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Computer Networks

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Chapter 2. Direct Link Networks

- Link Layer Service
  - Framing
  - Link access
  - Reliable delivery
  - Error detection and correction
- Local Area Network (LAN)
  - Token Ring
  - Ethernet
- Medium access control
- Bridges and Layer-2 switch
- Wireless Networks

Bridges and Layer-2 switch

Interconnection of LANs

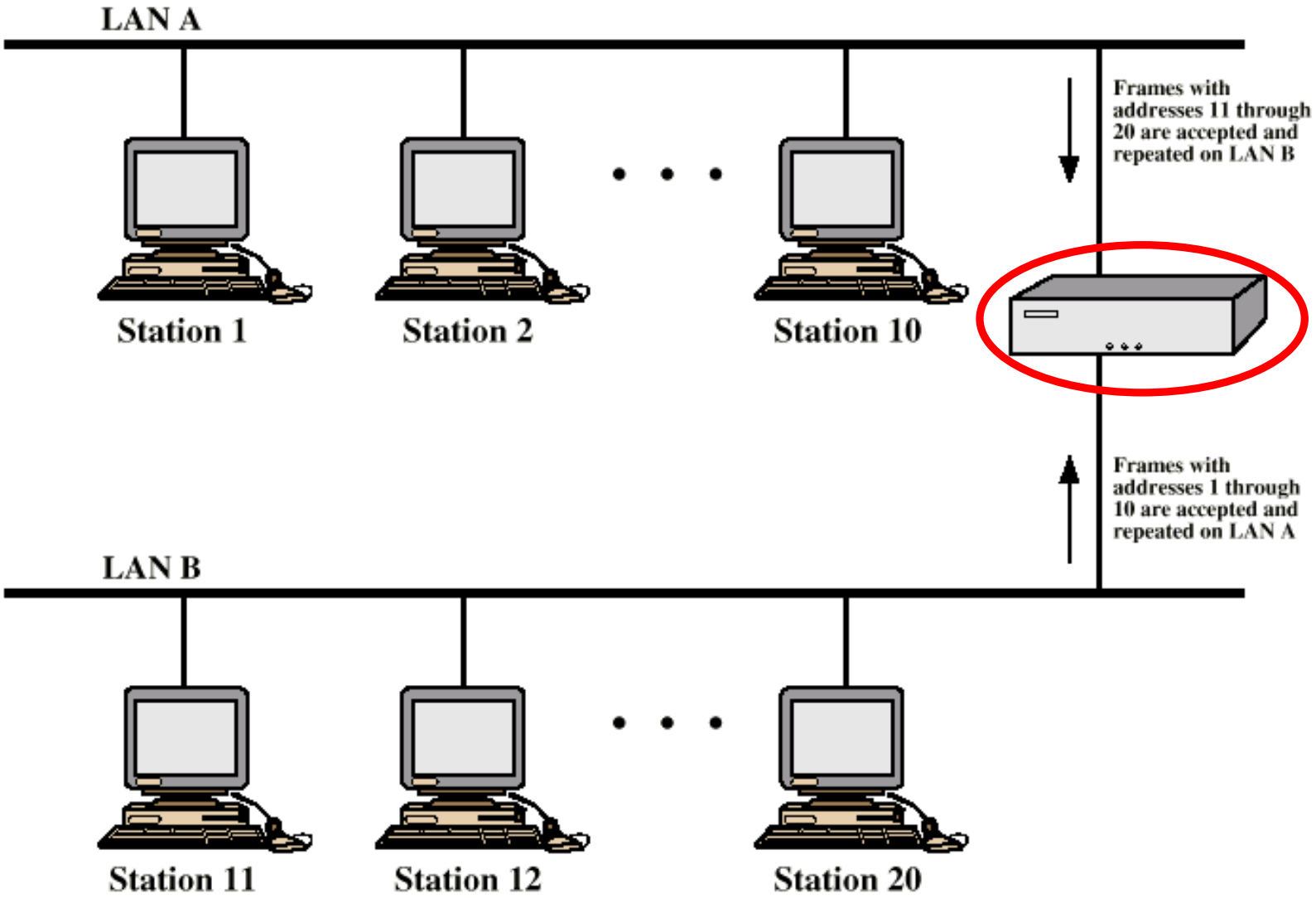
- Ability to expand beyond single LAN
- Provide interconnection to other LANs/WANs

- Bridge is used (later Layer-2 switch)
  - Connects LANs, usually more than two LANs
  - Identical protocols for physical and MAC layers

  - Store, forward LAN frames
  - Exact bitwise copy of frame

  - Switch (route) functions needed

Bridge Operation

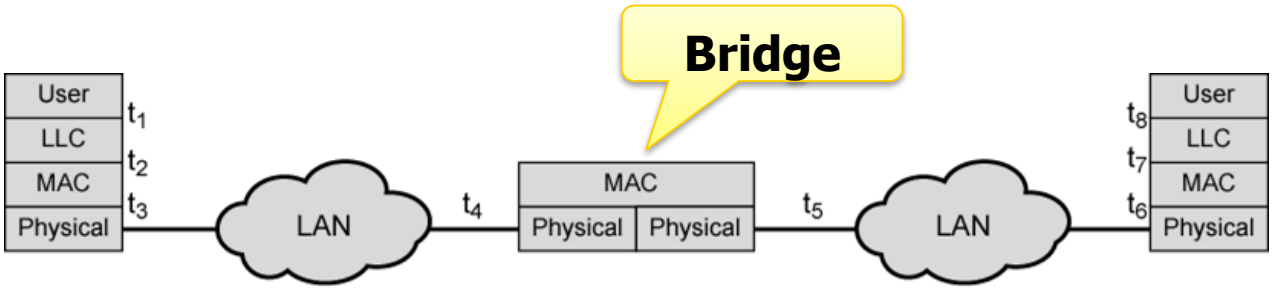


Requirements of a Bridge

- Store and Forward
  - Read frames transmitted on one LAN, Examine frames' MAC address, selectively store those address to other LANs
  - Using MAC protocol of second LAN, retransmit each frame
- Transparent
  - Stations are unaware of presence of bridges
- Plug-and-play, self-learning
  - Bridges do not need to be configured

Bridge Protocol Architecture

- IEEE 802.1D, MAC level
  - Use MAC address for switching
- Relaying MAC frames

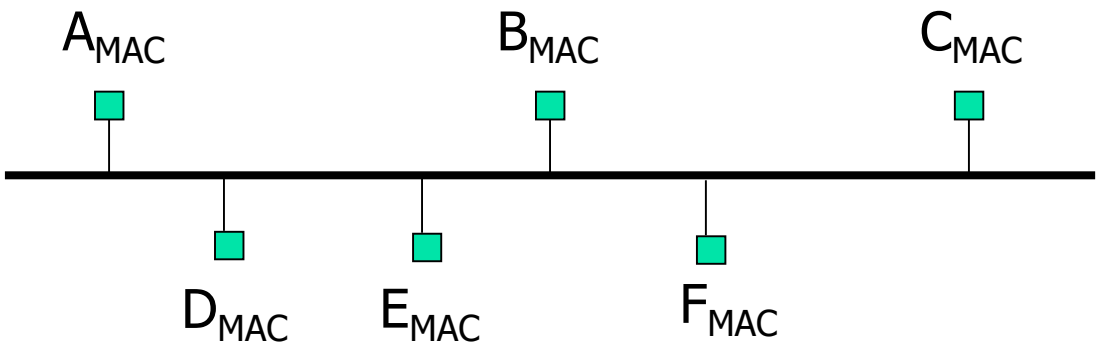


(a) Architecture

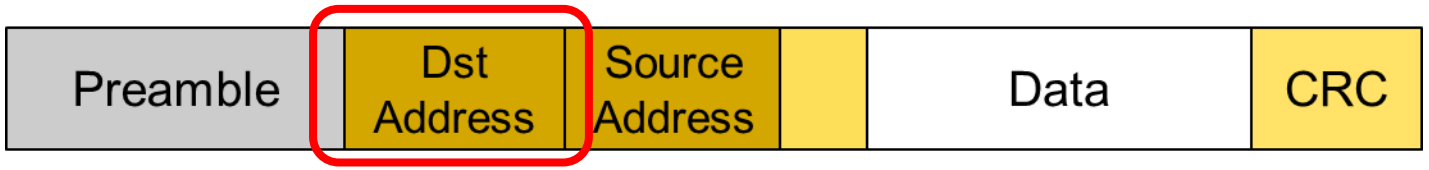
Mechanisms of a Bridge

- Mechanisms
  - Transparent bridge: 802.1D
    - Frame broadcasting
    - Loop resolution
    - Address learning

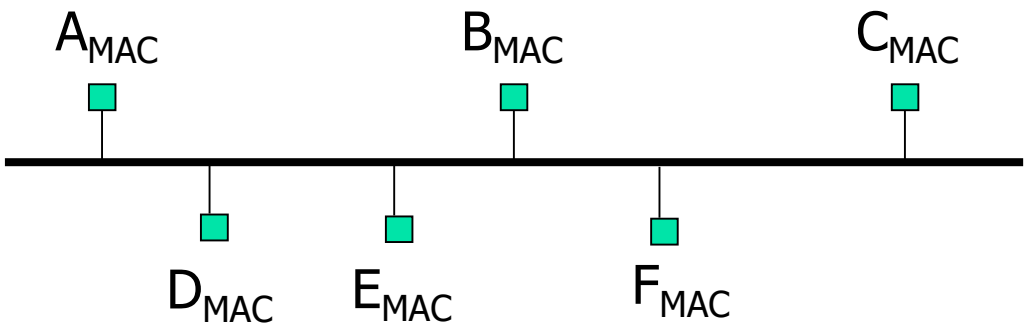
Broadcast Ethernet



- Sender transmits frame onto broadcast link
- Each receiver's link layer passes the frame to the network layer:
  - If destination address matches the receiver's MAC address OR if the destination address is the broadcast MAC address (ff:ff:ff:ff:ff:ff)

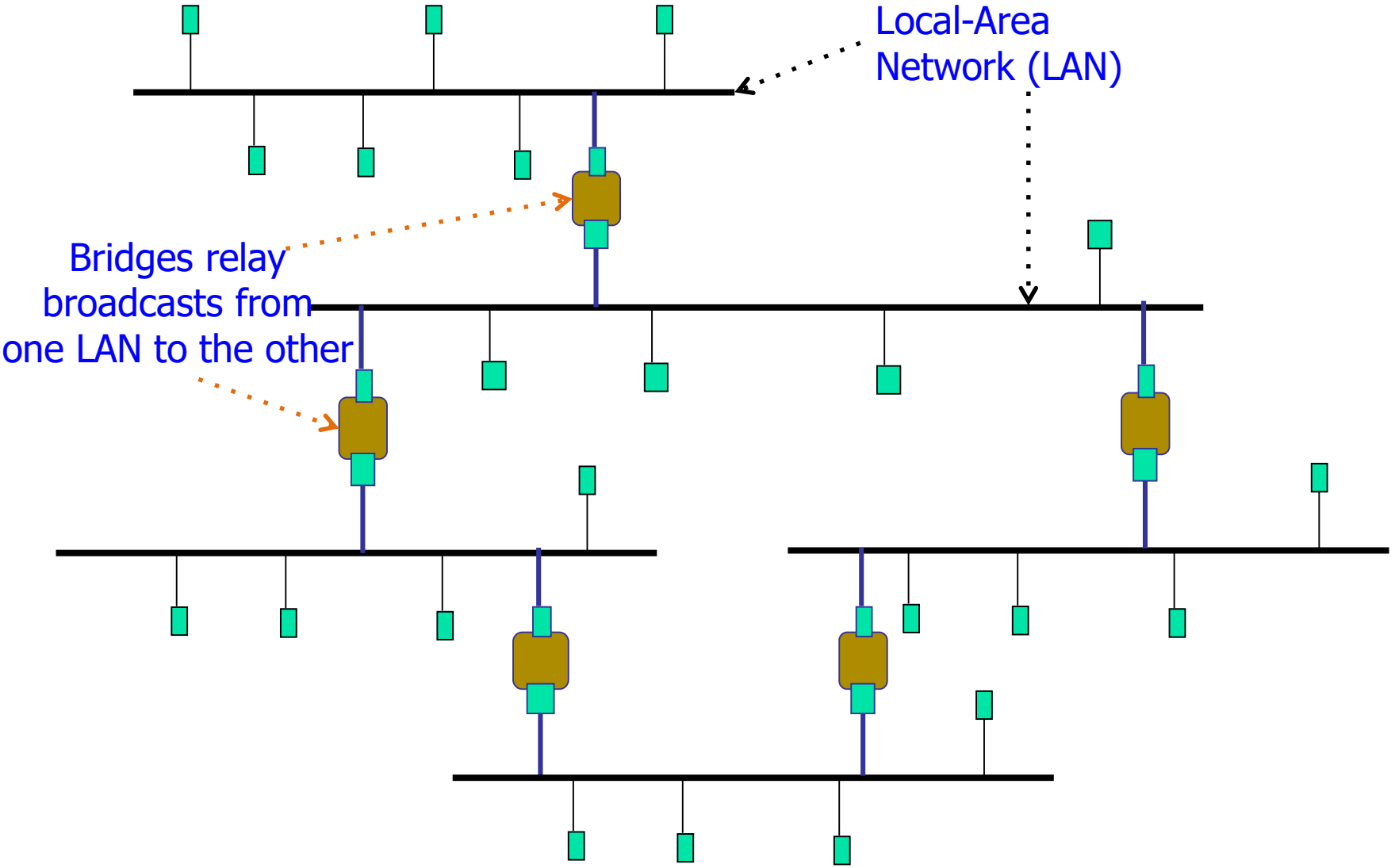


Broadcast Ethernet

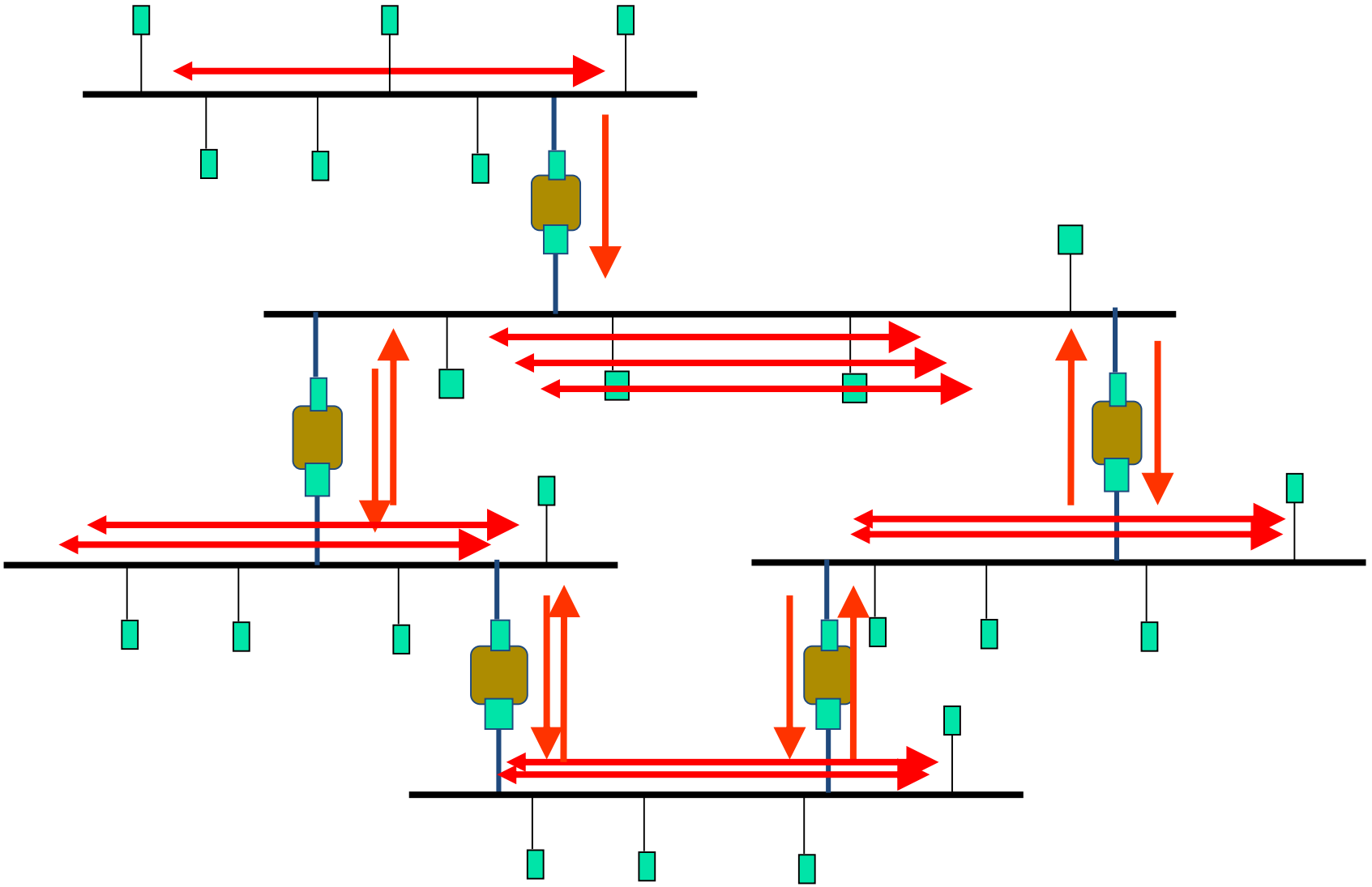


- Ethernet is "plug-n-play"
- A new host plugs into the Ethernet and is good to go
  - No configuration by users or network operators
  - Broadcast as a means of bootstrapping comm.

Broadcasting in extended LANs

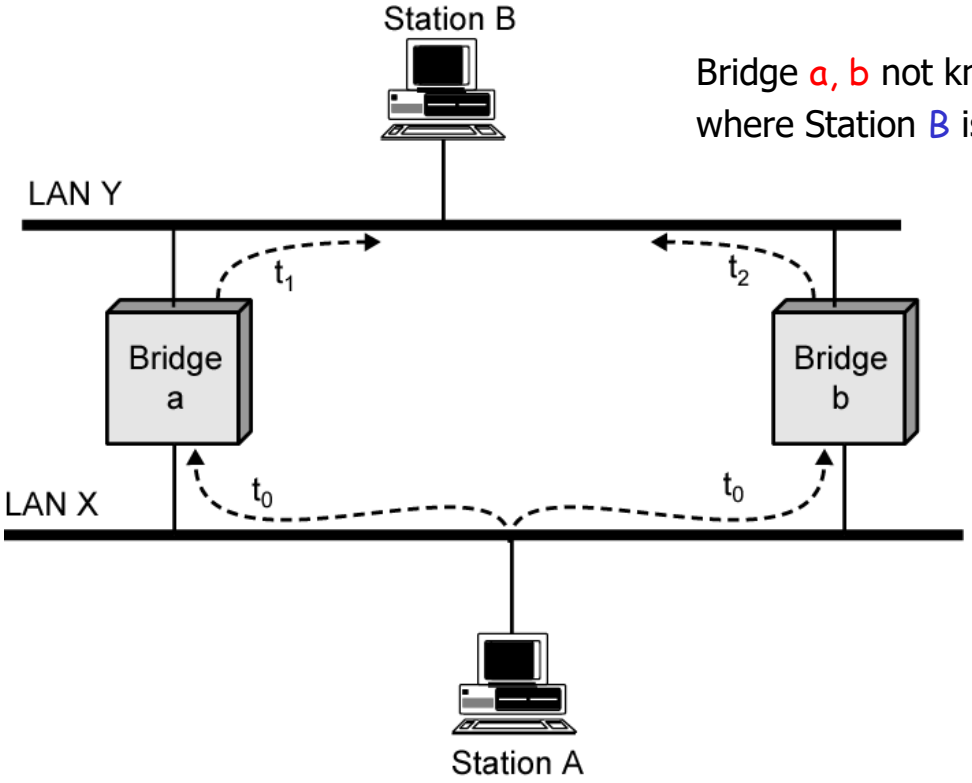


The "broadcast storm" problem



What causes "broadcast storm"?

Loops!



Bridge a, b not know where Station B is

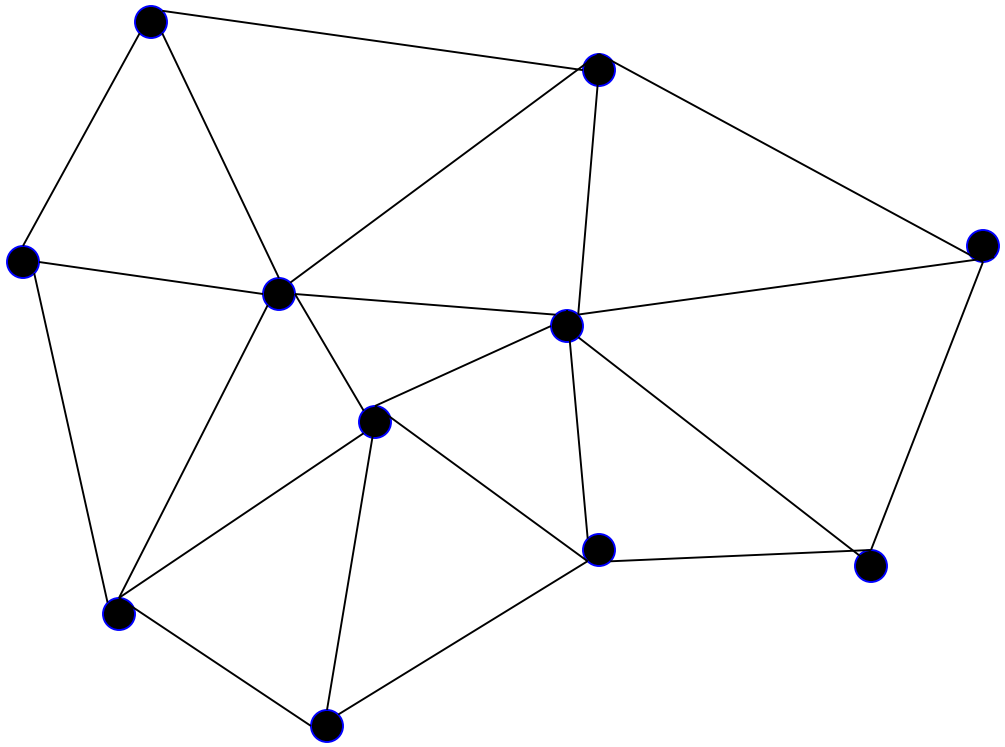
Radia Perlman

Perlman's idea: eliminate loops in the topology

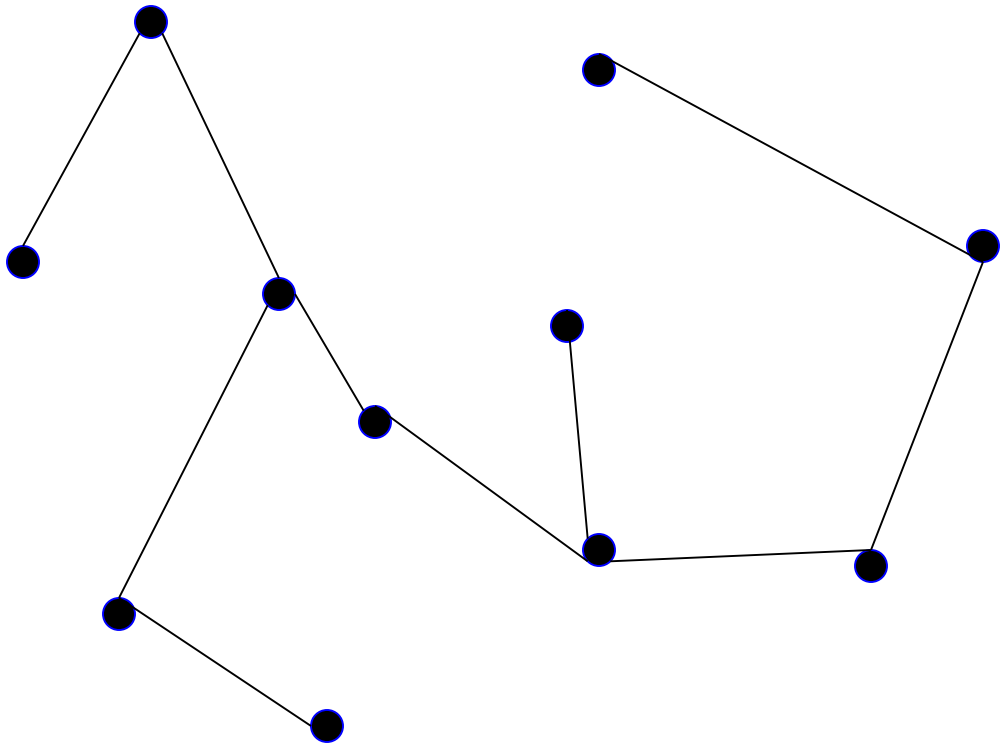
Easiest way to avoid loops

- Use a topology where loops are impossible!
- Take arbitrary topology and build a spanning tree
  - Sub-graph that includes all vertices but contains no cycles
  - Links not in the spanning tree are not used to forward frames

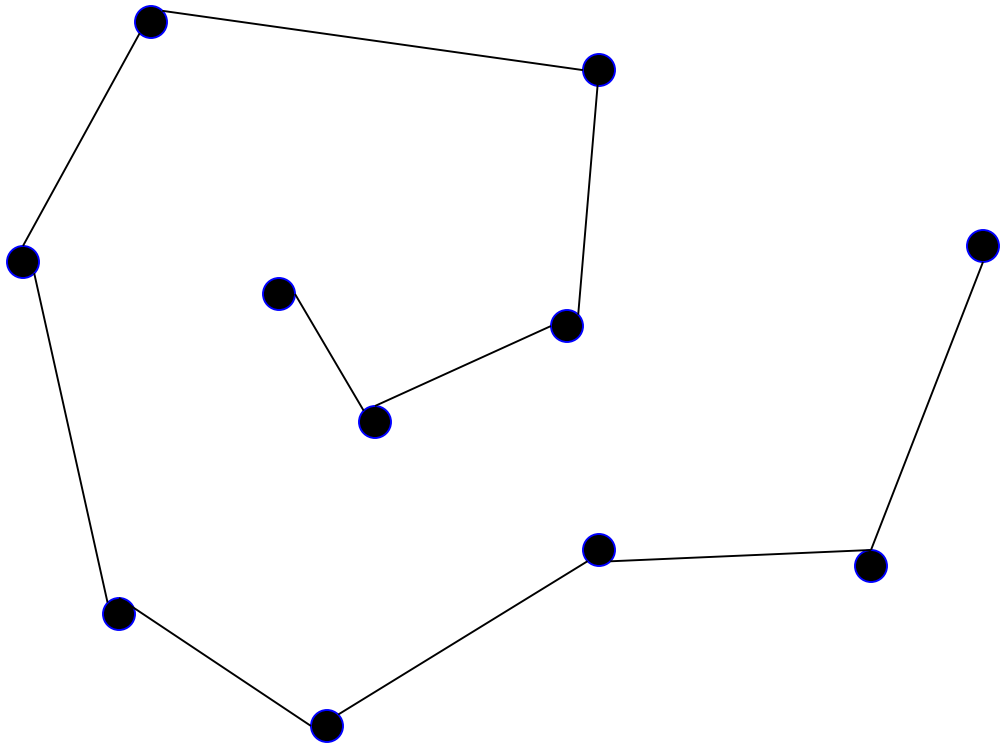
Consider a graph



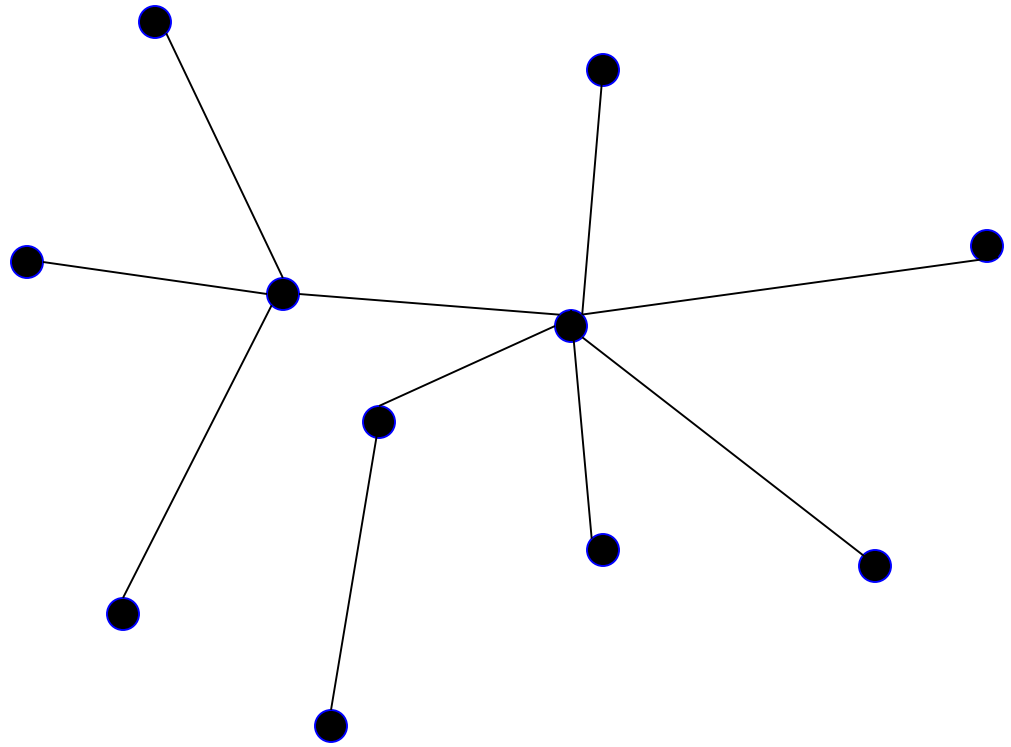
A spanning tree



Another spanning tree



Yet another spanning tree



Spanning tree protocol (Perlman'85)

- Protocol by which bridges construct a spanning tree
- Nice properties
  - Zero configuration (by operators or users)
  - Self healing
- Still used today

Spanning tree algorithm

- Take arbitrary network topology as input
- Pick subset of links that form a spanning tree

Algorithm has two aspects

- Pick a root
  - Destination to which shortest paths go
  - Pick the one with the smallest identifier (MAC addr.)
- Compute shortest paths to the root
  - No shortest path can have a cycle
  - Only keep the links on shortest-paths
  - Break ties in some way (so we only keep one shortest path from each node)
- Ethernet's spanning tree construction does both with a single algorithm

Breaking ties

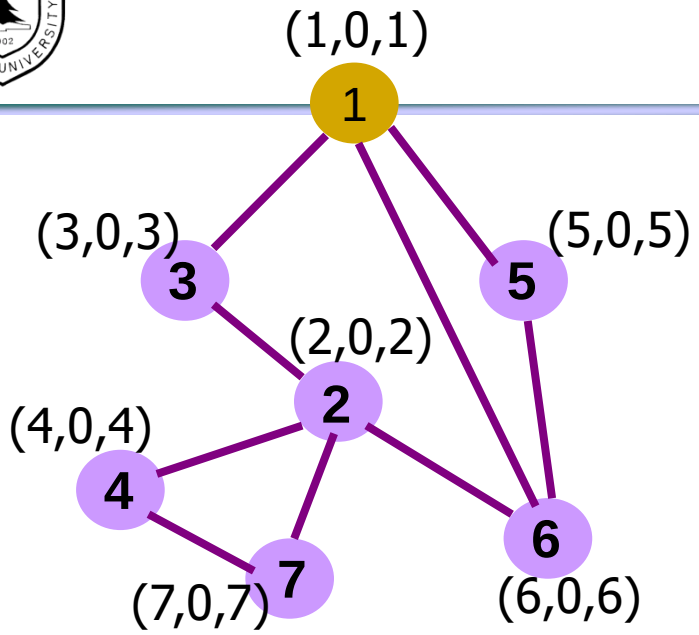
- When there are multiple shortest paths to the root, choose the path that uses the neighbor with the lower ID
  - One could use any tiebreaking system, but this is an easy one to remember and implement

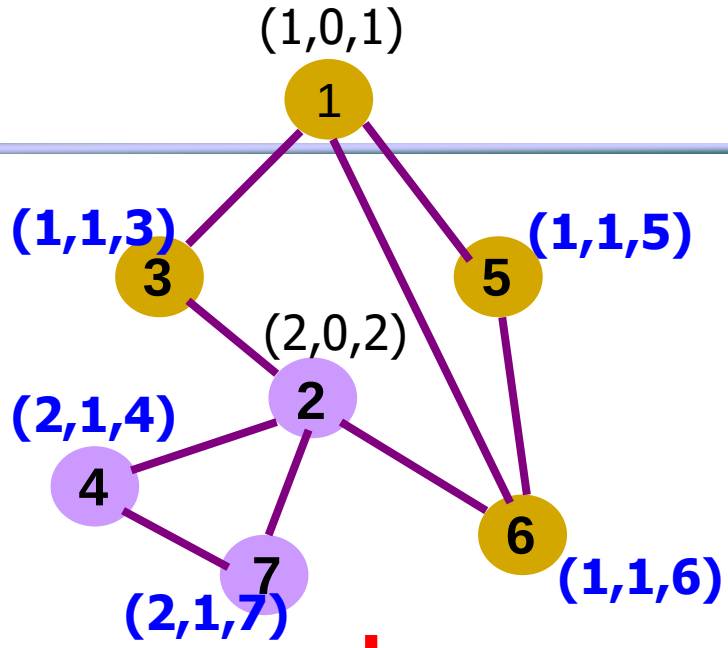
Constructing a spanning tree

- Messages (Y, d, X)
  - From node X
  - Proposing Y as the root
  - And advertising a distance d to Y
- Switches elect the node with smallest identifier (MAC address) as root
- Each node determines if a link is on its shortest path to the root; excludes it from the tree if not

Steps in the spanning tree algorithm

- Initially, each node proposes itself as the root
  - Switch X announces (X, 0, X) to its neighbors
- Nodes update their view of the root
  - Upon receiving (Y, d, Z) from Z, check Y's id
  - If Y's id < current root: set root = Y
- Nodes compute their distance from the root
  - Add 1 to the shortest distance received from a neighbor
- If root or shortest distance to it changed, send neighbors updated message (Y, d+1, X)


(1,0,1)
1
(3,0,3)
3
5
(5,0,5)
(2,0,2)
2
(4,0,4)
4
7
6
(7,0,7)
(6,0,6)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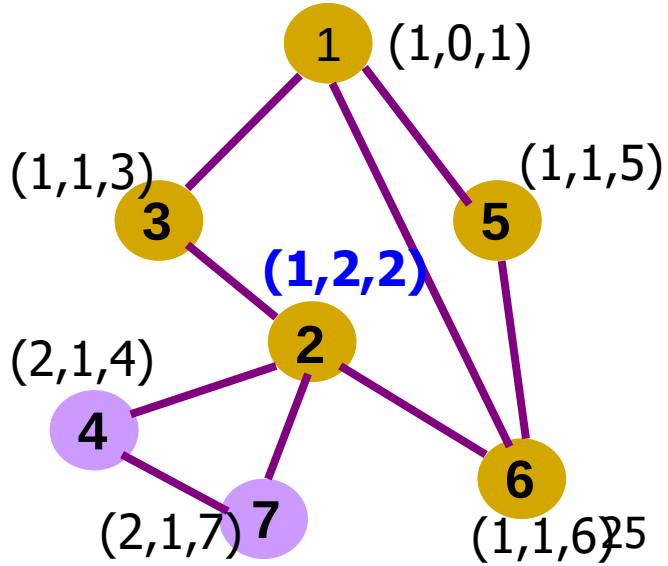
(1,1,6)
(2,1,7)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(1,1,3)
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(1,1,5)
(1,2,2)
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(2,1,4)
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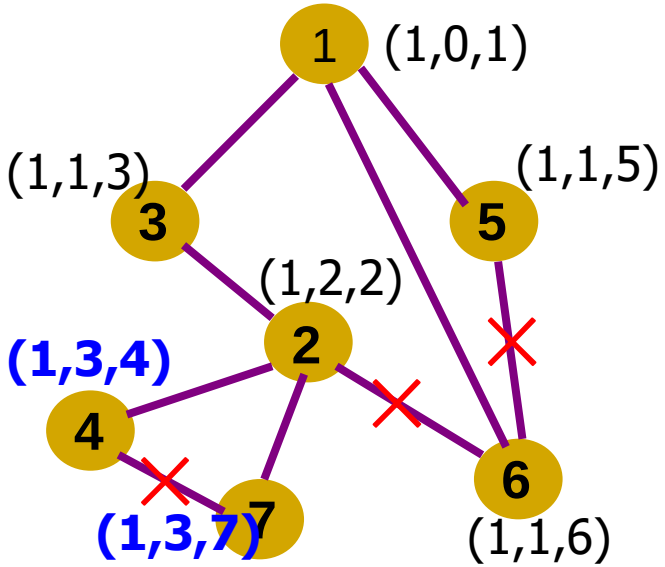
7
(2,1,7)
(1,1,6)


1
(1,0,1)
(1,1,3)
3
5
(1,1,5)
(1,2,2)
2
(1,3,4)
4
6
7
(1,3,7)
(1,1,6)

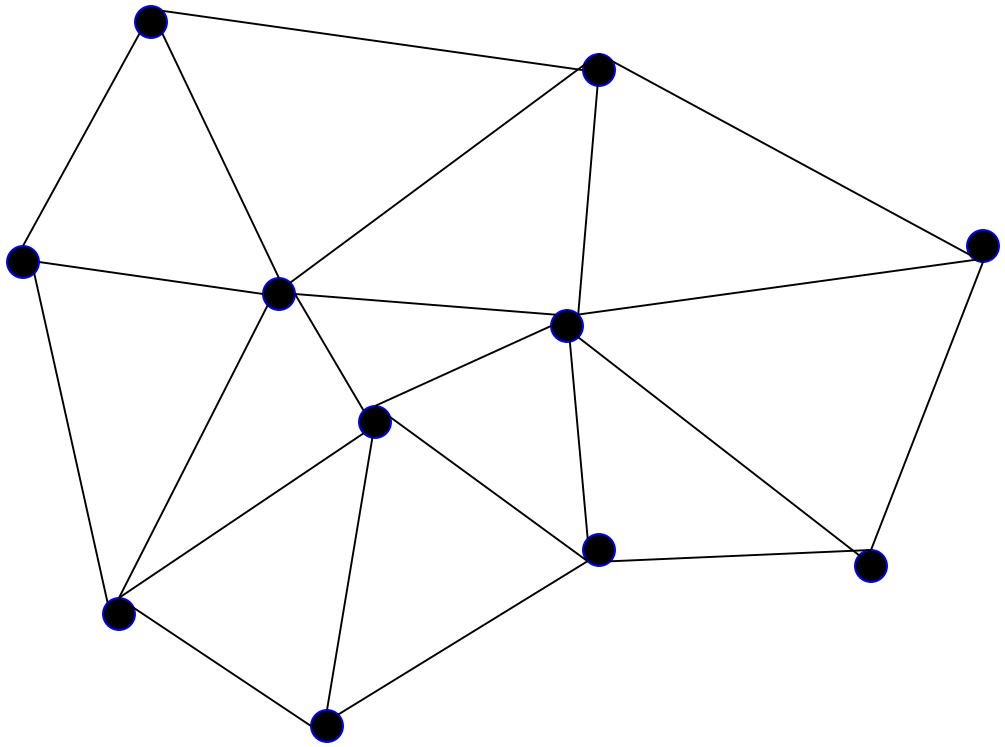
Robust spanning tree algorithm

- Algorithm must react to failures
  - Failure of the root node
  - Failure of other bridges and links
- Root sends periodic root announcement messages
  - Other bridges continue forwarding messages
- Detecting failures through timeout
  - If no word from root, time out and claim to be the root!

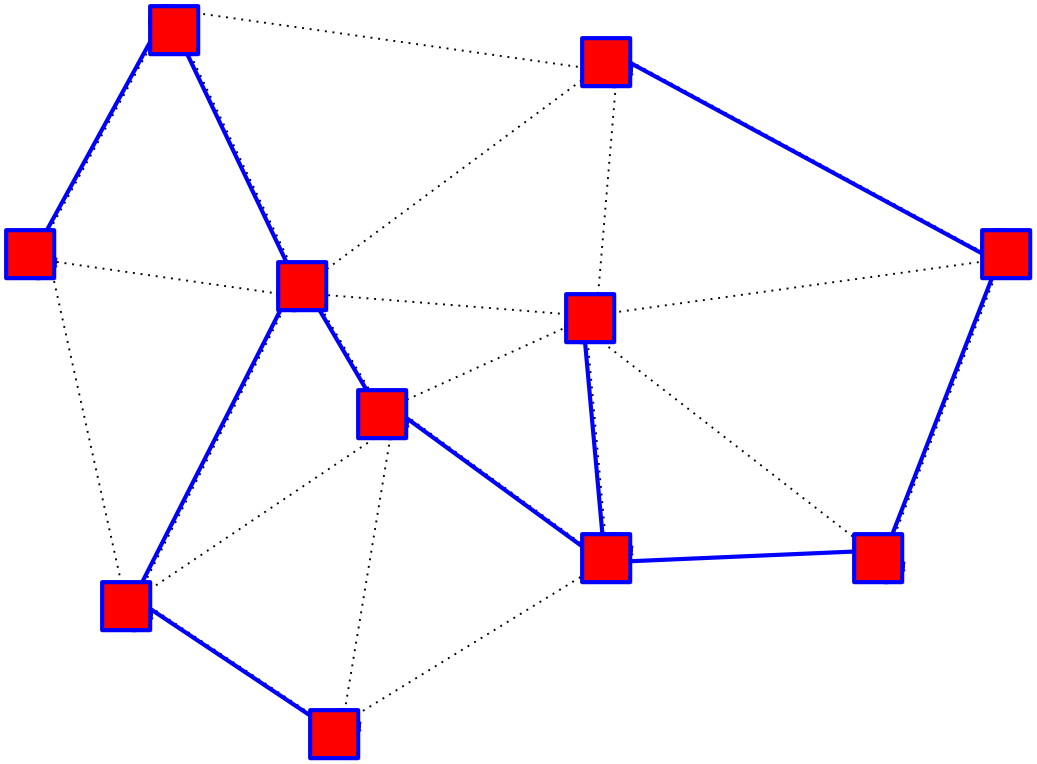
Flooding on a spanning tree

- Bridges flood using the following rule:
  - (Ignore all ports not on spanning tree!)
  - Originating bride sends packet out all ports
  - When a packet arrives on one incoming port, send it out all ports other than the incoming port

Flooding on spanning tree



Flooding on spanning tree



But isn't flooding wasteful?

- Yes, but we can use it to bootstrap more efficient forwarding
- Idea: watch the packets going by, and learn from them
  - If node A sees a packet from node B come in on a particular port, it knows what port to use to reach B!
  - Works because there is only one path to B

Nodes can "learn" routes

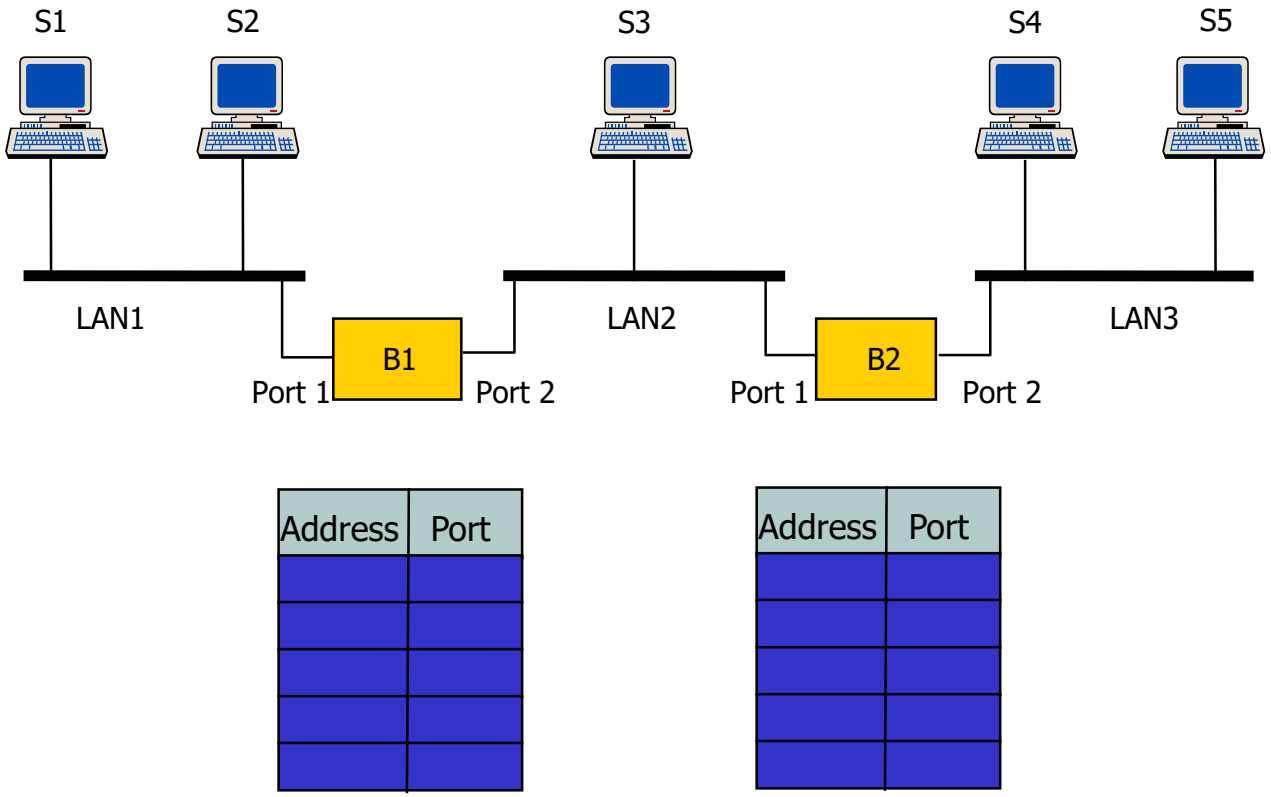
- Switch learns how to reach nodes by remembering where flooding packets came from
  - If flood packet from Node A entered bridegroom on port 4, then bridge uses port 4 to send to Node A

Address Learning

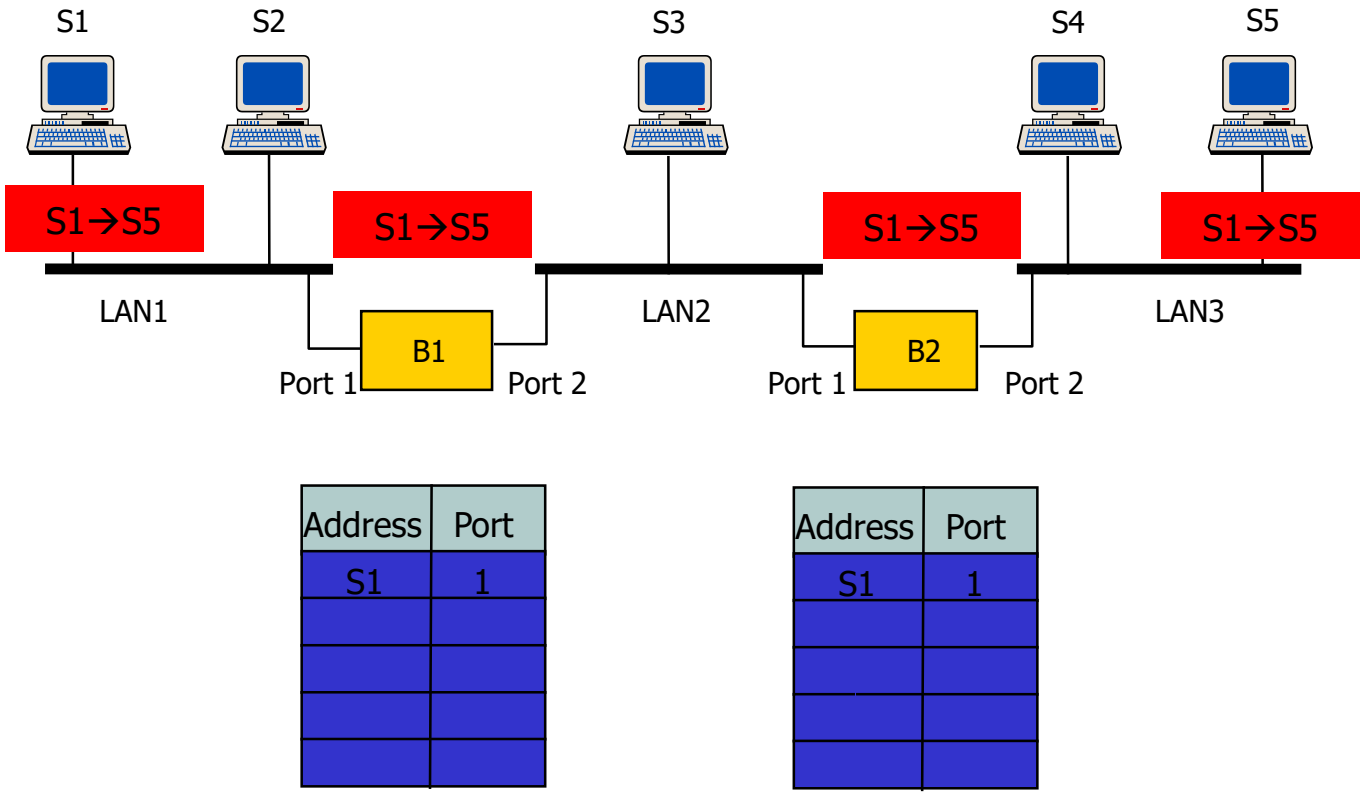
- Each bridge maintains a forwarding database
- Forwarding database can be learned
- When frame arrives at port X, it has come from the LAN attached to port X

- Use the source address to update forwarding database for port X to include that address
- Timer on each entry in database, Entry deleted when timer is off

- Each time frame arrives, source address checked against forwarding database


S1
S2
S3
S4
S5
LAN1
LAN2
LAN3
B1
B2
Port 1
Port 2
Port 1
Port 2
Address
Port
Address
Port

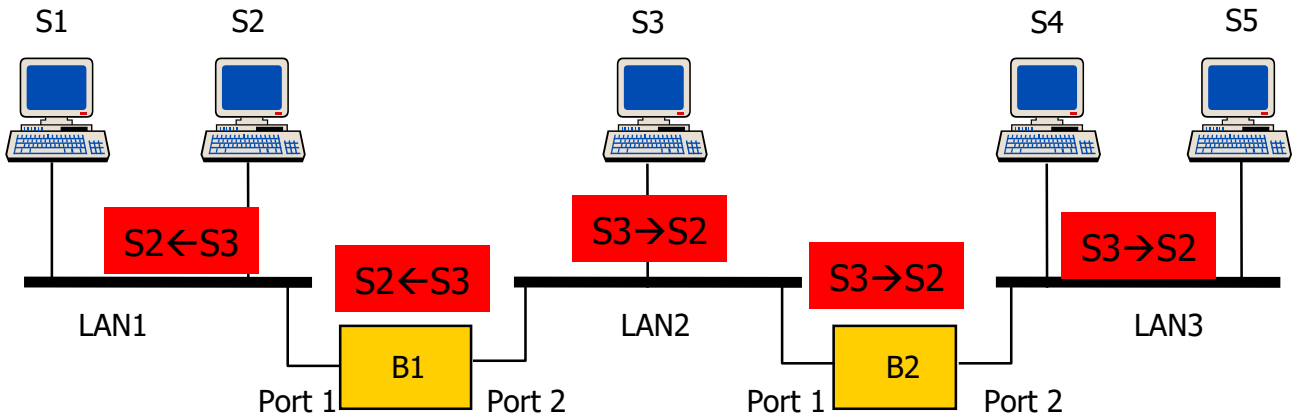
S1→S5



Address	Port
S1	1

Address	Port
S1	1

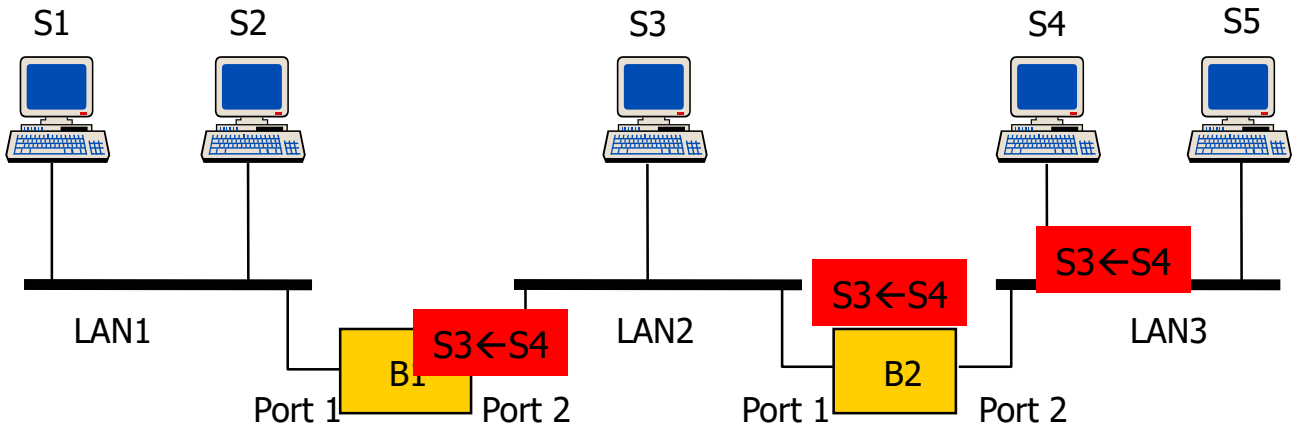
S3→S2



Address	Port
S1	1
S3	2

Address	Port
S1	1
S3	1

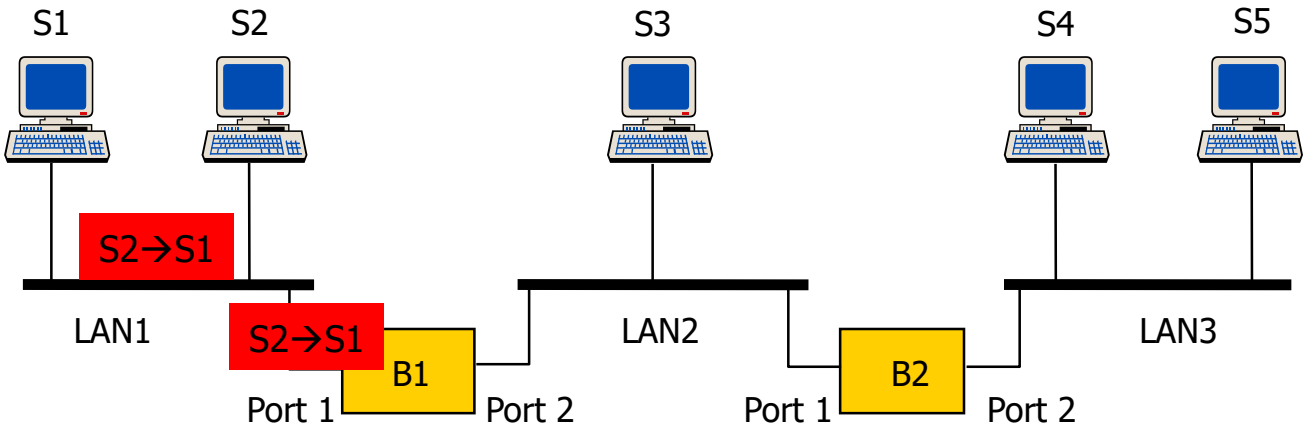
S4→S3



Address	Port
S1	1
S3	2
S4	2

Address	Port
S1	1
S3	1
S4	2

S2→S1



Address	Port
S1	1
S3	2
S4	2
S2	1

Address	Port
S1	1
S3	1
S4	2

Summary of bridge frame forwarding

- Maintain **forwarding database** for each port
  - <Mac Address, Port, Timestamp>: station addresses reached through each port
- For a frame arriving on port X
  - Search forwarding database to see if dest MAC address is listed for any port:
  - If address not found, forward to all ports (flooding) except X
  - If address listed for port X, drop it
  - If address listed for port Y, check port Y for Blocking or Forwarding state, transmit if Forwarding state
  - Blocking used to form a tree

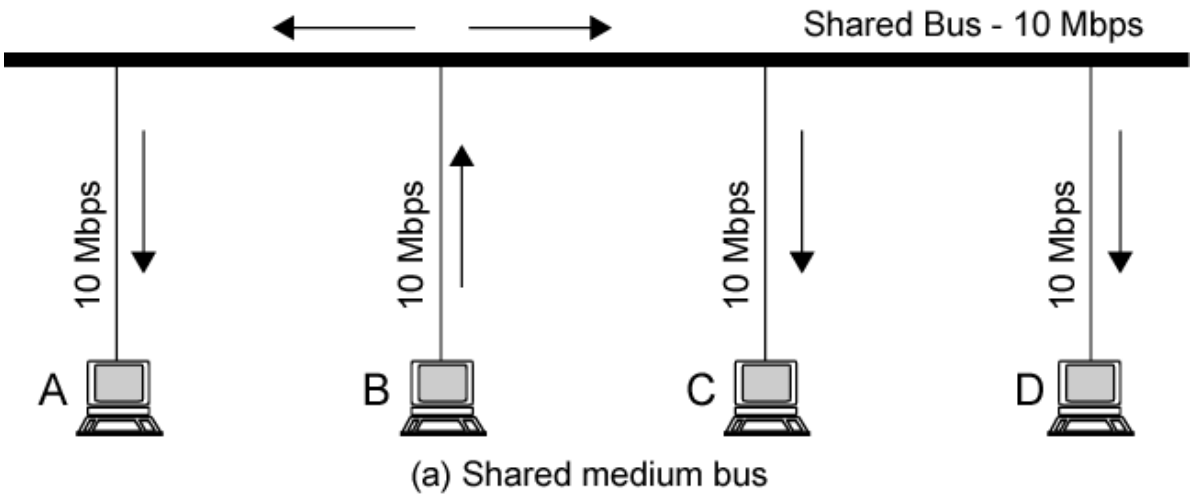
Types of devices for interconnecting LANs

- Hubs: physical repeaters
- Bridges：connecting LANs (forwarding + address learning)
- Layer 2 switches: connecting Hosts or LANs (bridge functions + collision free)
- Layer 3 switches: involving router functions

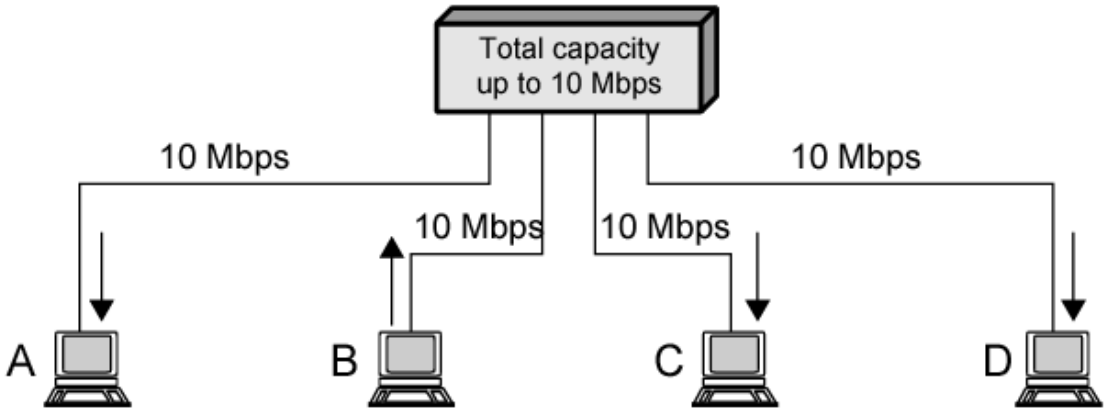
Hubs

- Active central element of star layout
- Each station connected to hub by two lines
  - Transmit and receive
- Hub acts as a repeater
  - When a station transmits, hub repeats signal on outgoing line to all other stations
- Physically star, logically bus
  - Transmission from any station received by all other stations
  - If two stations transmit at the same time, collision

Shared Medium Bus and Hub



(a) Shared medium bus



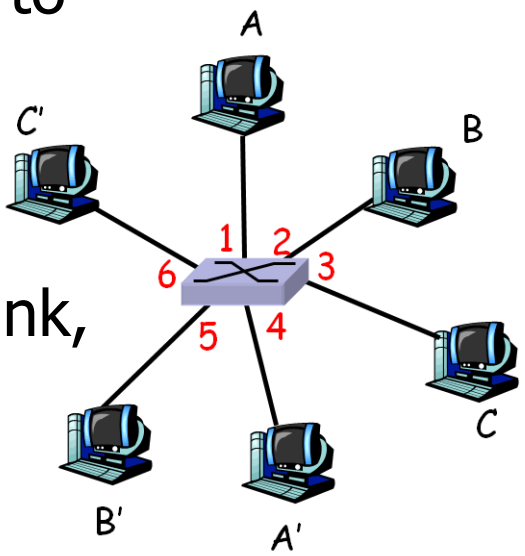
(b) Shared medium hub

Layer 2 Switch：Requirement

- Link-layer device: takes an active role
  - Store, forward Ethernet frames
  - Examine incoming frame's MAC address, selectively forward frame to one-or-more outgoing links when frame is to be forwarded on segment, uses CSMA/CD to access segment
- Transparent
  - Hosts are unaware of presence of switches
- Plug-and-play, self-learning
  - Switches do not need to be configured
- Switch vs. Bridge
  - Bridge: connect LANs (normally 2-4 ports)
  - Switch: connect multiple hosts/subnets (a lot of ports, can achieve collision-free transmission)

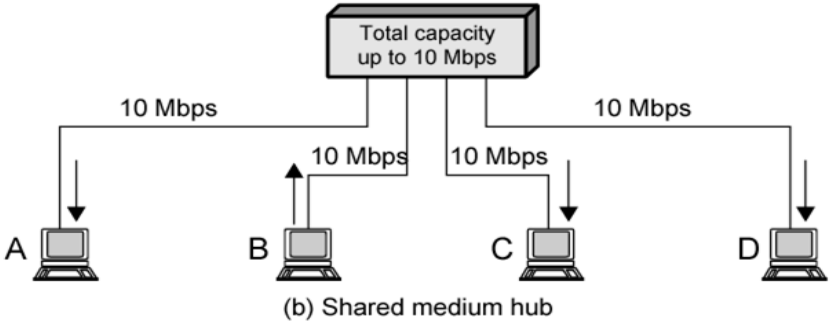
Why switched Ethernet?

- Stations have dedicated, direct connection to switch
- Switches buffer and forward frames
- Ethernet protocol used on *each* incoming link, but no collisions; full duplex
  - each link is its own collision domain
- *Switching:* A-to-A' and B-to-B' can transmit simultaneously, without collisions

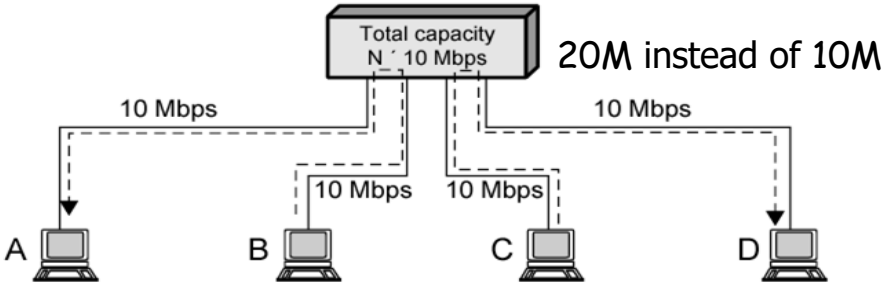


- Multiplying capacity of LANs
  - Each port/link forms a LAN segment (no collisions)
  - More than one station transmitting at a time

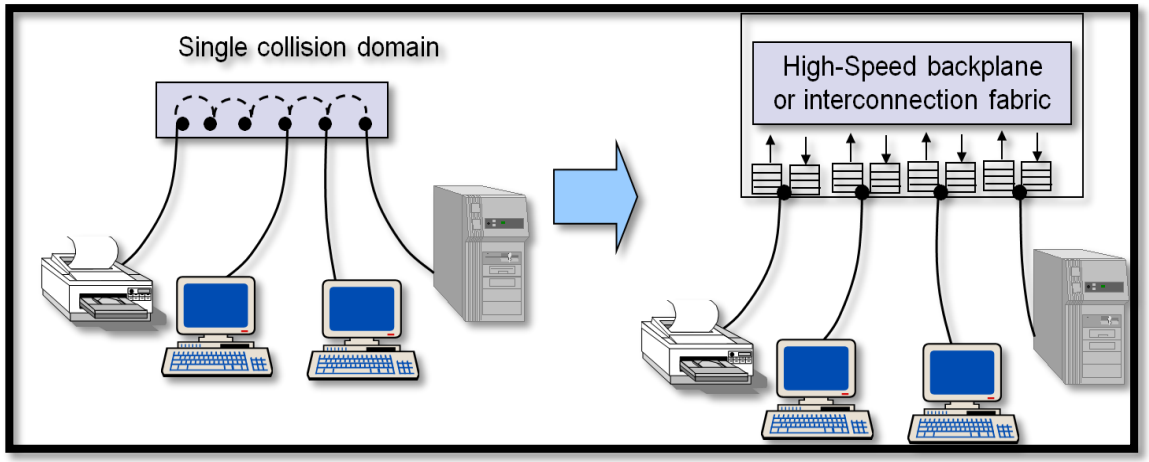
Shared Medium Hub and Layer 2 Switch

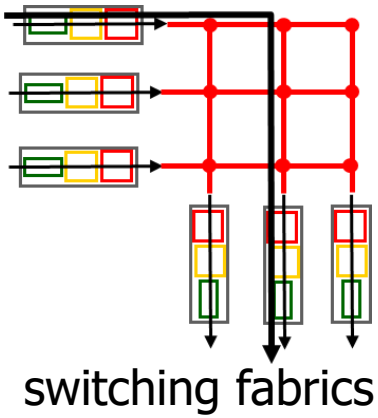


(b) Shared medium hub



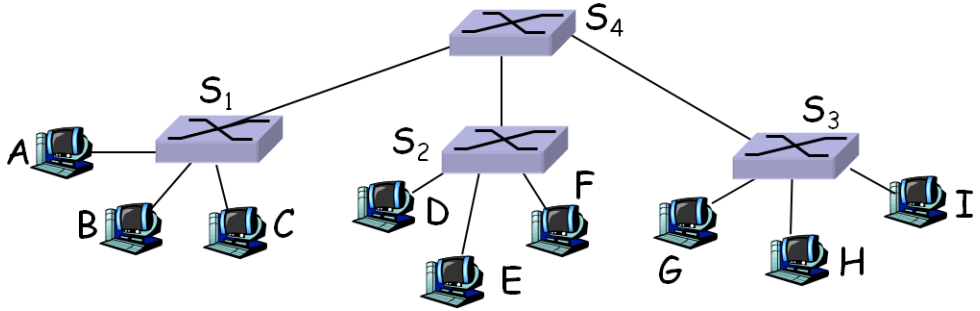
(c) Layer 2 switch




switching fabrics

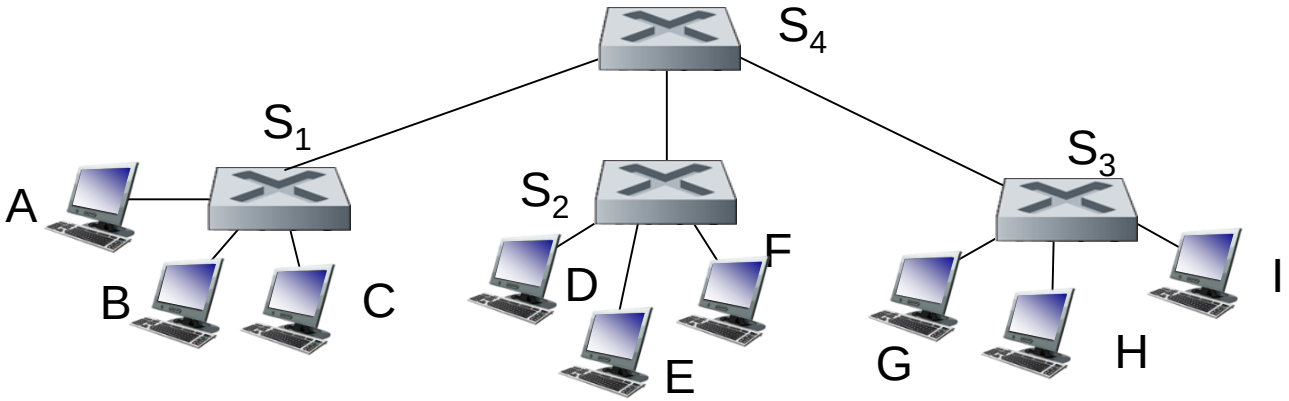
Layer 2 Switch Benefits

- No change to attached stations to convert bus/hub LAN to switched LAN
  - For Ethernet LAN, each station uses Ethernet MAC protocol
- Station has dedicated capacity equal to original LAN
  - Assuming switch has sufficient capacity to keep up with all stations
- Layer 2 switch scales easily
  - New layer 2 switch added to accommodate additional stations



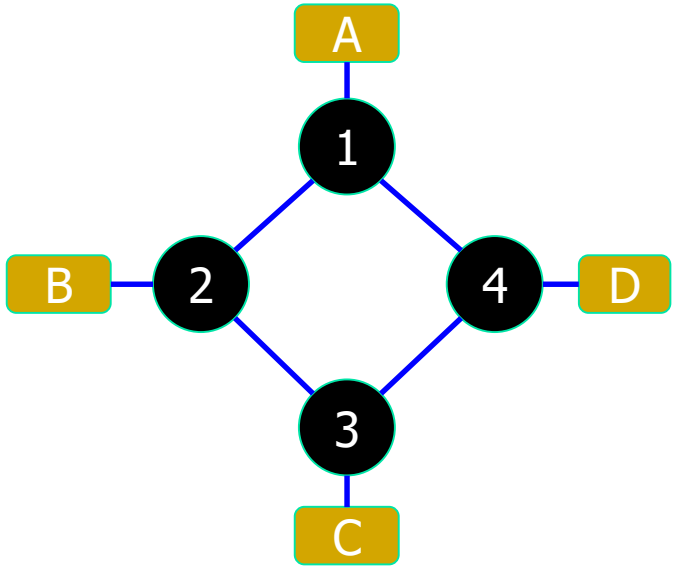
Interconnecting switches

- Switches can be connected together



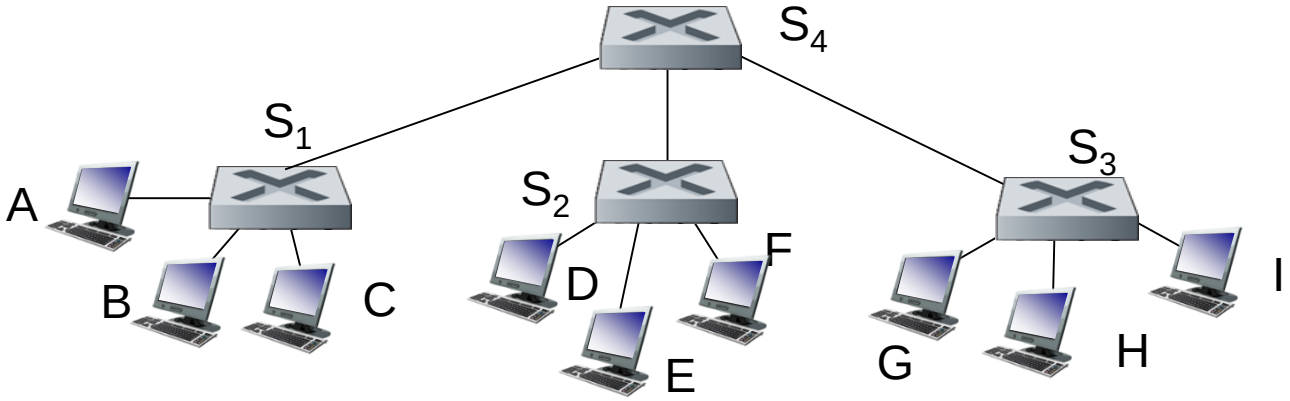
Loop resolution

- Example: A wants to broadcast a message
  - A sends packet to 1
  - 1 Floods to 2 and 4
  - 2 Floods to B and 3
  - 4 Floods to D and 3
  - 3 Floods packet from 2 to C and 4
  - 3 Floods packet from 4 to C and 2
  - 4 Floods packet from 3 to D and 1
  - 2 Floods packet from 3 to B and 1
  - 1 Floods packet from 2 to A and 4
  - 1 Floods packet from 4 to B and 2
  - ….



- Broadcast storm still happens in a switched network if it contains a cycle of switches
- Loop resolution: spanning tree algorithm

Ethernet switches are "self learning"

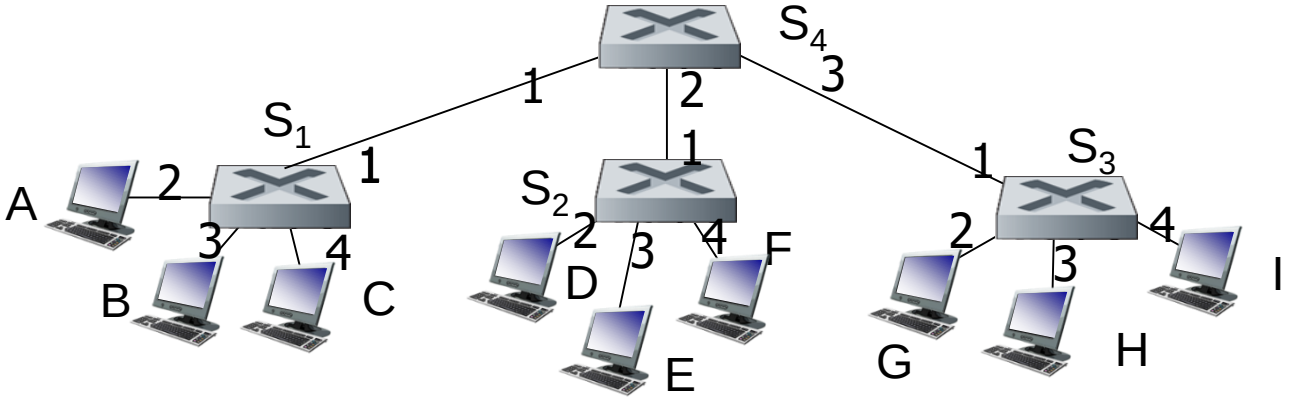


Q: sending from A to G - how does S_1 know to forward frame destined to G via S_4 and S_3?

- A: self learning! (works exactly the same as in single-switch case!)

Self-learning multi-switch example

Suppose C sends frame to I, I responds to C



- Q: show switch tables and packet forwarding in S_1, S_2, S_3, S_4 (assuming they are empty in the beginning)

Summary of switch frame forwarding

when frame received at switch:

1. record incoming link, MAC address of sending host
2. index switch table using MAC destination address
3. if entry found for destination
   then {
   if destination on segment from which frame arrived
   then drop frame
   else forward frame on interface indicated by entry
   }
   else flood /* forward on all interfaces except arriving interface */

Layer 3 Switches

- As number of stations grows, layer 2 switches reveal inadequacies
  - Broadcast overload
  - Lack of multiple paths
- Layer 3 switch
  - Implement packet-forwarding (IP) logic of a router in hardware
  - Interconnecting similar LANs, as in layer 2 switches

Broadcast Overload

- Set of stations and LANs connected by layer 2 switches builds singular physical net
- All nodes share common MAC broadcast address

- Broadcast frame delivered to all stations attached to LANs connected by layer 2 switches
- Under broadcast, layer 2 switches become hubs

- IP causes many broadcasts under daily work, e.g. ARP, DHCP, IGMP

Lack of Multiple Paths

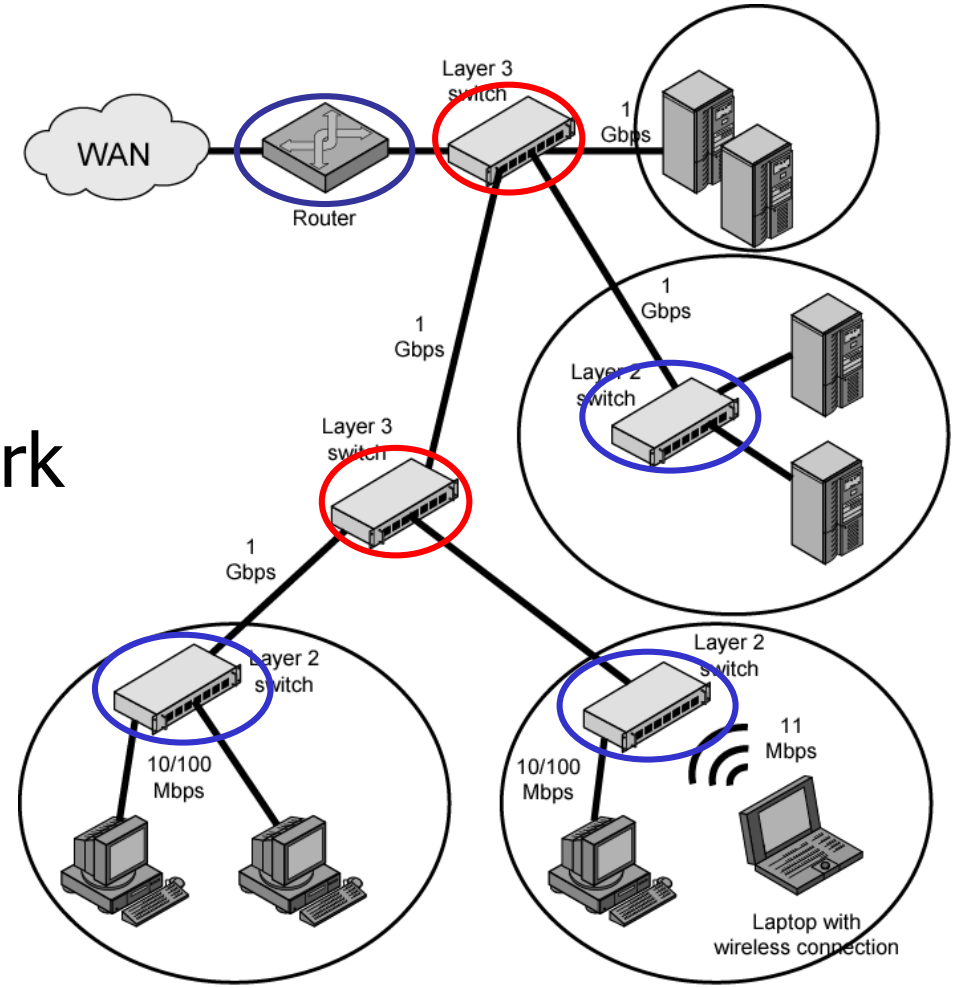
- Layer 2 switches uses spanning tree for routing (switching)
- Dictate no closed loops: only one path between any two stations
- Limits both performance and reliability

Solution:

- Break up LANs into sub-networks connected by switches using router functions (layer 3 switch)
- MAC broadcast frames limited to single sub-network
- Allow use of multiple paths between sub-networks

Typical Large LANs in an Organization

- Circles in diagram identify separate LAN subnetworks
- MAC broadcast frame limited to its subnetwork



Summary

- Bridge and Layer 2 Switch
  - 概念
  - 广播风暴问题
  - 生成树算法
  - 地址学习机制

- 比较：Bridge, hub, Layer 2 Switch, Layer 3 Switch (Router)

Homework

- 第5章：P23, P24, P25, P26