e

Practically, CSMA/CA is CSMA with explicit ACK frame

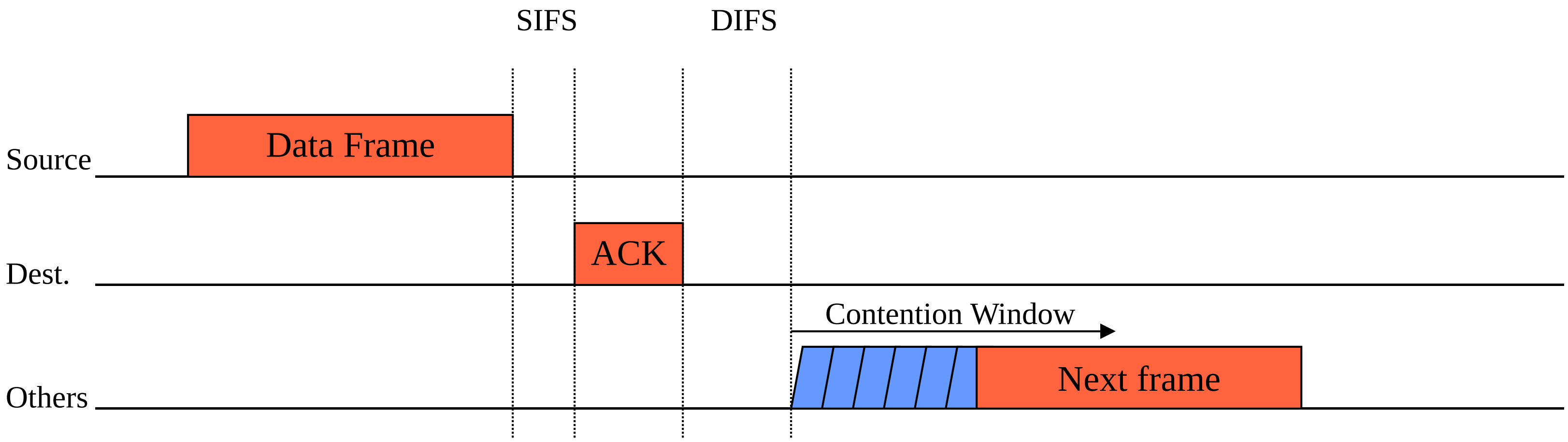
IEEE 802.11 MAC Layer Priority

MAC layer priority is defined through different Inter Frame Spaces

- DIFS(DCF IFS)
  - Lowest priority, for asynchronous data service
- PIFS (PCF IFS)
  - Medium priority, for time-bounded service using PCF
- SIFS (Short Inter Frame Spacing)
  - Highest priority, for ACK, Clear To Send (CTS), Polling response



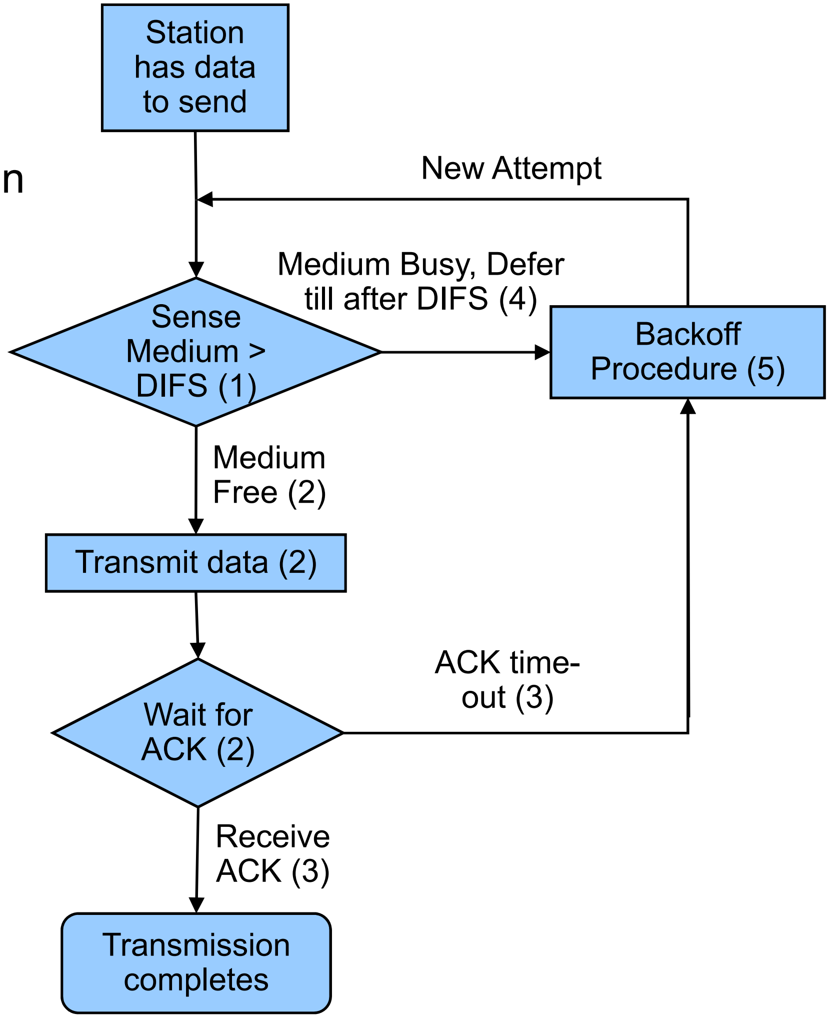
CSMA/CA : ACK Protocol



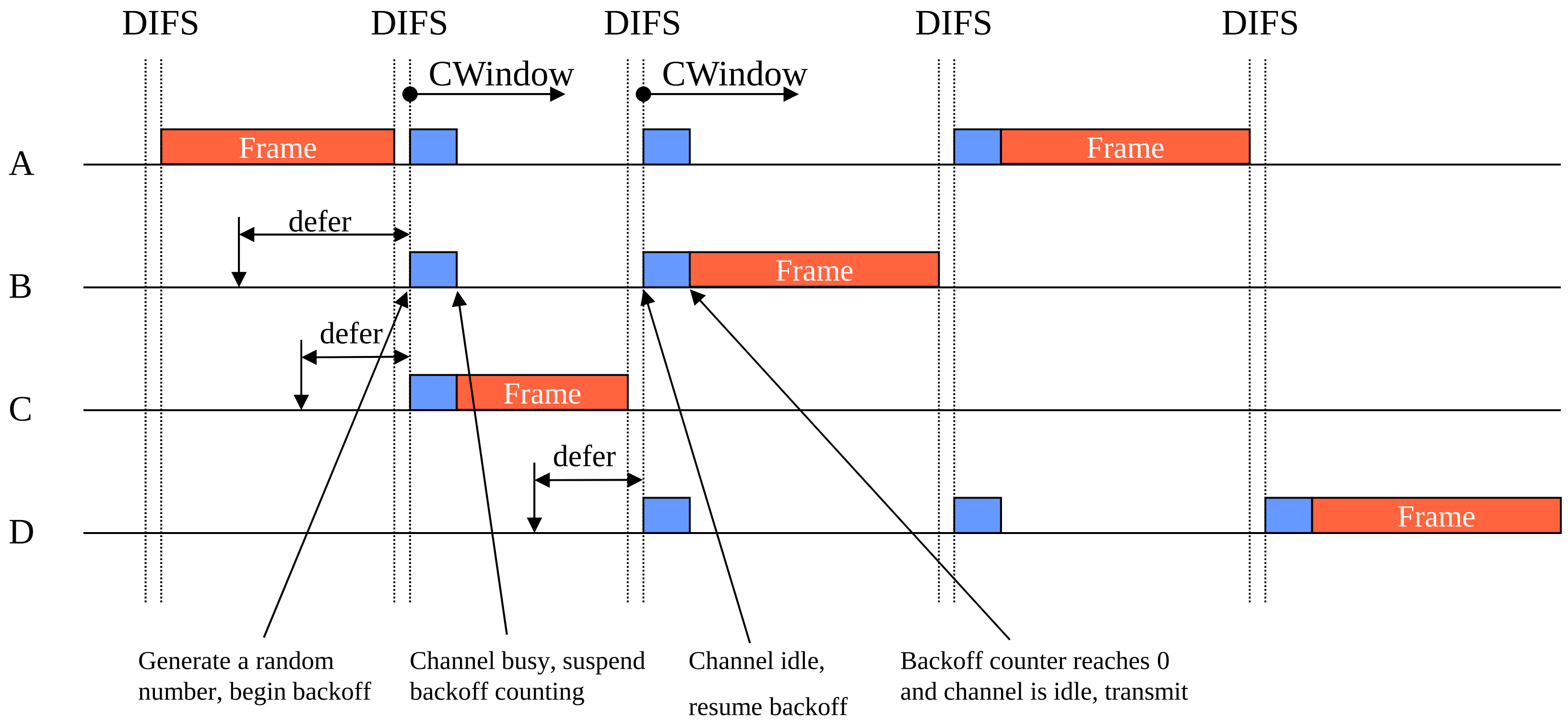
- Receiver of directed frames returns an 14 Byte ACK immediately when CRC is correct.
- If no ACK received, the sender will retransmit after a random backoff

CSMA/CA in DIF Mode

1. Sense medium for a free slot ≥ DCF Inter Frame Space (DIFS)
2. Immediate access when medium is free and start an ACK timer
3. If timeout, goto Backoff procedure. Otherwise transmission completes
4. When medium is not free, defer until the end of current frame transmission + DIFS, then begin backoff procedure
5. To begin Backoff procedure:
   - Choose a random number in (0, Cwindow)
   - Listen to determine if the medium is busy for each time slot
   - Decrement backoff time by one slot if medium is idle
   - Suspend backoff procedure if channel is busy in a time slot
   - Resume backoff when the channel becomes idle again.



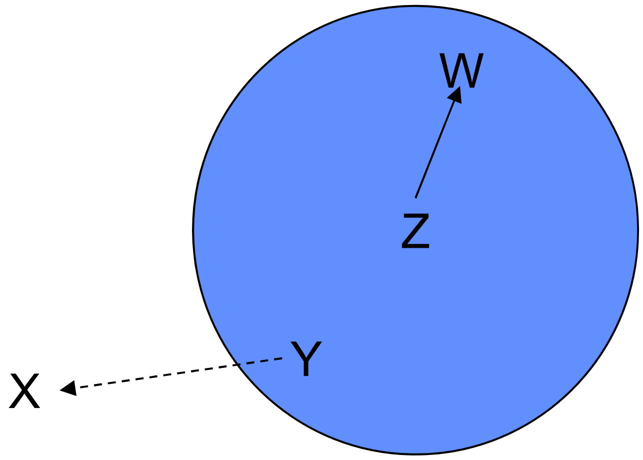
CSMA/CA: Backoff with Cwindow


DIFS
DIFS
DIFS
DIFS
DIFS
CWindow
CWindow
A
Frame
Frame
defer
B
Frame
defer
C
Frame
defer
D
Frame
Generate a random number, begin backoff
Channel busy, suspend backoff counting
Channel idle, resume backoff
Backoff counter reaches 0 and channel is idle, transmit

C(ontention)window in unit of slot time:

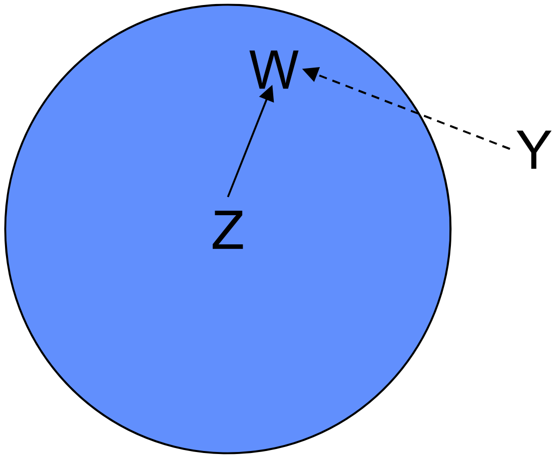
- Increase after each failure: 31, 63, 127, 255, 511, 1023, then give up
- Reset to 31 after each successful transmission

Exposed & Hidden Terminal Problems



The Exposed Terminal problem

- Y will not transmit to X even though it can do so



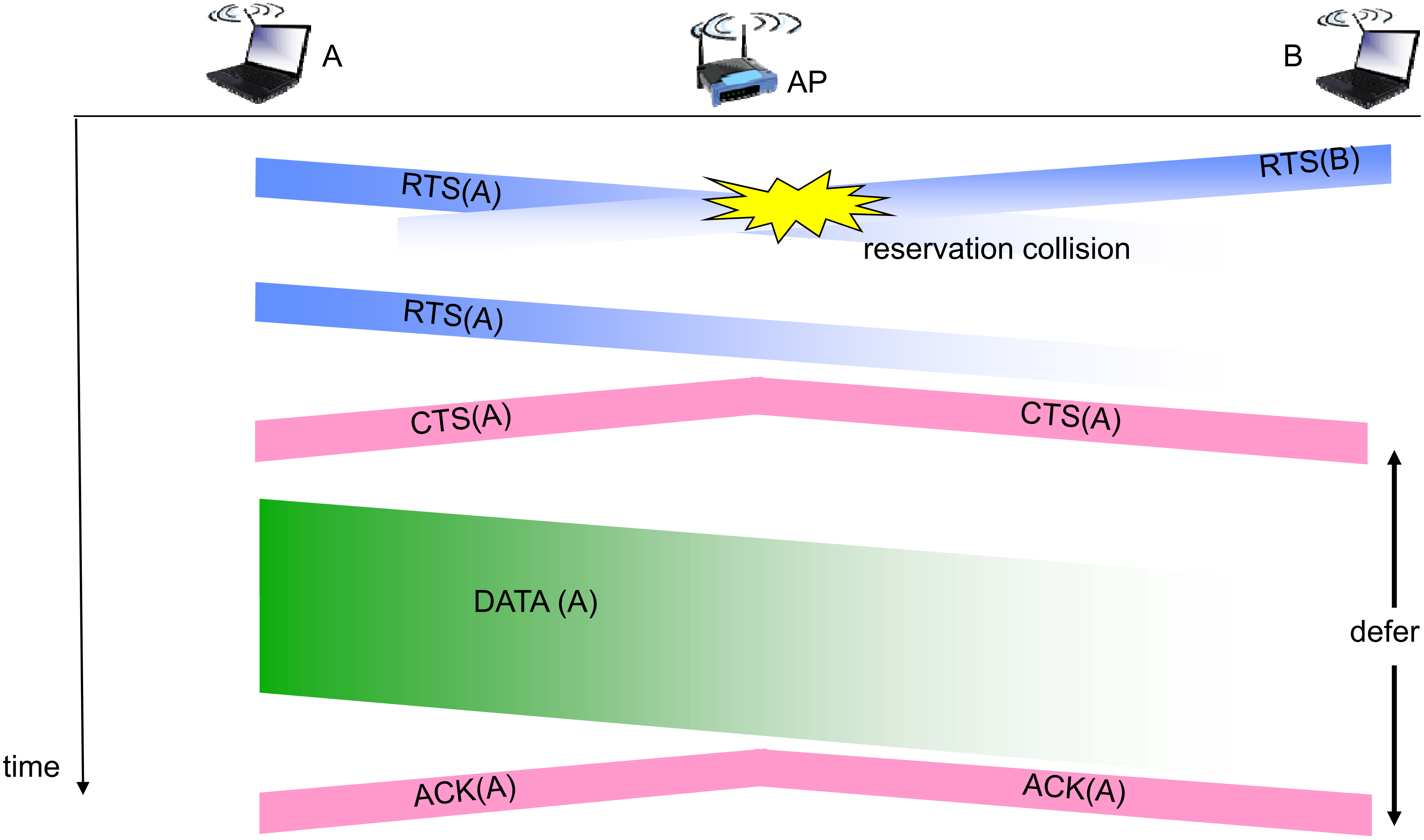
The Hidden Terminal problem

- Y finds that medium is free and transmits a packet to W

RTS/CTS

- The sender send Request-to-Send (RTS): 20bytes
- Receiver returns Clear-to-Send (CTS): 14 bytes
- Then transmission begins
- Solves Hidden Terminal problem

Collision Avoidance: RTS-CTS exchange



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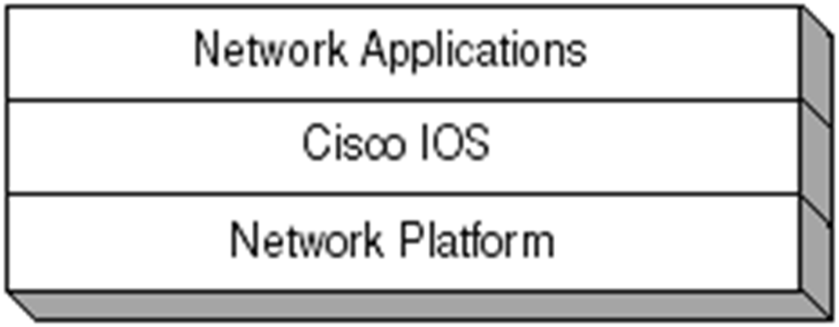
Configure a Bridge or Router

- All network devices require initial configuration and ongoing management carried by higher layer functions (in network system software) for configuration and management tasks.
- Cisco Internet Operating System (IOS) is the one used by widely deployed Cisco made network equipment.

Cisco IOS

Cisco IOS provides different ways to configure and maintain a Cisco device.

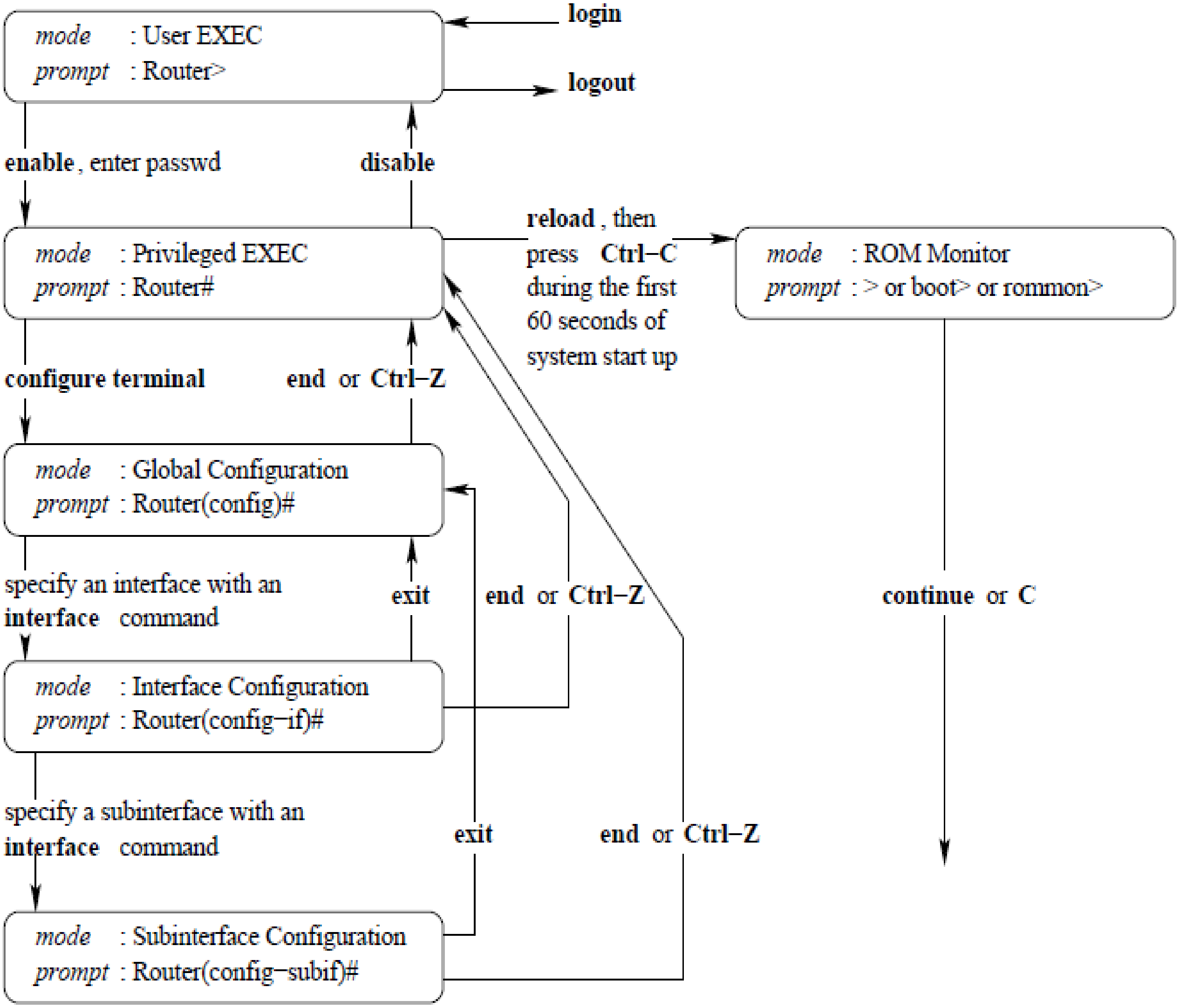
- Delivers network services such as Operations, Administration, and Maintenance (OAM) of the network platforms and Internet applications.
- Supports a broad range of platforms and many networking protocol families.
- Enables network applications on the network platforms.



Cisco IOS Configuration Modes

- Cisco IOS Command-Line Interface (CLI) is the primary user interface.
- There are six different configuration modes in Cisco CLI:

  User EXEC, Privileged EXEC, ROM Monitor, Global Configuration, Interface Configuration, and Subinterface Configuration


mode : User EXEC
prompt : Router>
login
logout
enable, enter passwd
disable
mode : Privileged EXEC
prompt : Router#
reload, then press Ctrl–C during the first 60 seconds of system start up
mode : ROM Monitor
prompt : > or boot> or rommon>
configure terminal
end or Ctrl–Z
mode : Global Configuration
prompt : Router(config)#
specify an interface with an interface command
exit
end or Ctrl–Z
continue or C
mode : Interface Configuration
prompt : Router(config–if)#
specify a subinterface with an interface command
exit
end or Ctrl–Z
mode : Subinterface Configuration
prompt : Router(config–subif)#