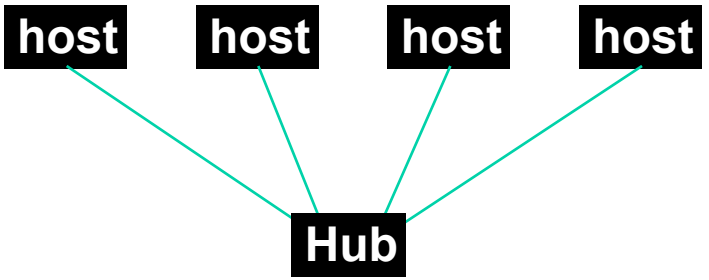
CS4700/CS5700
Fundamentals of Computer Networks

Lecture 9: Bridging

Slides used with permissions from Edward W. Knightly,
T. S. Eugene Ng, Ion Stoica, Hui Zhang

Recap

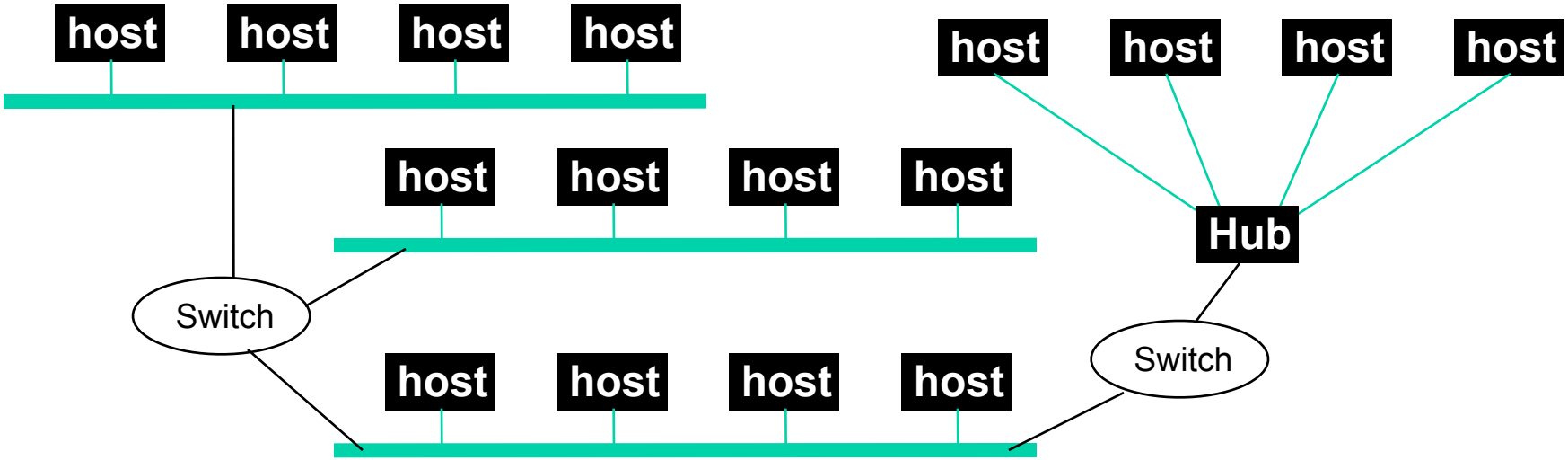
Broadcast technology



Hub emulates a broadcast channel
Easy to add a new host

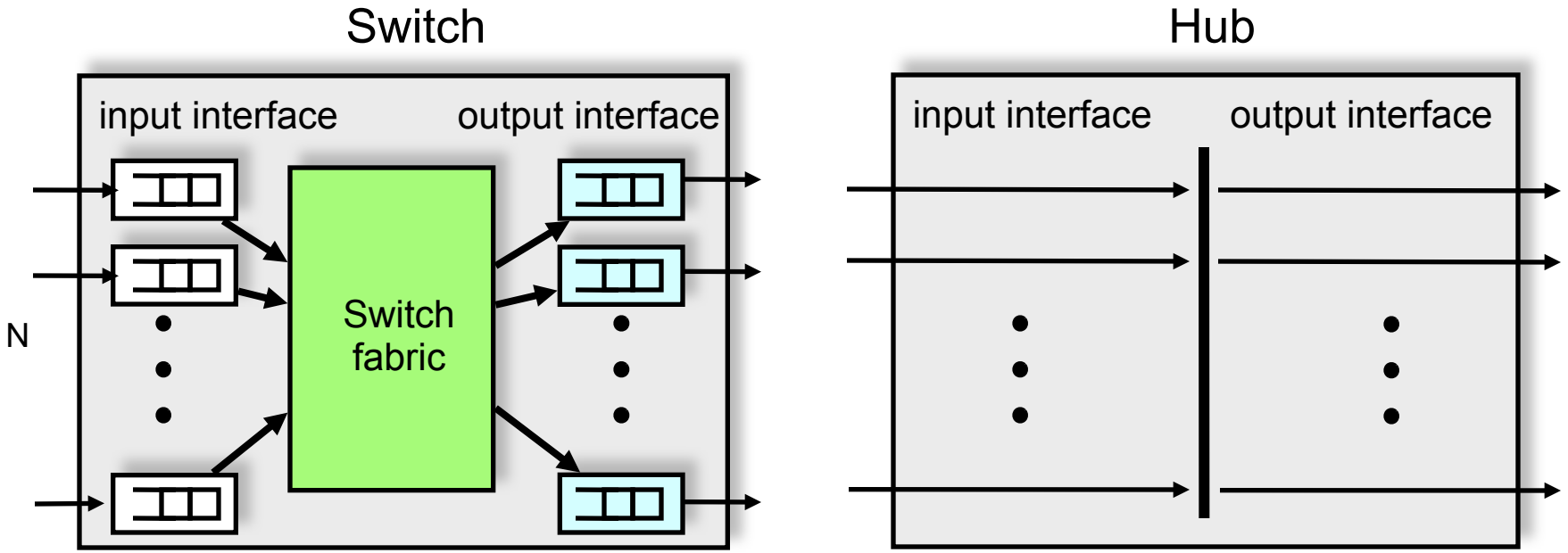
- Broadcast network is a simple way to connect hosts
  - Everyone hears everything
- Need MAC protocol to control medium sharing
- Problem: Cannot scale up to connect large number of nodes
  - Too many nodes, too many collisions, goodput (throughput of useful data) goes to zero

Need Switching Techniques



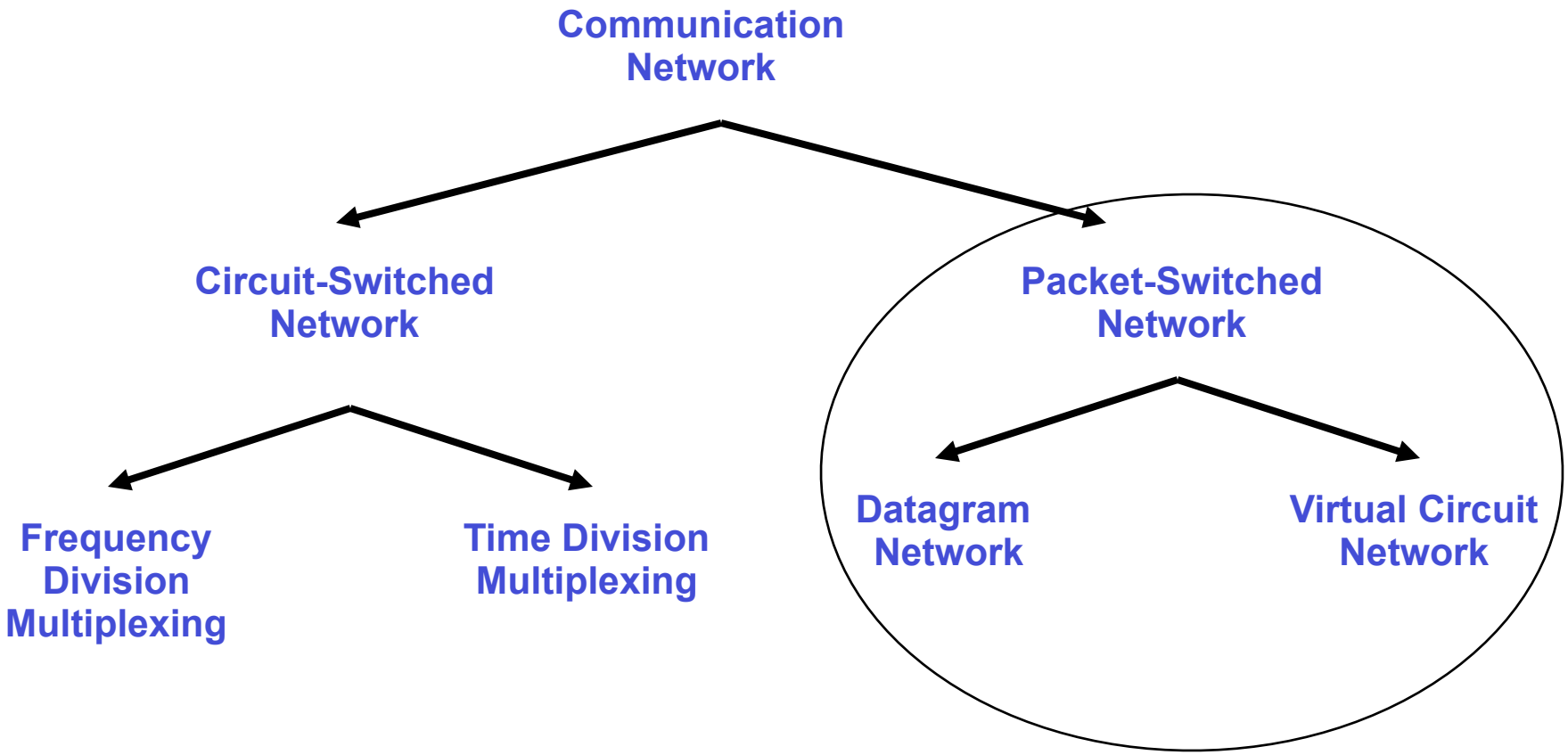
- Switching limits size of collision domains, allows network size to scale up
  - To how big? Can Internet be one big switched Ethernet?
  - Will return to this question
- Switches are more complex than hubs
  - Intelligence, memory buffers, high performance

Switch



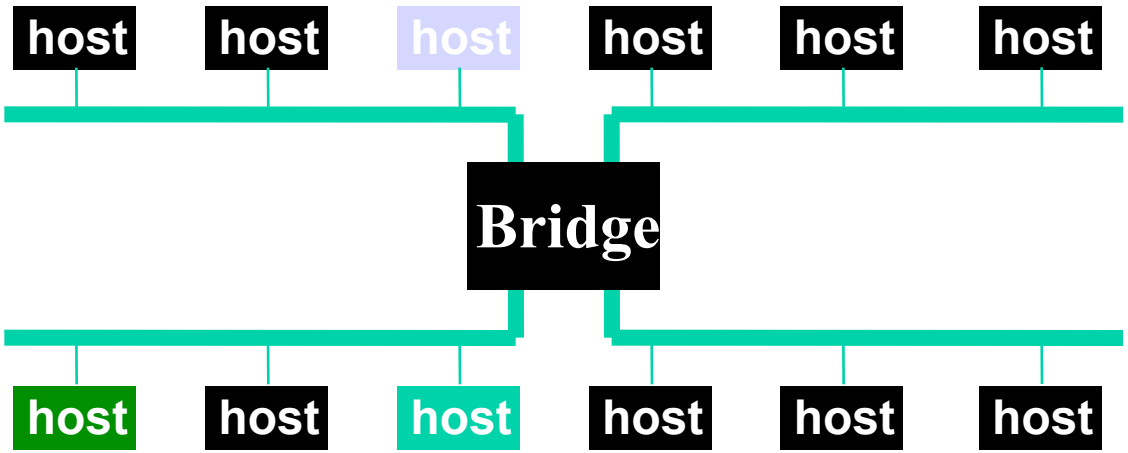
- Switch has memory buffers to queue packets, reduce loss
- Switch is intelligent: Forward an incoming packet to the correct output interface only
- High performance: Full N x line rate possible

Taxonomy of Networks



Building Large LAN Using Bridges

- Bridges connect multiple IEEE 802 LANs at layer 2
  - Datagram packet switching
  - Only forward packets to the right port
  - Reduce collision domain
- In contrast, hubs rebroadcast packets.



Transparent Bridges

- Overall design goal: **Complete transparency**
  - "Plug-and-play"
  - Self-configuring without hardware or software changes
  - Bridges should not impact operation of existing LANs
- Three parts to transparent bridges:
  - **(1) Forwarding of Frames**
  - **(2) Learning of Addresses**
  - **(3) Spanning Tree Algorithm**

Frame Forwarding

- Each bridge maintains a **forwarding database** with entries

  `< MAC address, port, age>`

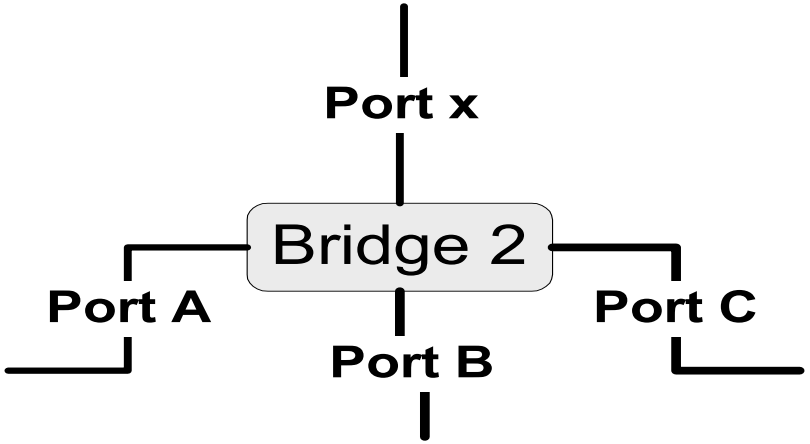
`MAC address:`	host address or group address
`port:`	port number of bridge
`age:`	aging time of entry

interpretation:

- a machine with `MAC address` lies in direction of the `port` number from the bridge. The entry is `age` time units old.

Frame Forwarding 2

- Assume a frame arrives on port x.



Search if MAC address of destination is listed for ports A, B, or C.

Found?

Not found ?

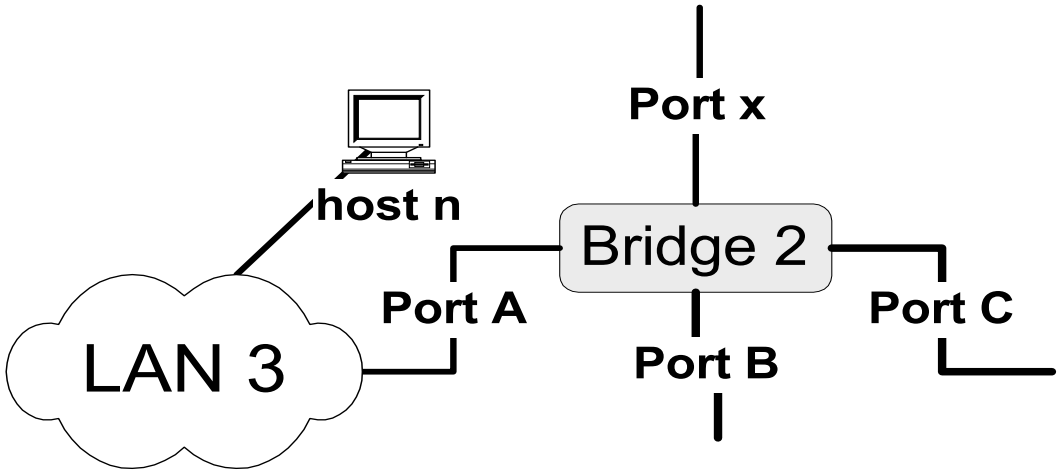
Forward the frame on the appropriate port

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

Address Learning

- In principle, the forwarding database could be set statically (=static routing)
- In the 802.1 bridge, the process is made automatic with a simple heuristic:

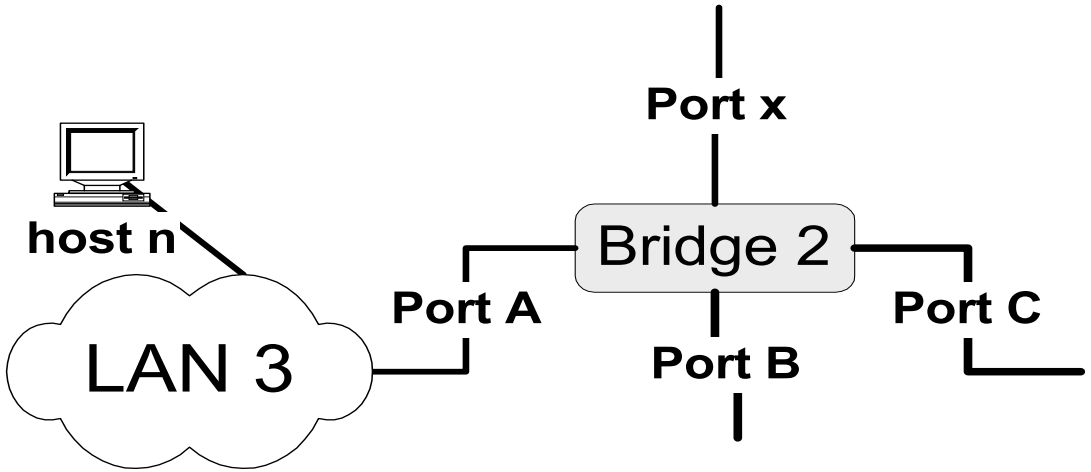
  The source field of a frame that arrives on a port tells which hosts are reachable from this port.



Address Learning 2

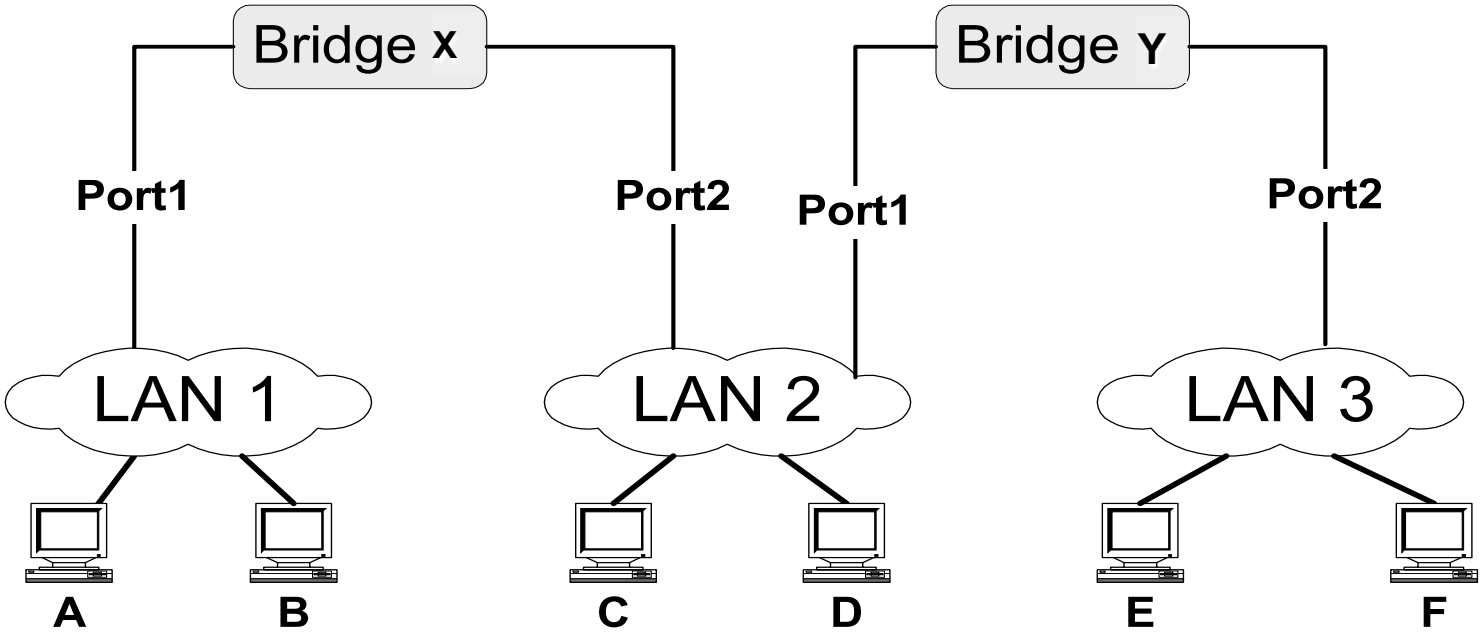
Algorithm:

- For each frame received, stores the source address in the forwarding database together with the port where the frame was received.
- An entry is deleted after some time out (default is 15 seconds).

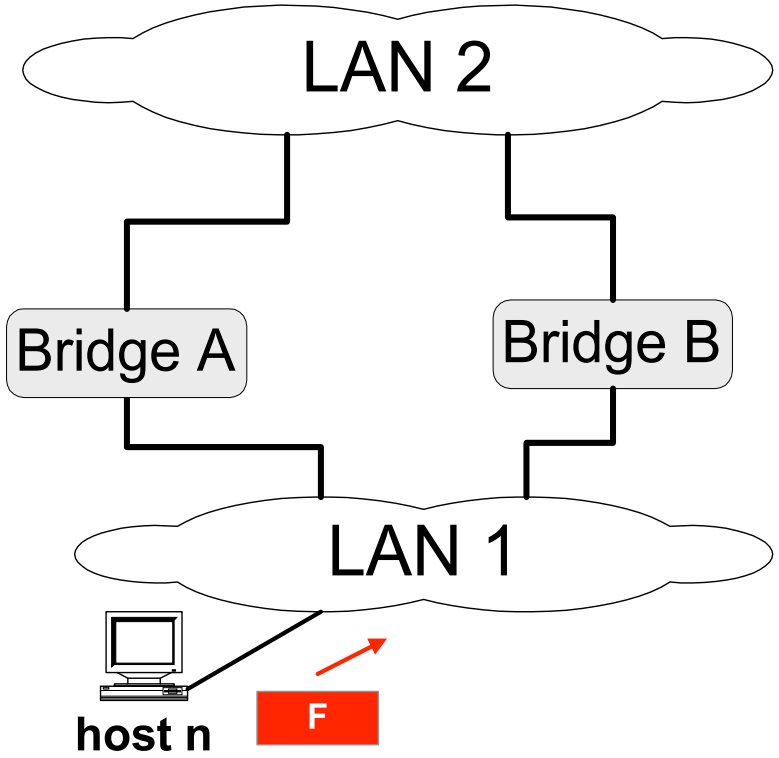


Example

- Consider the following packets:
<Src=A, Dest=F>, <Src=C, Dest=A>, <Src=E, Dest=C>
- What have the bridges learned?

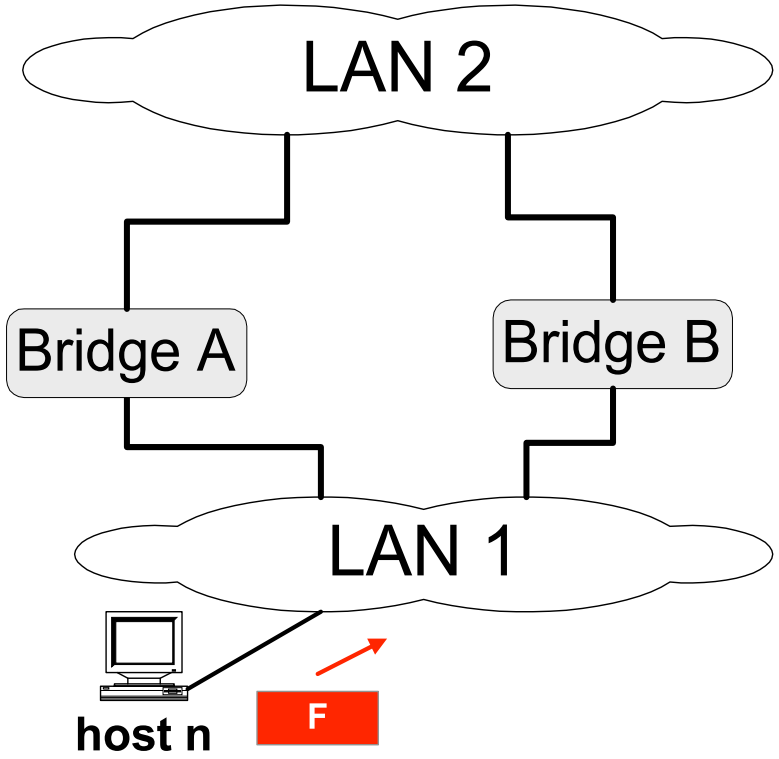


Danger of Loops



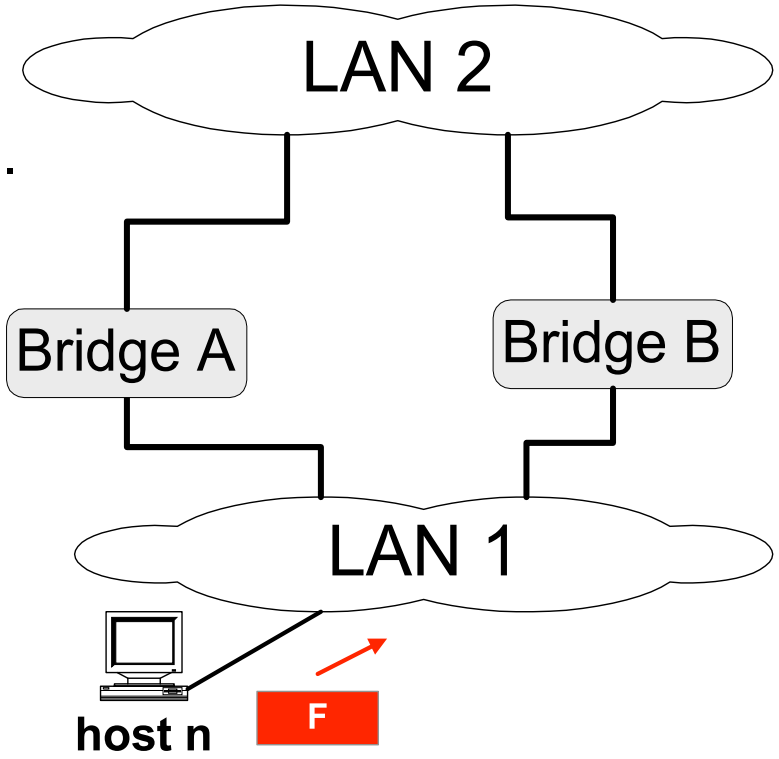
Danger of Loops

- Consider the two LANs that are connected by two bridges.



Danger of Loops

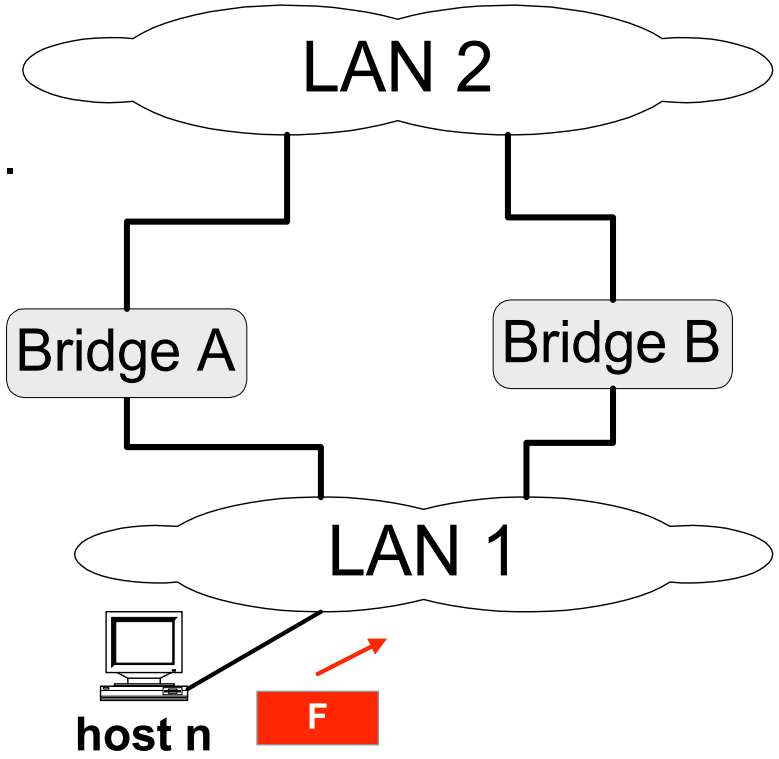
- Consider the two LANs that are connected by two bridges.
- Assume *host n* is transmitting a frame F with unknown destination.



Danger of Loops

- Consider the two LANs that are connected by two bridges.
- Assume *host n* is transmitting a frame F with unknown destination.

What is happening?

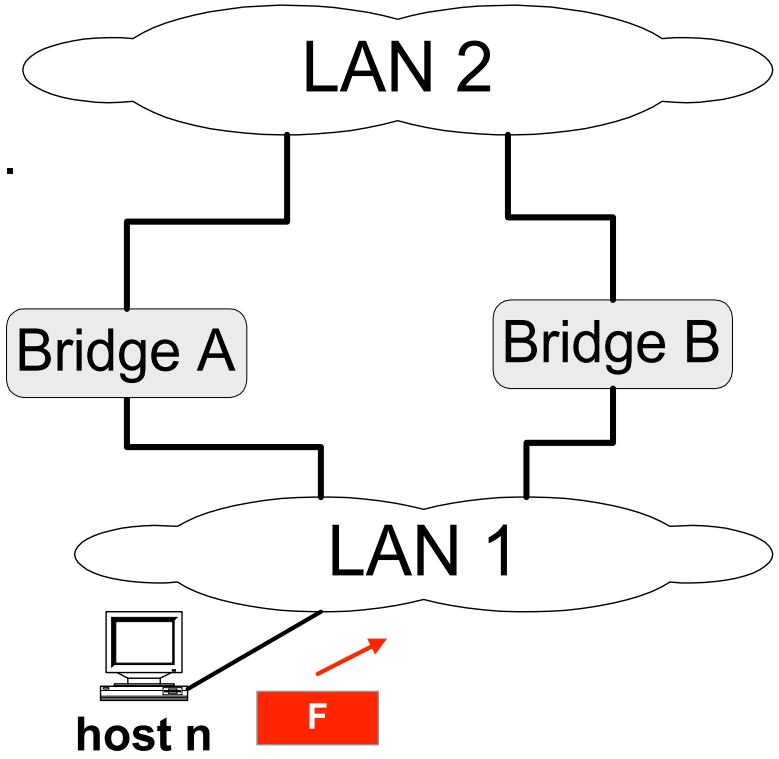


Danger of Loops

- Consider the two LANs that are connected by two bridges.
- Assume *host n* is transmitting a frame F with unknown destination.

What is happening?

- Bridges A and B flood the frame to LAN 2.

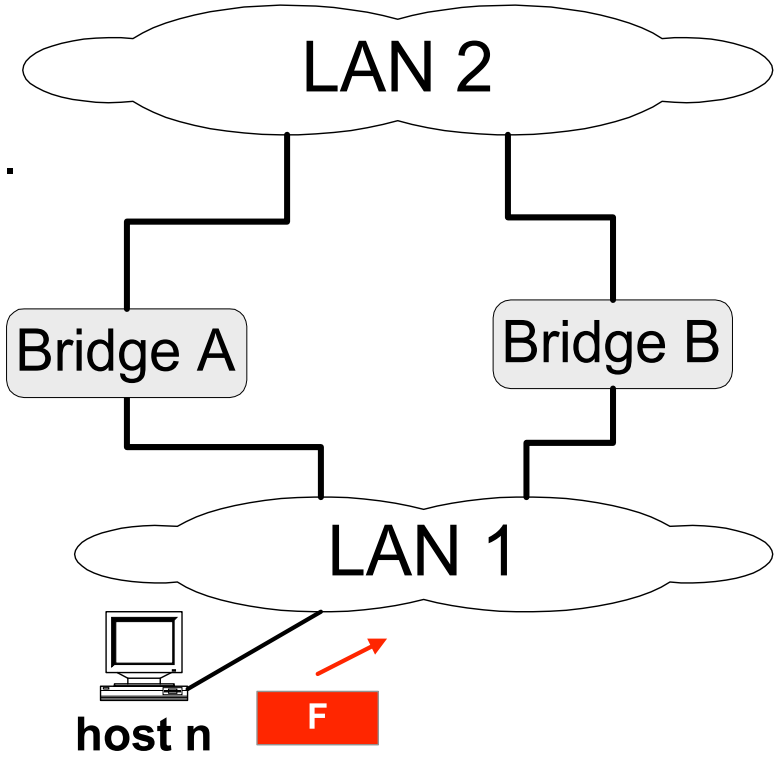


Danger of Loops

- Consider the two LANs that are connected by two bridges.
- Assume *host n* is transmitting a frame F with unknown destination.

What is happening?

- Bridges A and B flood the frame to LAN 2.
- Bridge B sees F on LAN 2 (with unknown destination), and copies the frame back to LAN 1

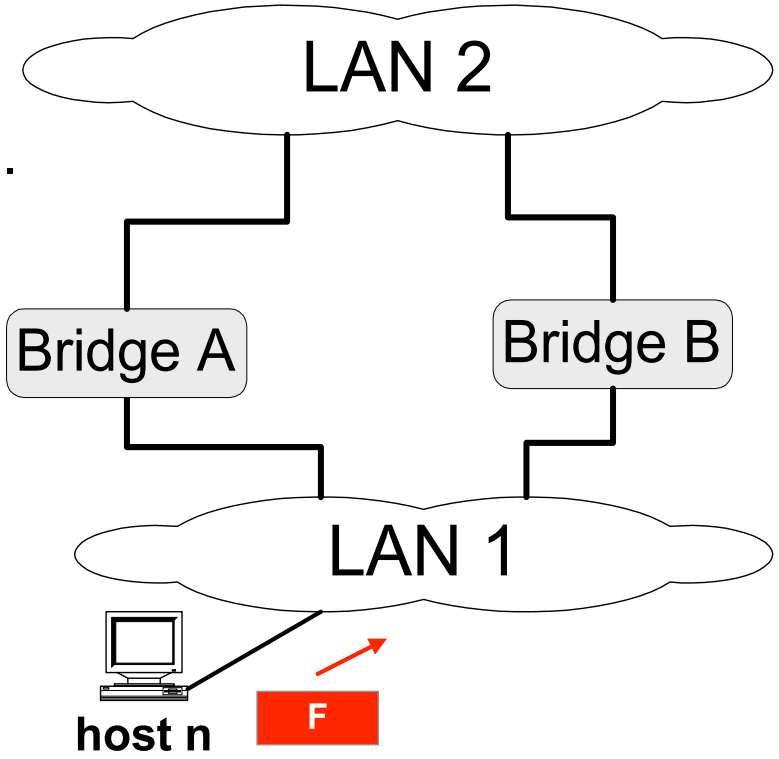


Danger of Loops

- Consider the two LANs that are connected by two bridges.
- Assume *host n* is transmitting a frame F with unknown destination.

What is happening?

- Bridges A and B flood the frame to LAN 2.
- Bridge B sees F on LAN 2 (with unknown destination), and copies the frame back to LAN 1
- Bridge A does the same.

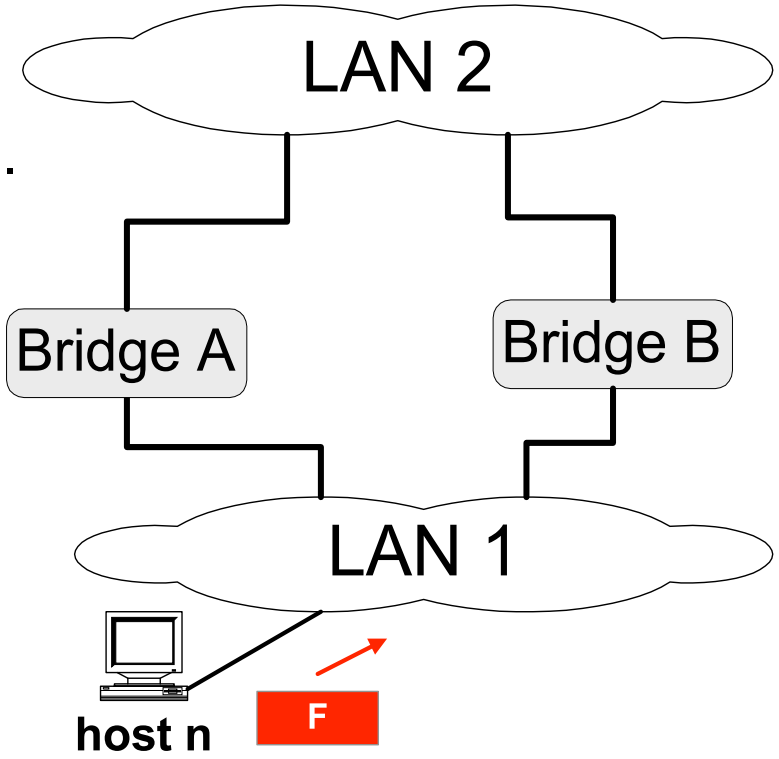


Danger of Loops

- Consider the two LANs that are connected by two bridges.
- Assume *host n* is transmitting a frame F with unknown destination.

What is happening?

- Bridges A and B flood the frame to LAN 2.
- Bridge B sees F on LAN 2 (with unknown destination), and copies the frame back to LAN 1
- Bridge A does the same.
- The copying continues



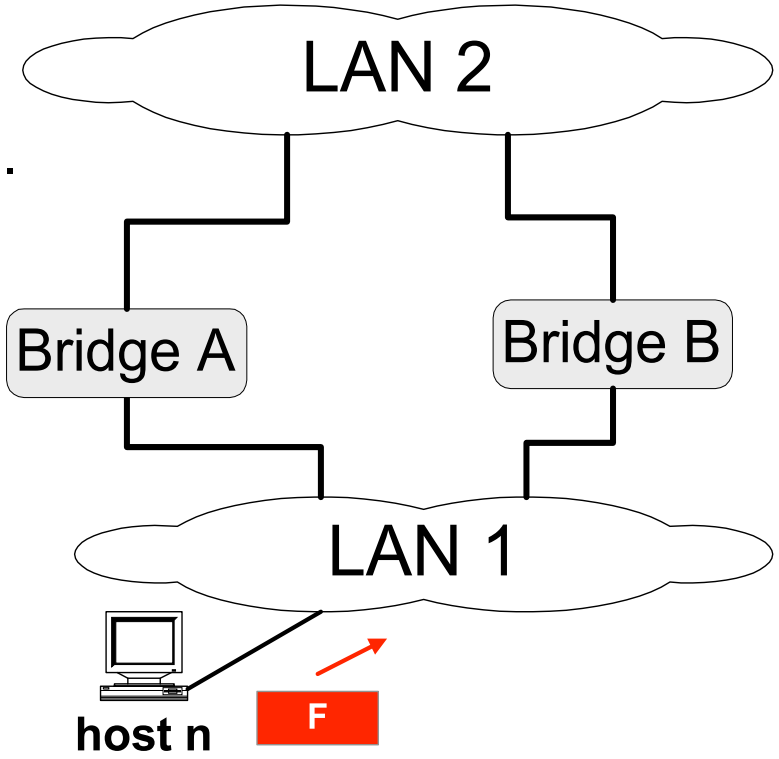
Danger of Loops

- Consider the two LANs that are connected by two bridges.
- Assume *host n* is transmitting a frame F with unknown destination.

What is happening?

- Bridges A and B flood the frame to LAN 2.
- Bridge B sees F on LAN 2 (with unknown destination), and copies the frame back to LAN 1
- Bridge A does the same.
- The copying continues

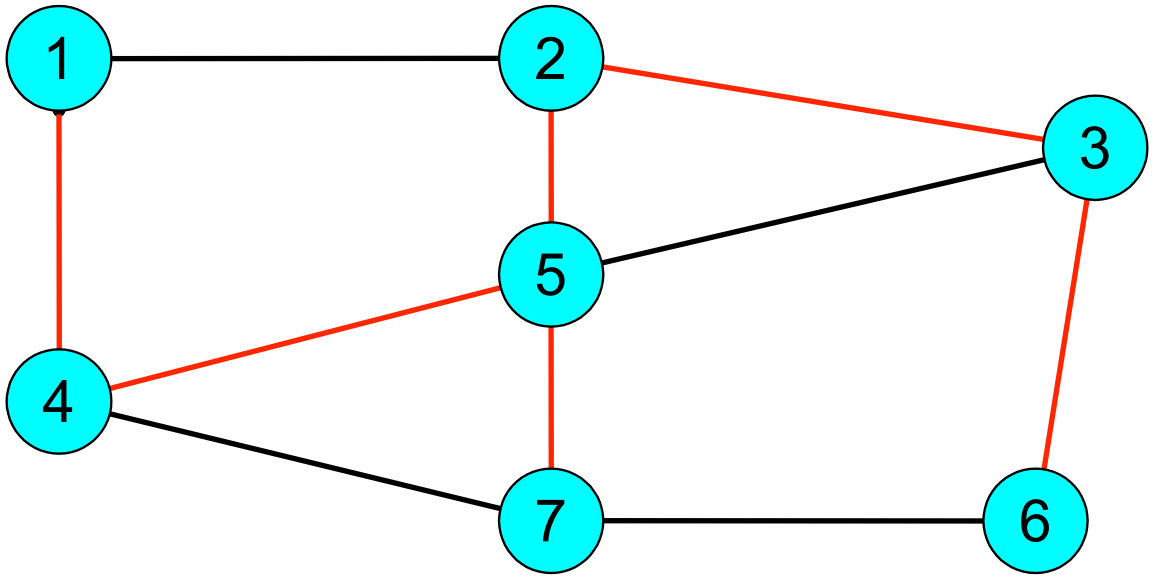
Where's the problem? What's the solution ?



Spanning Trees

- The solution to the loop problem is to not have loops in the topology
- IEEE 802.1 has an algorithm that builds and maintains a spanning tree in a dynamic environment.
- Bridges exchange messages (Configuration Bridge Protocol Data Unit (BPDU)) to configure the bridge to build the tree.

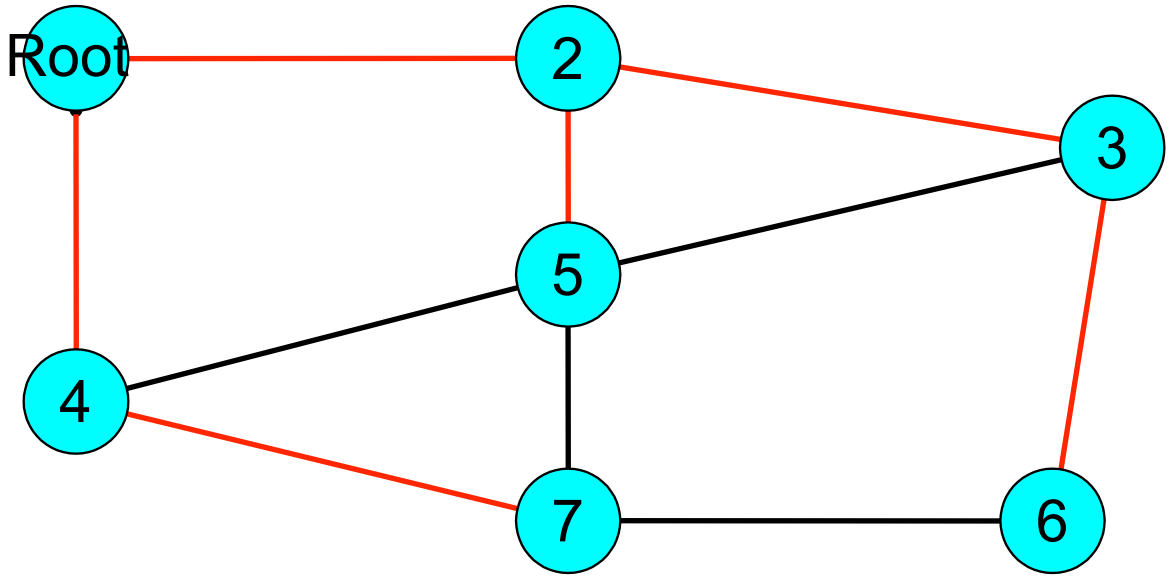
What's a Spanning Tree?



- A subset of edges of a graph that spans all the nodes without creating any cycle (i.e. a tree)

802.1 Spanning Tree Approach (Sketch)

- Elect a bridge to be the root of the tree
- Every bridge finds shortest path to the root
- Union of these paths become the spanning tree



What do the BPDU messages do?

With the help of the BPDUs, bridges can:

- Elect a single bridge as the **root bridge**.
- Calculate the distance of the shortest path to the root bridge
- Each LAN can determine a **designated bridge**, which is the bridge closest to the root. The designated bridge will forward packets towards the root bridge.
- Each bridge can determine a **root port**, the port that gives the best path to the root.
- Select ports to be included in the spanning tree.

Concepts

- Each bridge as a unique identifier:

  Bridge ID = <MAC address + priority level>

  Note that a bridge has several MAC addresses (one for each port), but only one ID

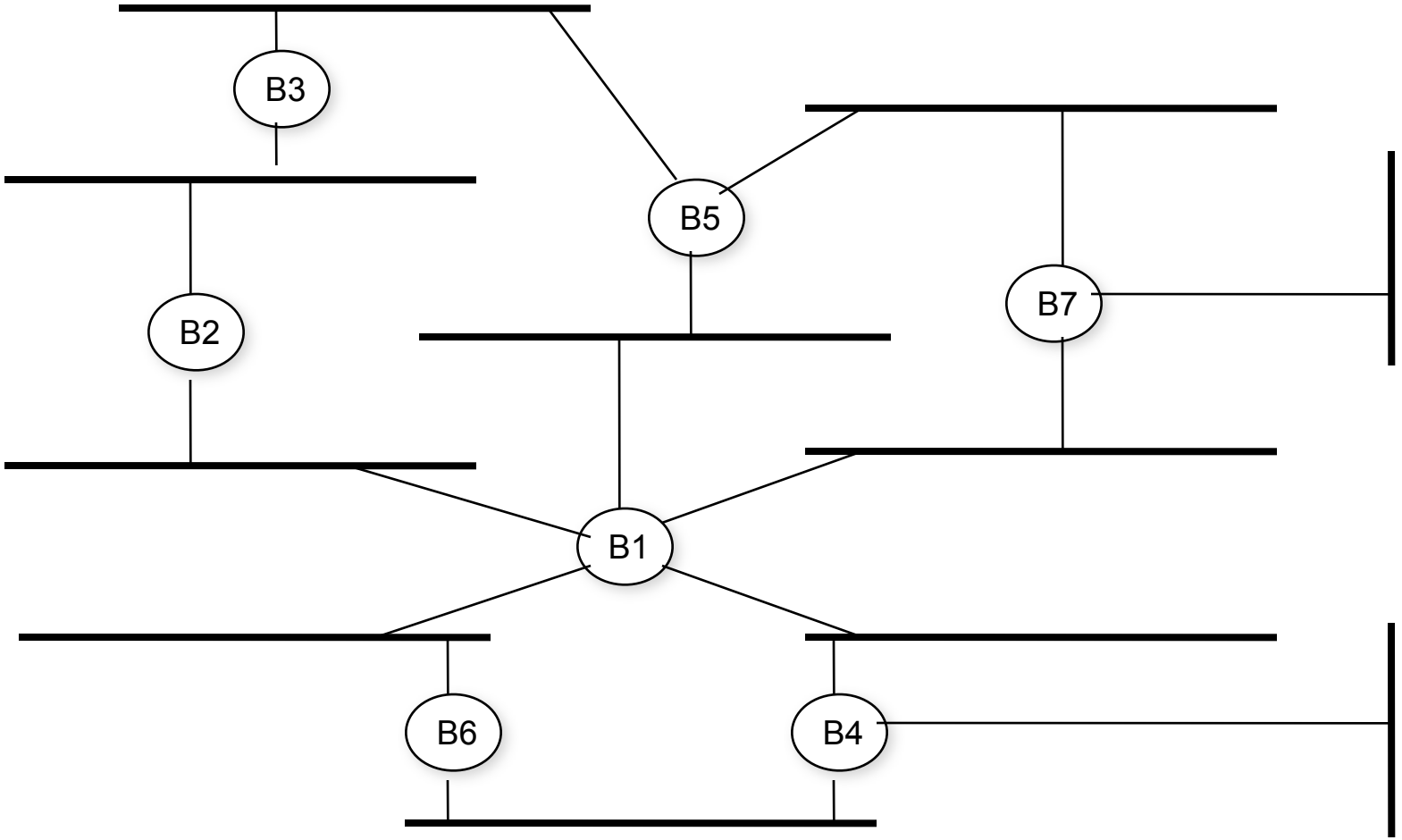
- Each port within a bridge has a unique identifier (port ID).
- **Root Bridge:** The bridge with the lowest identifier is the root of the spanning tree.
- **Path Cost:** Cost of the least cost path to the root from the port of a transmitting bridge; Assume it is measured in # of hops to the root.
- **Root Port**: Each bridge has a root port which identifies the next hop from a bridge to the root.

Concepts

- **Root Path Cost**: For each bridge, the cost of the min-cost path to the root
- **Designated Bridge, Designated Port:** Single bridge on a LAN that provides the minimal cost path to the root for this LAN:
  - if two bridges have the same cost, select the one with highest priority (smallest bridge ID)
  - if the min-cost bridge has two or more ports on the LAN, select the port with the lowest identifier

- **Note:** We assume that “cost” of a path is the number of “hops”.

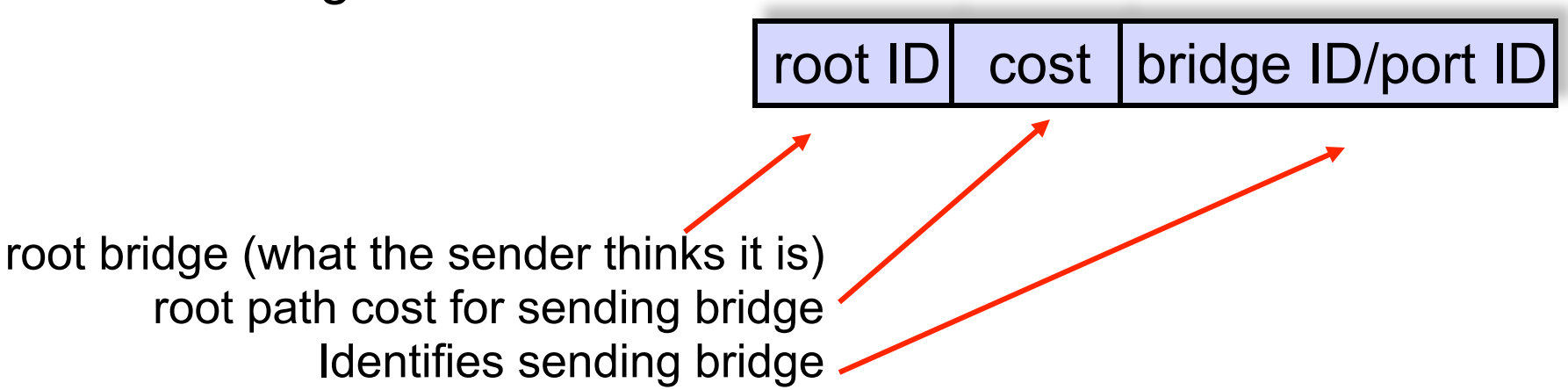
A Bridged Network



Steps of Spanning Tree Algorithm

1. **Determine the root bridge**
2. **Determine the root port on all other bridges**
3. **Determine the designated bridge on each LAN**

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



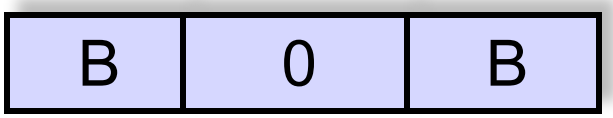
Ordering of Messages

- We can order BPDU messages with the following ordering relation "**í**" (let's call it "lower cost"):

If (R1 < R2)
    M1 í M2
elseif ((R1 == R2) and (C1 < C2))
    M1 í M2
elseif ((R1 == R2) and (C1 == C2) and (B1 < B2))
    M1 í M2
else
    M2 í M1

Determine the Root Bridge

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



- 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

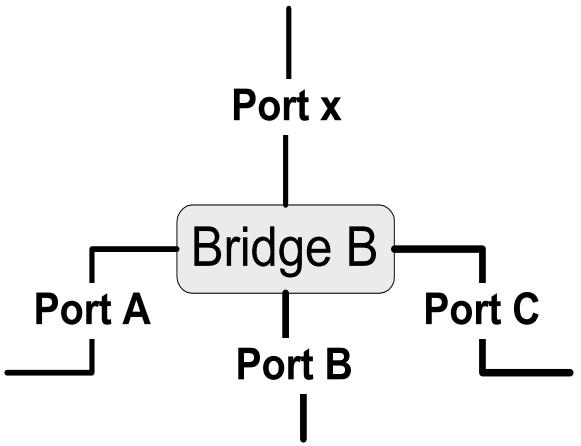
- At this time: A bridge B has a belief of who the root is, say R.
- Bridge B determines the Root Path Cost (Cost) as follows:
  - *If B = R :* Cost = 0.
  - *If B ≠ R:* Cost = {Smallest Cost in any of BPDUs that were received from R} + 1
- **B's root port** is the port from which B received the lowest cost path to R (in terms of relation "**i**").
- Knowing R and Cost, B can generate its BPDU (but will not necessarily send it out):

Calculate the Root Path Cost
Determine the Root Port

- At this time: B has generated its BPDU

R	Cost	B

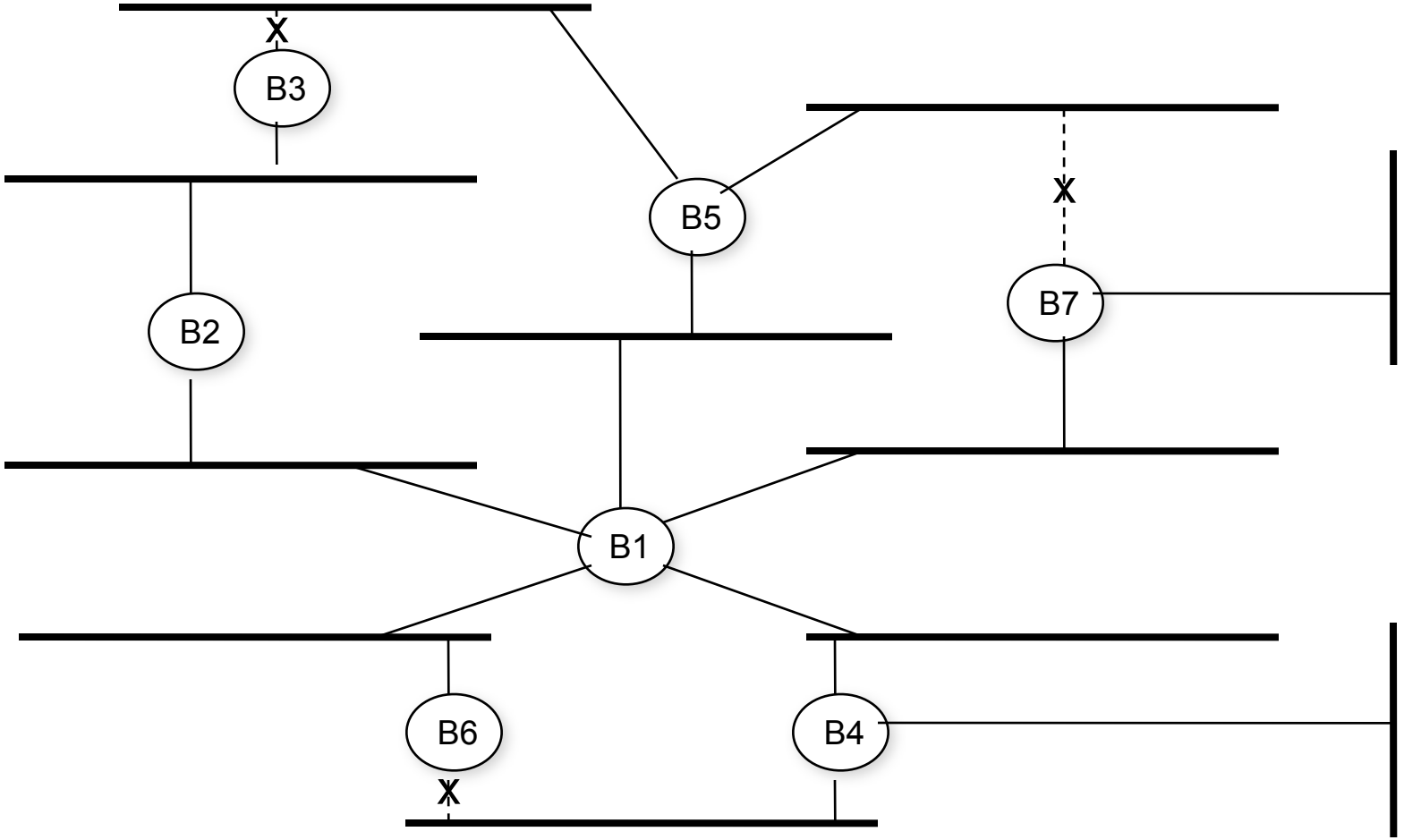
- B will send this BPDU on one of its ports, say **port x**, only if its BPDU is lower (via relation "**í**") than any BPDU that B received from port x.
- In this case, B also assumes that it is the **designated bridge** for the LAN to which the port connects.



Selecting the Ports for the Spanning Tree

- At this time: Bridge B has calculated the root, the root path cost, and the designated bridge for each LAN.
- 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 not forward packets **(=blocking state)**

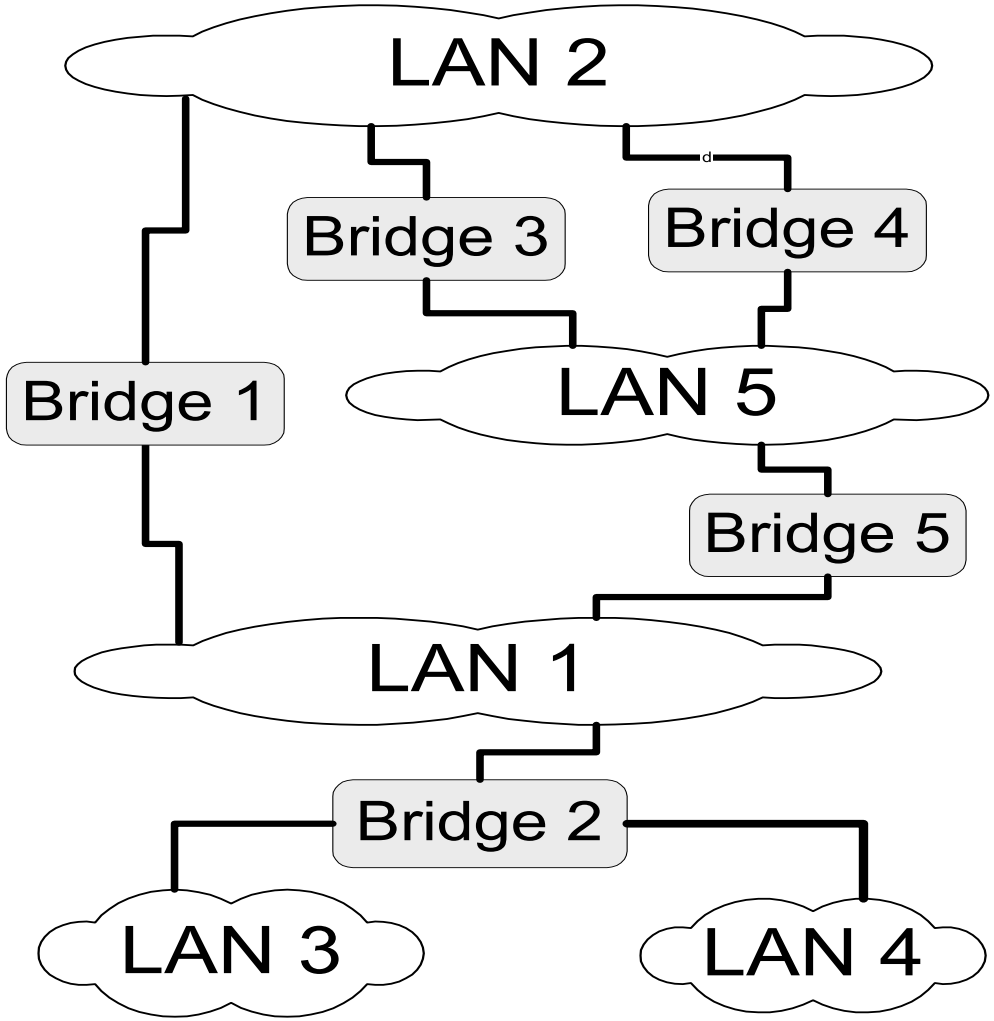
A Bridged Network (End of Spanning Tree Computation)



Ethernet Switches

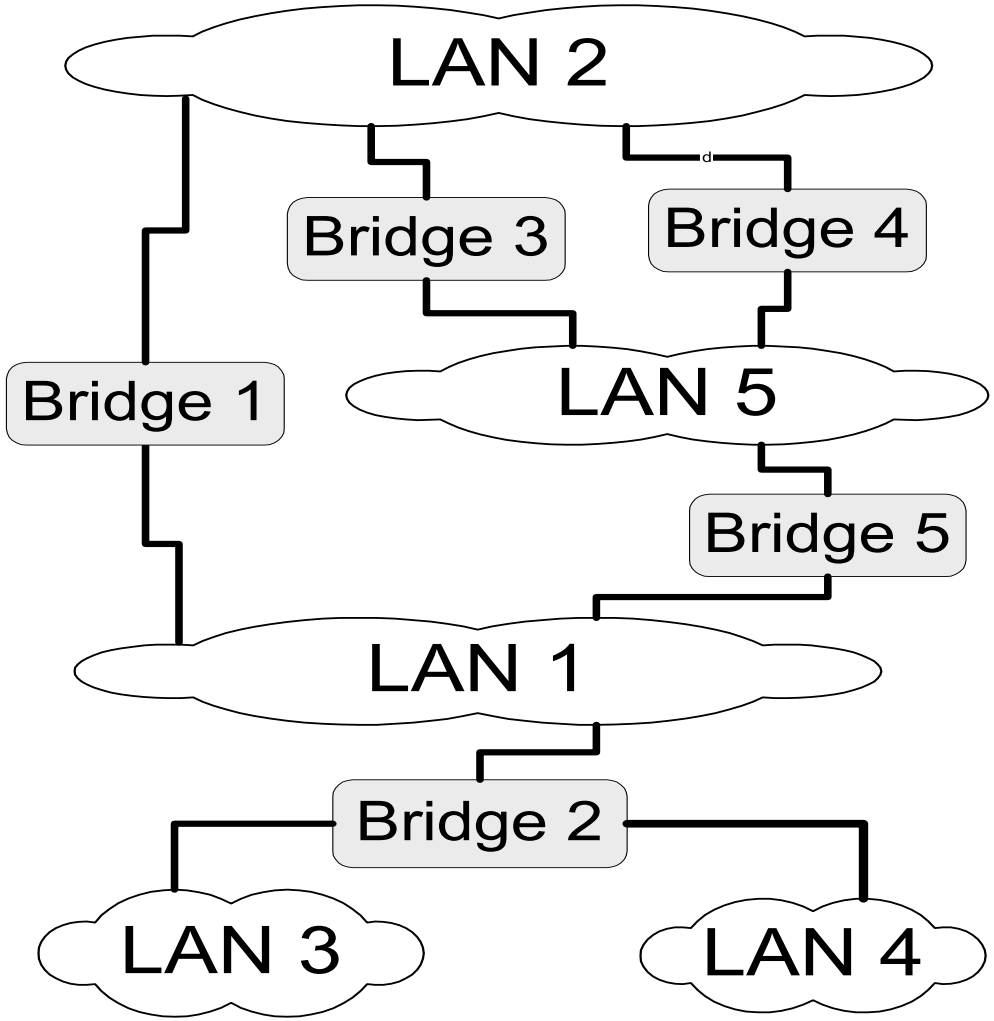
- Bridges make it possible to increase LAN capacity.
  - Packets are no longer broadcasted - they are only forwarded on selected links
  - Adds a switching flavor to the broadcast LAN
- Ethernet switch is a special case of a bridge: each bridge port is connected to a single host.
  - Can make the link full duplex (really simple protocol!)
  - Simplifies the protocol and hardware used (only two stations on the link) – no longer full CSMA/CD
  - Can have different port speeds on the same switch
    - Unlike in a hub, packets can be stored

Can the Internet be One Big Switched Ethernet?



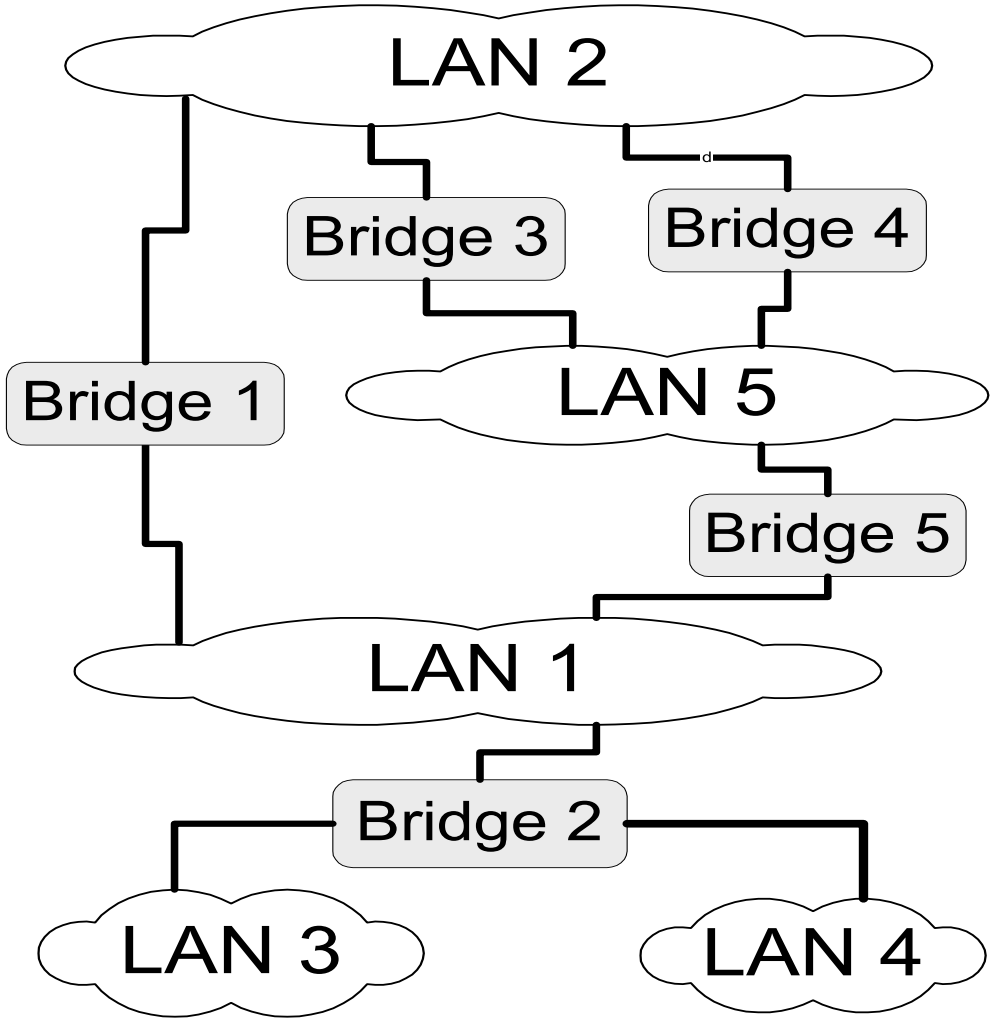
Can the Internet be One Big Switched Ethernet?

- Inefficient
  - Too much flooding



Can the Internet be One Big Switched Ethernet?

- Inefficient
  - Too much flooding
- Explosion of forwarding table
  - Need to have one entry for every Ethernet address in the world!
- Poor performance
  - Tree topology does not have good load balancing properties
  - Hot spots



Can the Internet be One Big Switched Ethernet?

- Inefficient
  - Too much flooding
- Explosion of forwarding table
  - Need to have one entry for every Ethernet address in the world!
- Poor performance
  - Tree topology does not have good load balancing properties
  - Hot spots
- Etc…