CompSci 356: Computer Network Architectures

Lecture 9: Ethernet Switches
[PD] Ch 3.1.4

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Review

- Past lectures
  - Single link networks
    - Point-to-point, shared media
      - Ethernet, token ring, wireless networks
    - Encoding, framing, error detection, reliability
      - Delay-bandwidth product, sliding window, exponential backoff, carrier sense collision detection, hidden/exposed terminals
  - Packet switching: how to connect multiple links
    - Connectionless: Datagram
    - Connection-oriented: Virtual circuits
    - Source routing
    - Pros and cons

Today

- Ethernet switches
  - Forwarding
  - Address learning
  - Spanning Tree Algorithm

- Virtual LAN

Ethernet Learning Bridges

- Local Area Network (LAN) switches
  - Bridges

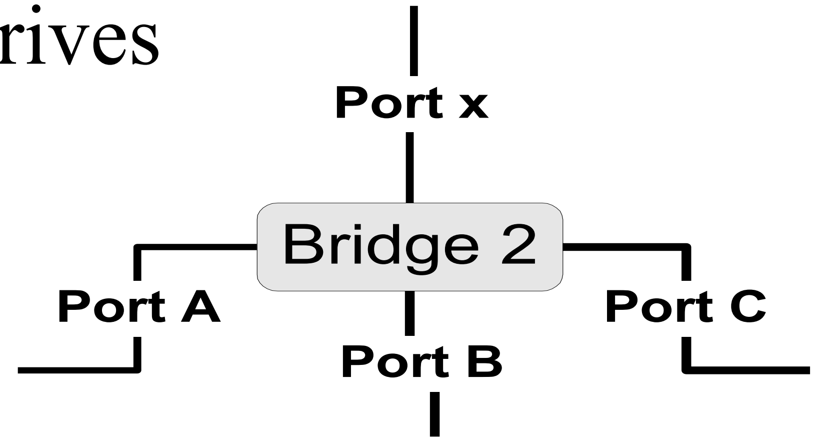
- Overall design goal: **complete transparency**
    - "Plug-and-play"
    - Self-configuring without hardware or software changes
    - Bridges should not impact operations of existing LANs

Three main functions

- **(1) Forwarding of Ethernet Frames**
- **(2) Learning of Addresses**
- **(3) Spanning Tree Algorithm**

(1) Frame Forwarding

- Assume a MAC frame arrives



Is MAC address of destination in forwarding table?

Found?

Forward the frame on the appropriate port

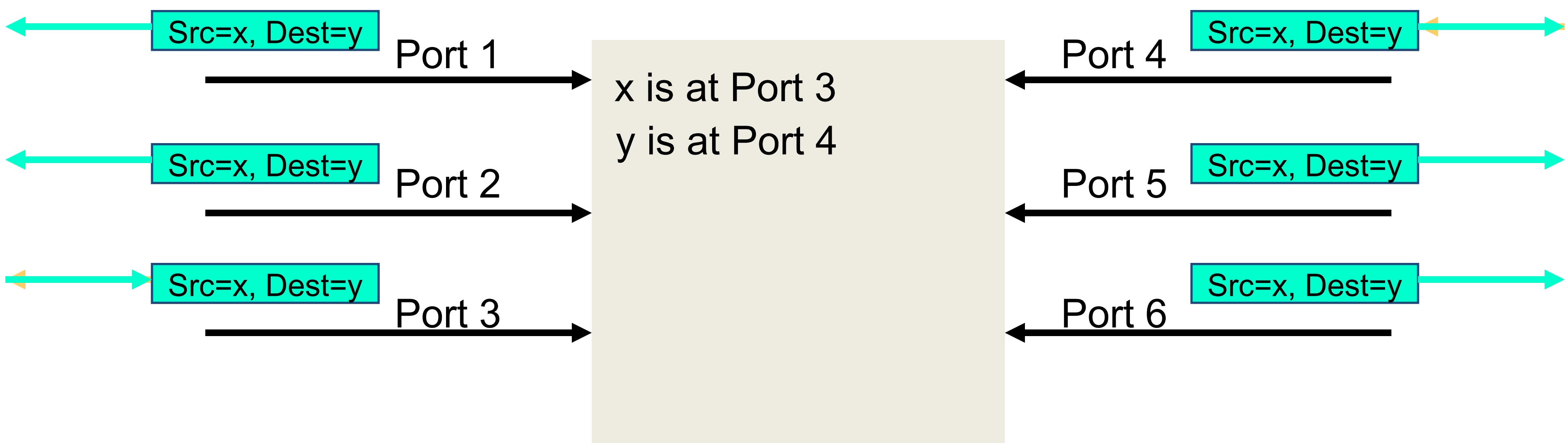
Not found ?

Flood the frame,
i.e.,
send the frame on all ports except port x.

(2) Address Learning

- When a bridge reboots, its forwarding table is empty
- Forwarding table entries are *learned* automatically with a simple heuristic:

  The source field of a frame that arrives on a port tells which hosts are reachable from this port.



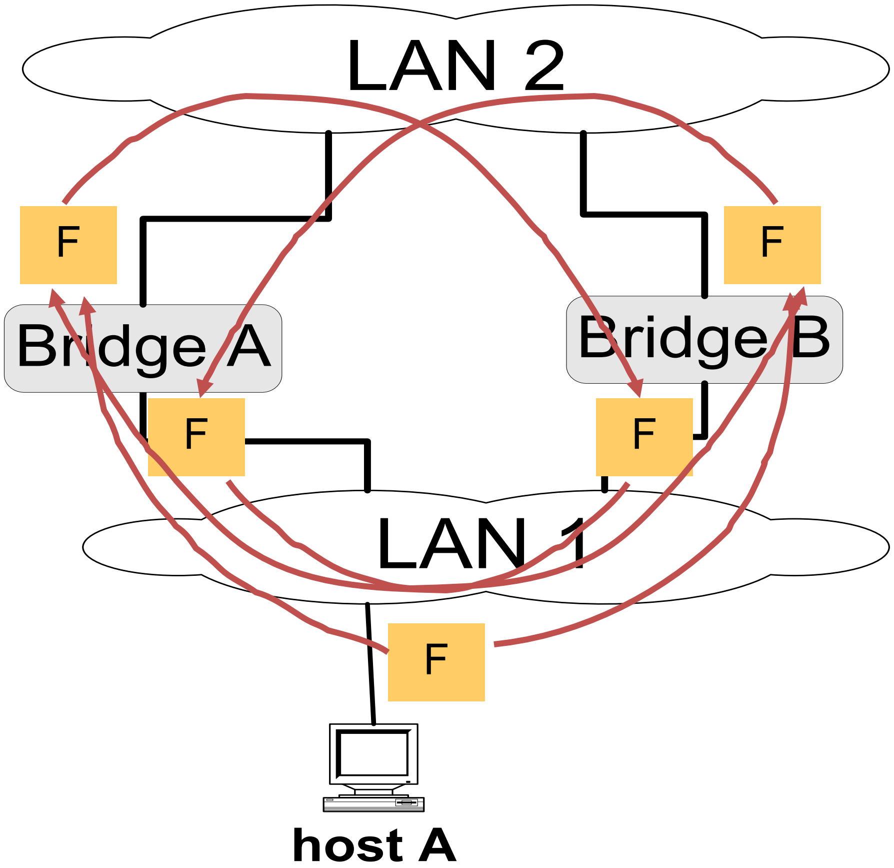
Danger of Loops

- Consider the two LANs that are connected by two bridges.
- Assume *host A* is transmitting a frame F with a broadcast address

What is happening?

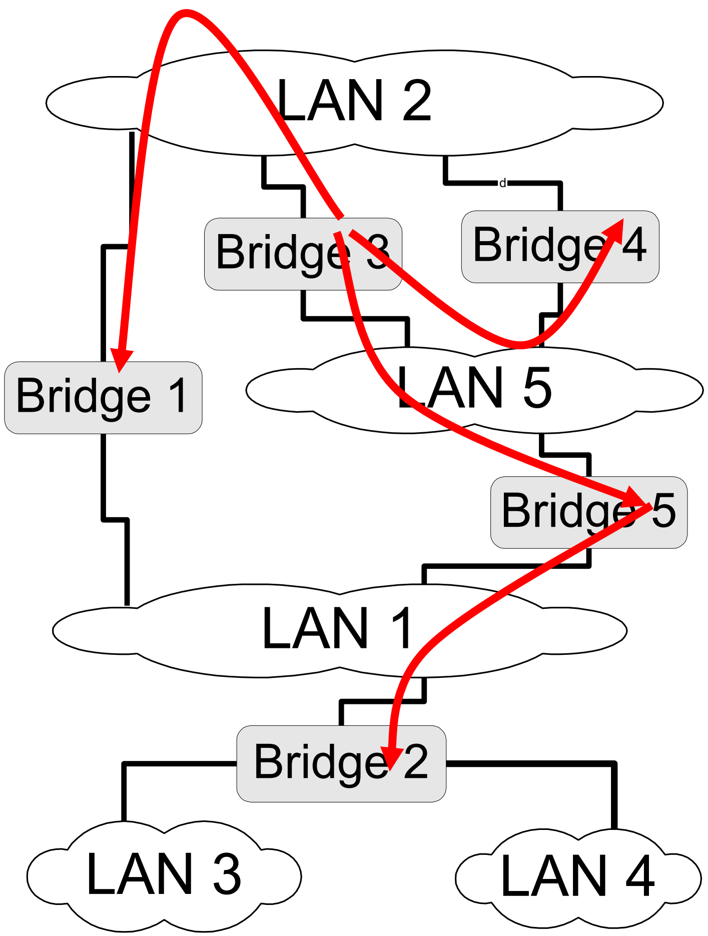
- Bridges A and B flood the frame to LAN 2.
- Bridge B sees F on LAN 2, and updates the port mapping of MAC_A, and copies the frame back to LAN 1
- Bridge A does the same.
- The copying continues

Where's the problem? What's the solution ?



(3) Spanning Tree Algorithm

- A solution is the spanning tree algorithm that prevents loops in the topology
  - By Radia Perlman at DEC



Algorhyme (the spanning tree poem)

- I think that I shall never see
  A graph more lovely than a tree.
  A tree whose crucial property
  Is loop-free connectivity.
  A tree that must be sure to span
  So packets can reach every LAN.
  First, the root must be selected.
  By ID, it is elected.
  Least-cost paths from root are traced.
  In the tree, these paths are placed.
  A mesh is made by folks like me,
  Then bridges find a spanning tree.

- —Radia Perlman

Graph theory on spanning tree

- For any connected graph consisting of nodes and edges connecting pairs of nodes, a spanning tree of edges maintains the connectivity of the graph but contains no loops
  - n-node' s graph, n - 1 edges on a spanning tree
  - No redundancy

Protocols vs Algorithms

- Protocols are a set of rules that define message formats and actions to be taken when messages are sent or received

- Underlying a network protocol there is often a distributed algorithm

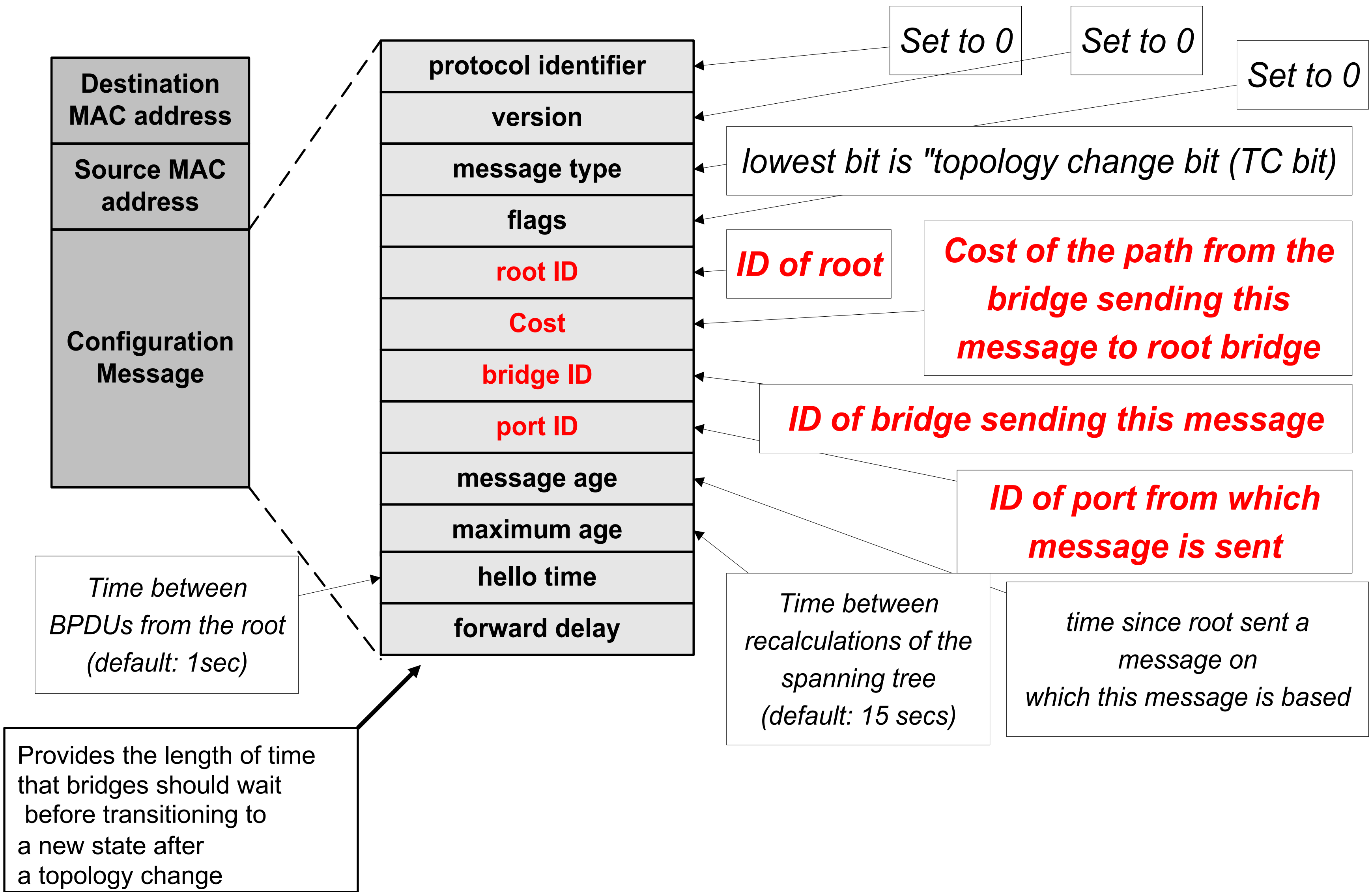
- Protocols must consider practical constraints, e.g.
  - Limited size of a field
  - Non-synchronized clocks

The protocol

- IEEE 802.1d has an algorithm that organizes the bridges as spanning tree in a dynamic environment

- Bridges exchange messages to configure the bridge (Configuration Bridge Protocol Data Unit, Configuration BPDUs) to build the tree
  - Select ports they use to forward packets

Configuration BPDUs



What do the BPDUs do?

- Elect a single bridge as the **root bridge**
- Calculate the distance of the shortest path to the root bridge
- Each bridge can determine a **root port**, the port that gives the best path to the root
- Each LAN can determine a **designated bridge**, which is the bridge closest to the root. A LAN's *designated bridge* is the only bridge allowed to forward frames to and from the LAN for which it is the designated bridge.
- A LAN's **designated port** is the port that connects it to the designated bridge
- Select ports to be included in the spanning tree.

Terms

- Each bridge has a unique identifier: Bridge ID
  Bridge ID = {Priority : 2 bytes; Bridge MAC address: 6 bytes}
  - Priority is configured
  - Bridge MAC address is the lowest MAC addresses of all ports

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

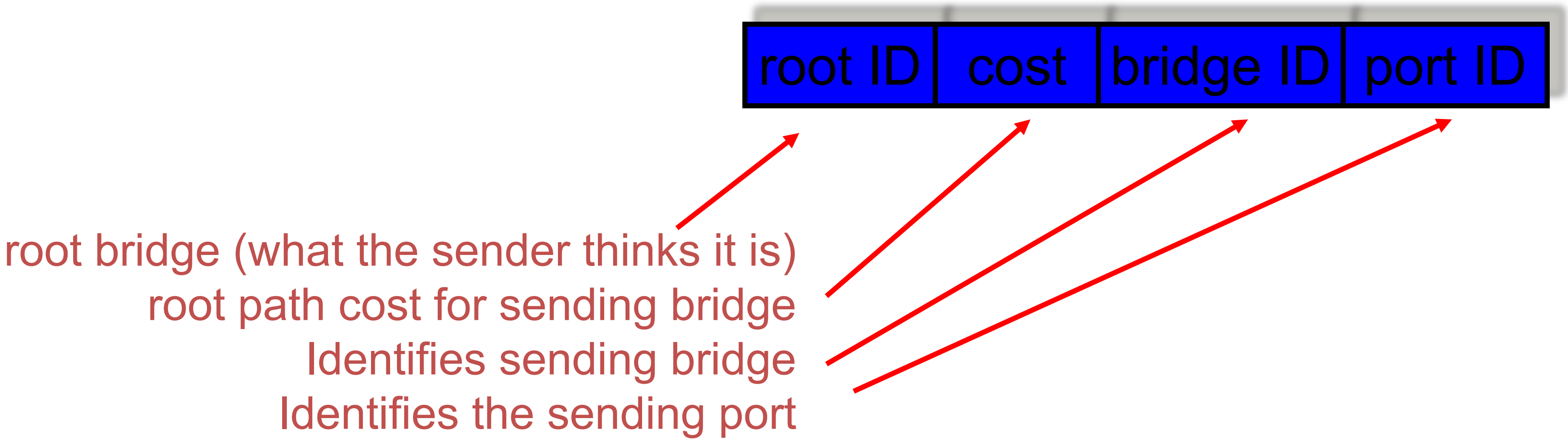
- **Root Bridge:** The bridge with the lowest identifier is the root of the spanning tree
- **Root Port**: Each bridge has a root port which identifies the next hop from a bridge to the root

Terms

- **Root Path Cost:** For each bridge, the cost of the min-cost path to the root
  - Assume it is measured in #hops to the root
- **Designated Bridge, Designated Port:** Single bridge on a LAN that is closest to the root for this LAN:
  - If two bridges have the same cost, select the one with the highest priority; if they have the same priority, select based on the bridge ID
  - If the min-cost bridge has two or more ports on the LAN, select the port with the lowest identifier

Spanning Tree Algorithm

- Each bridge is sending out BPDUs that contain the following information:

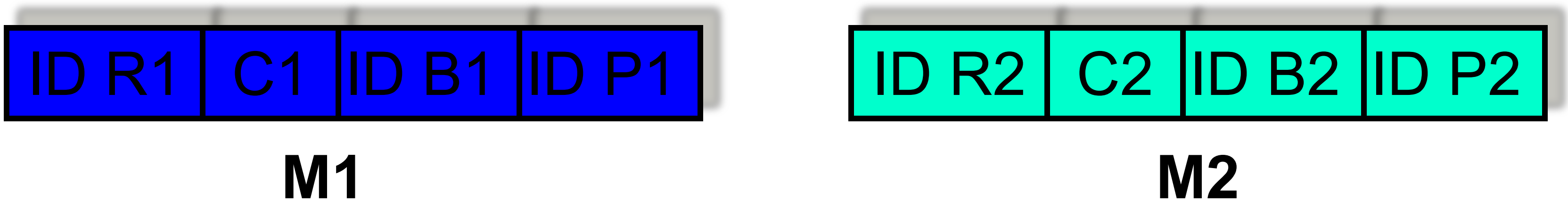


- The transmission of BPDUs results in the distributed computation of a spanning tree

- The convergence of the algorithm is very fast

Ordering of Messages

- We define an ordering of BPDU messages (lexicographically)



We say M1 **advertises a better path** than M2 (“**M1<M2**”) if

(R1 < R2),

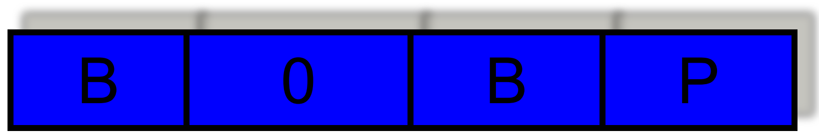
Or (R1 == R2) and (C1 < C2),

Or (R1 == R2) and (C1 == C2) and (B1 < B2),

Or (R1 == R2) and (C1 == C2) and (B1 == B2) and (P1 < P2)

Initializing the Spanning Tree Protocol

- Initially, all bridges assume they are the root bridge.
- Each bridge B sends BPDUs of this form on its LANs from each port P:



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

Spanning Tree Protocol

- Each bridge B looks on all its ports for BPDUs that are better than its own BPDUs
- Suppose a bridge with BPDU:

M1	R1	C1	B1	P1

receives a "better" BPDU:

M2	R2	C2	B2	P2

Then it will update the BPDU to:

R2	C2+1	B1	P1

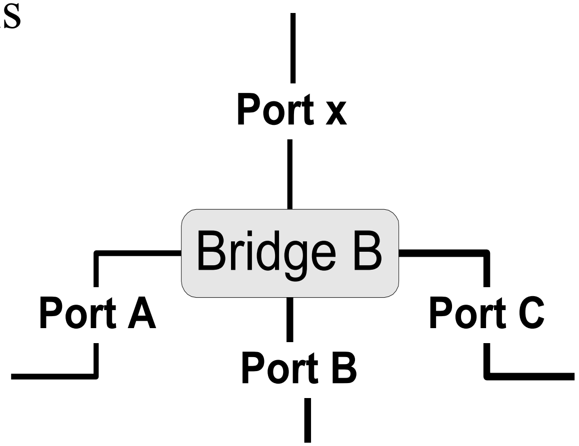
- However, the new BPDU is not necessarily sent out
- On each bridge, the port where the "best BPDU" (via relation "<") was received is the **root port of the bridge**
  - No need to send out updated BPDUs to root port

When to send a BPDU

- Say, B has generated a BPDU for each port x

R	Cost	B	x

- B will send this BPDU on port x only if its BPDU is better (via relation “<“) than any BPDU that B received from port x.



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

- And port x is the **designated port** of that LAN

Selecting the Ports for the Spanning Tree

- Each bridge makes a local decision which of its ports are part of the spanning tree
- Now **B can decide which ports are in the spanning tree:**
    - B's root port is part of the spanning tree
    - All designated ports are part of the spanning tree
    - All other ports are not part of the spanning tree

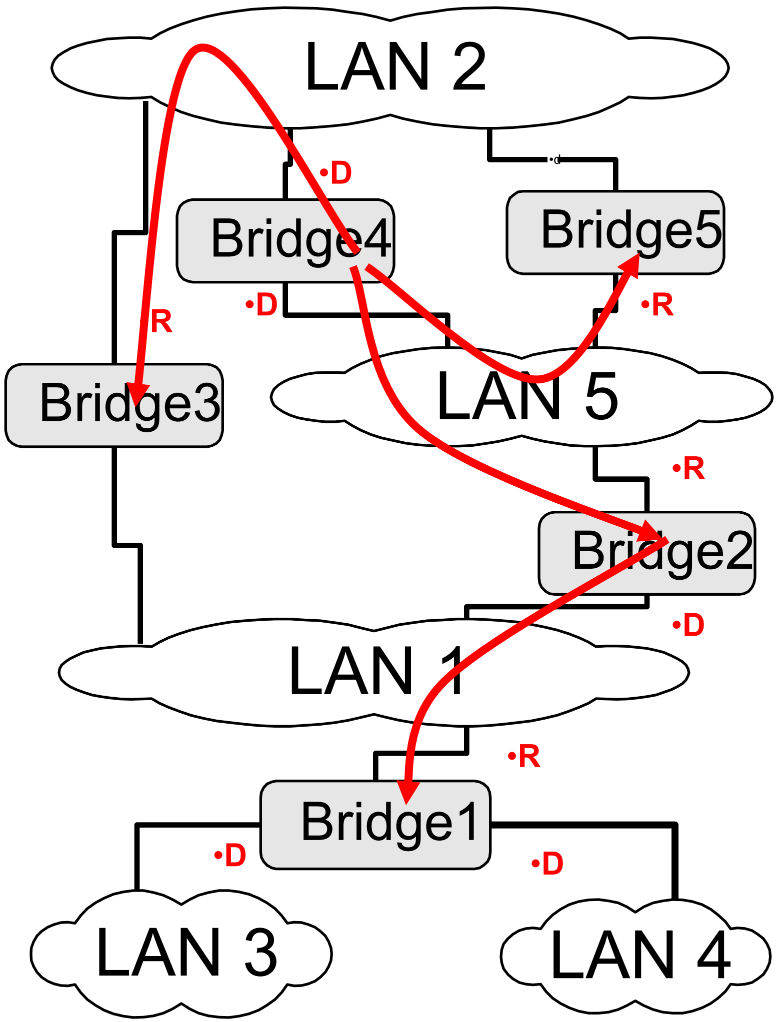
- B's ports that are in the spanning tree will forward packets (=forwarding state)
- B's ports that are not in the spanning tree will not forward packets (=blocking state)

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.

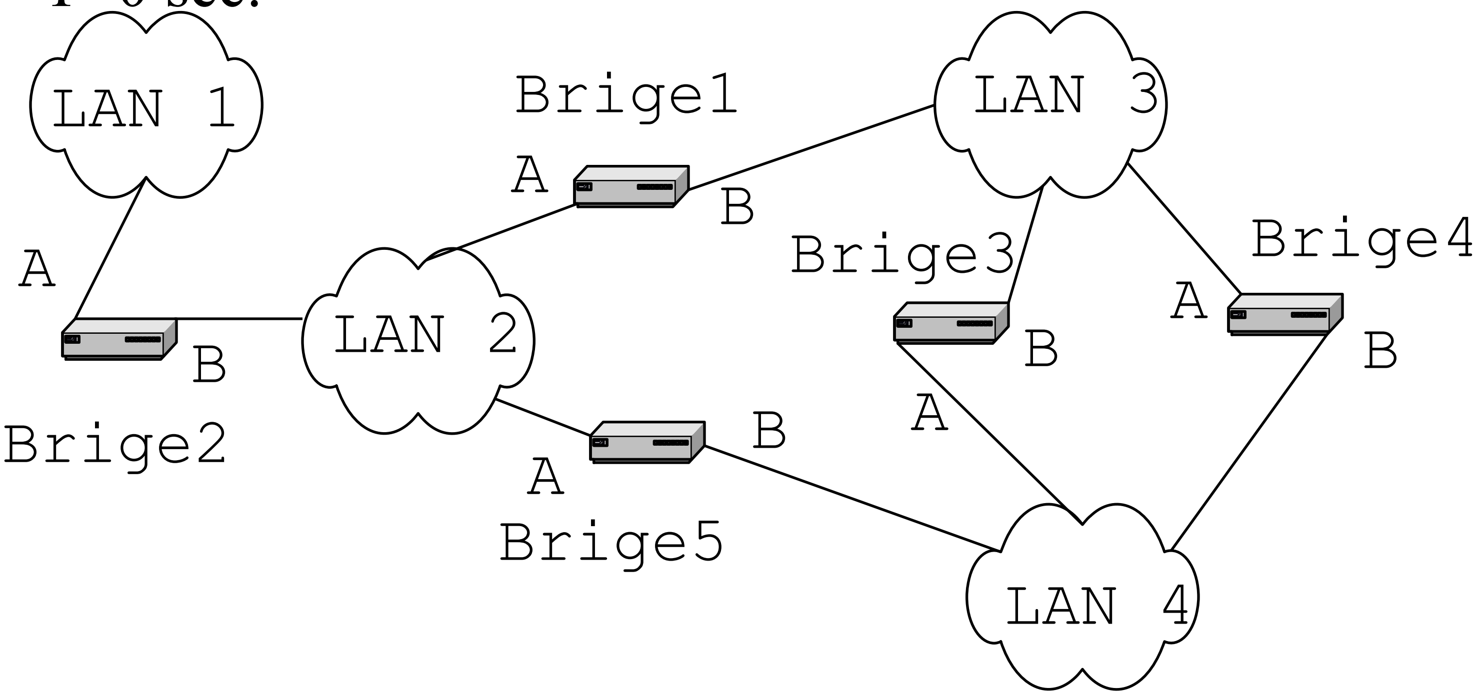
- What is the spanning tree?
  - On each LAN, connect D ports to the R ports on this LAN
  - Which bridge is the root bridge?

- Suppose a packet is originated in LAN 5. How is the packet flooded?



Example

- Assume that all bridges send out their BPDU's once per second, and assume that all bridges send their BPDUs at the same time
- Bridge1 < Bridge2 < Bridge3 < Bridge4 < Bridge5
- Assume that all bridges are turned on simultaneously at time T=0 sec.



Example: BPDUs sent

	Bridge1	Bridge2	Bridge3	Bridge4	Bridge5
T=1sec					

Example: BPDUs sent

	Bridge1	Bridge2	Bridge3	Bridge4	Bridge5
T=2sec					

Example: BPDUs sent

	Bridge1	Bridge2	Bridge3	Bridge4	Bridge5
T=3sec					

Example: BPDUs sent

	Bridge1	Bridge2	Bridge3	Bridge4	Bridge5
T=1sec	Send: A: (B1,0,B1,A) B: (B1,0,B1,B) Recv: A: (B5,0,B5,A) (B2,0,B2,B) B: (B3,0,B3,B) (B4,0,B4,A)	Send: A: (B2,0,B2,A) B: (B2,0,B2,B) Recv: A: B: (B1,0,B1,A) (B5,0,B5,A)	Send: A:(B3,0,B3,A) B:(B3,0,B3,B) Recv: A: (B5,0,B5,B) (B4,0,B4,B) B: (B1,0,B1,B) (B4,0,B4,A)	Send: A:(B4,0,B4,A) B:(B4,0,B4,B) Recv: A: (B3,0,B3,B) (B1,0,B1,B) B: (B3,0,B3,A) (B5,0,B5,B)	Send: A:(B5,0,B5,A) B:(B5,0,B5,B) Recv: A: (B2,0,B2,B) (B1,0,B1,A) B: (B3,0,B3,A) (B4,0,B4,B)

Example: BPDU’s sent

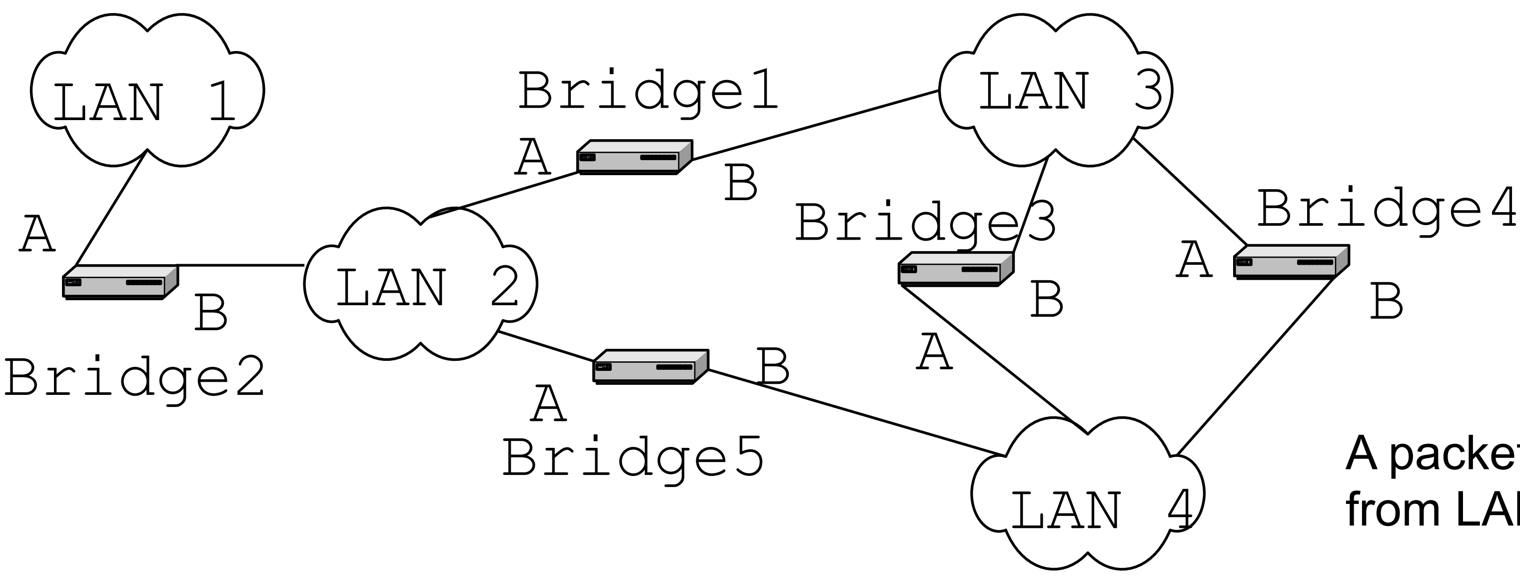
	Bridge1	Bridge2	Bridge3	Bridge4	Bridge5
T=2sec	D-port: A,B Send: A: (B1,0,B1,A) B: (B1,0,B1,B) Recv:	R-port: B D-port: A Send: A: (B1,1,B2,A) Recv: A: B: (B1,0,B1,A)	R-port: B D-port: A Send: A: (B1,1,B3,A) Recv: A: (B1,1,B4,B) (B1,1,B5,B) B: (B1,0,B1,B)	R-port: A D-port: B Send: B: (B1,1,B4,B) Recv: A: (B1,0,B1,B) B: (B1,1,B3,A) (B1,1,B5,B)	R-port: A D-port: B Send: B: (B1,1,B5,B) Recv: A: (B1,0,B1,A) B: (B1,1,B3,A) (B1,1,B4,B)

Example: BPDU's sent

	Bridge 1	Bridge 2	Bridge 3	Bridge4	Bridge5
T=3sec	D-port: A,B Send: A: (B1,0,B1,A) B: (B1,0,B1,B) Recv:	R-port: B D-port: A Send: A: (B1,1,B2,A) Recv: A: B: (B1,0,B1,A)	R-port: B D-port: A Send: A: (B1,1,B3,A) Recv: A: B: (B1,0,B1,B)	R-port: A Blocked: B Recv: A: (B1,0,B1,B) B: (B1,1,B3,A)	R-port: A Blocked: B Recv: A: (B1,0,B1,A) B: (B1,1,B3,A)

Example: the spanning tree

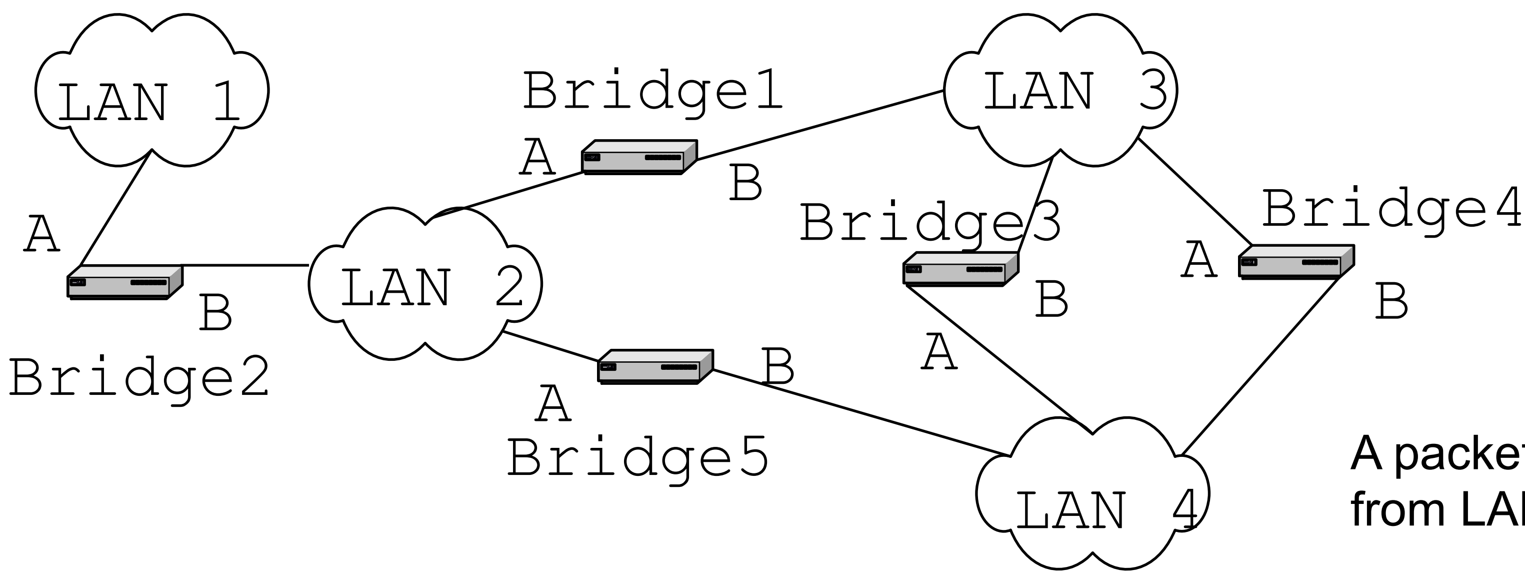
	Bridge1	Bridge2	Bridge3	Bridge4	Bridge5
Root Port					
Designated bridge					
Designated ports					



A packet is sent from LAN2

Example: the spanning tree

	Bridge1	Bridge2	Bridge3	Bridge4	Bridge5
Root Port		B	B	A	A
Designated bridge	LAN2,3	LAN1	LAN4		
Designated ports	A,B	A	A		



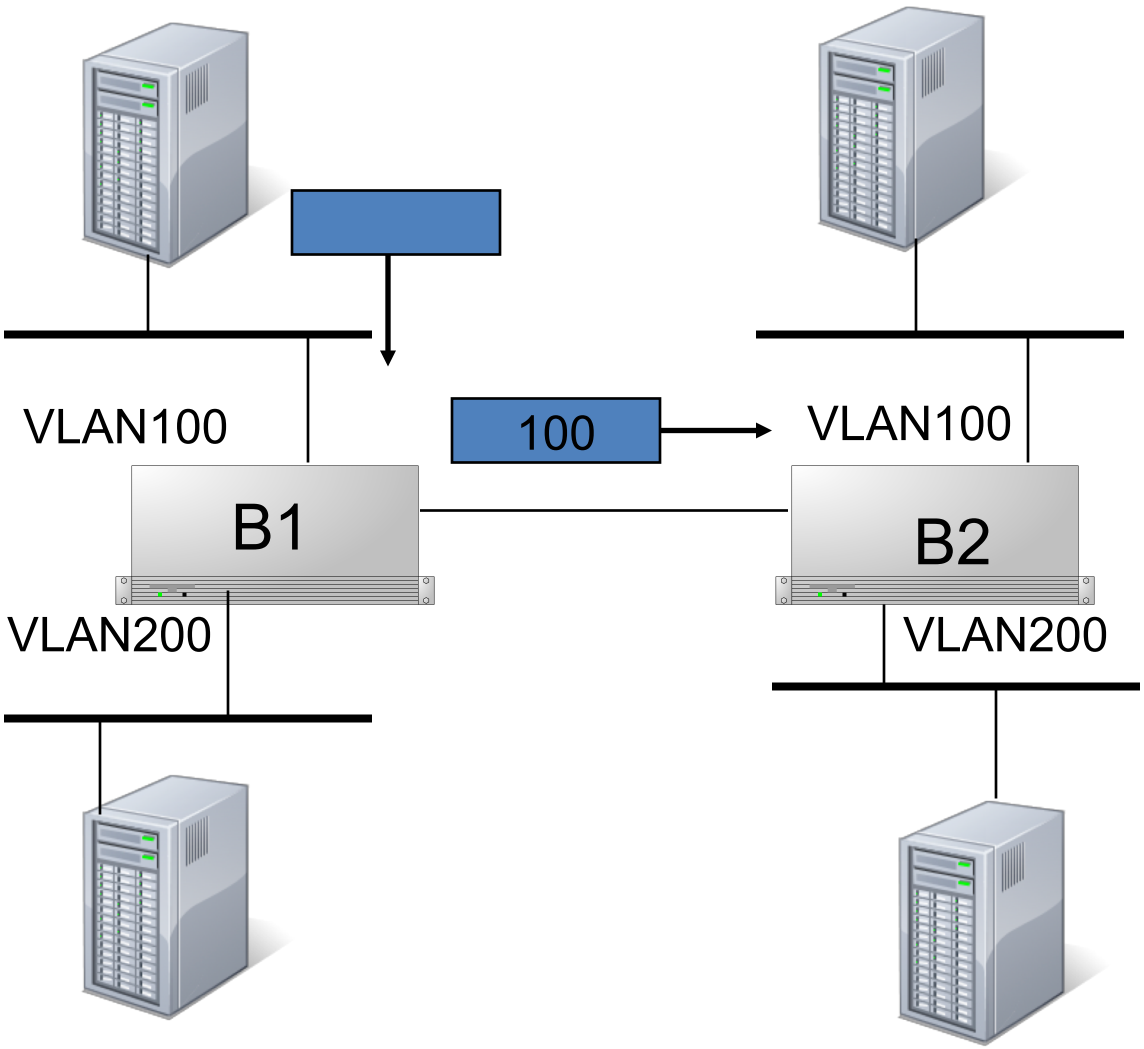
A packet is sent from LAN2

Limitations of bridges

- Scalability
  - Broadcast packets reach every host!
- Security
  - Every host can snoop
- Non-heterogeneity
  - Can't connect ATM networks

Virtual LANs

- To address the scalability and security issues
- A bridge's port is configured to have a VLAN ID
- Each VLAN has a spanning tree
- A VLAN header is inserted to a packet
- Packets are flooded to ports with the same VLAN ID



VLAN100
100
VLAN100
B1
B2
VLAN200
VLAN200

Summary

- LAN switches
  - Forwarding
  - Address learning
  - Spanning Tree Algorithm
- Virtual LAN
- Next:
  - Internetworking: how to connect LANs of different types together