CS4450

Computer Networks:
Architecture and Protocols

Lecture 7
"Why" Frames
"Why" Switched Ethernet
Spanning Tree Protocol

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Announcements

- **Problem Set 2 is out (course webpage)**

Goals for Today's Lecture

- **Dive deep into Link layer design**
  - Redo CSMA/CD
  - **Why** Frames? — Implementing Link Layer on top of Physical Layer
  - **Why** Switched Ethernet? — Understanding scalability problems

- Introduction to Switched Ethernet: THE **Spanning Tree Protocol**

Recap from last lecture

Recap: Data Link Layer

- **Communication Medium**
  - **Point-to-point**
    - The high-level ideas discussed so far were for point-to-point
  - **Broadcast**
    - **Original design of Link layer protocols**
    - More recent versions have moved to point-to-point
      - We will discuss why so!

- **Network Adapters (e.g., NIC — network interface card)**
  - The hardware that connects a machine to the network
  - Has a “name” — MAC (Medium access control) address

Recap: Sharing a broadcast channel

- **Context: a shared broadcast channel**
  - Must avoid/handle having multiple sources speaking at once
  - Otherwise collisions lead to garbled data
  - Need **distributed algorithm** for sharing channel
  - Algorithm determines **when** and **which** source can transmit

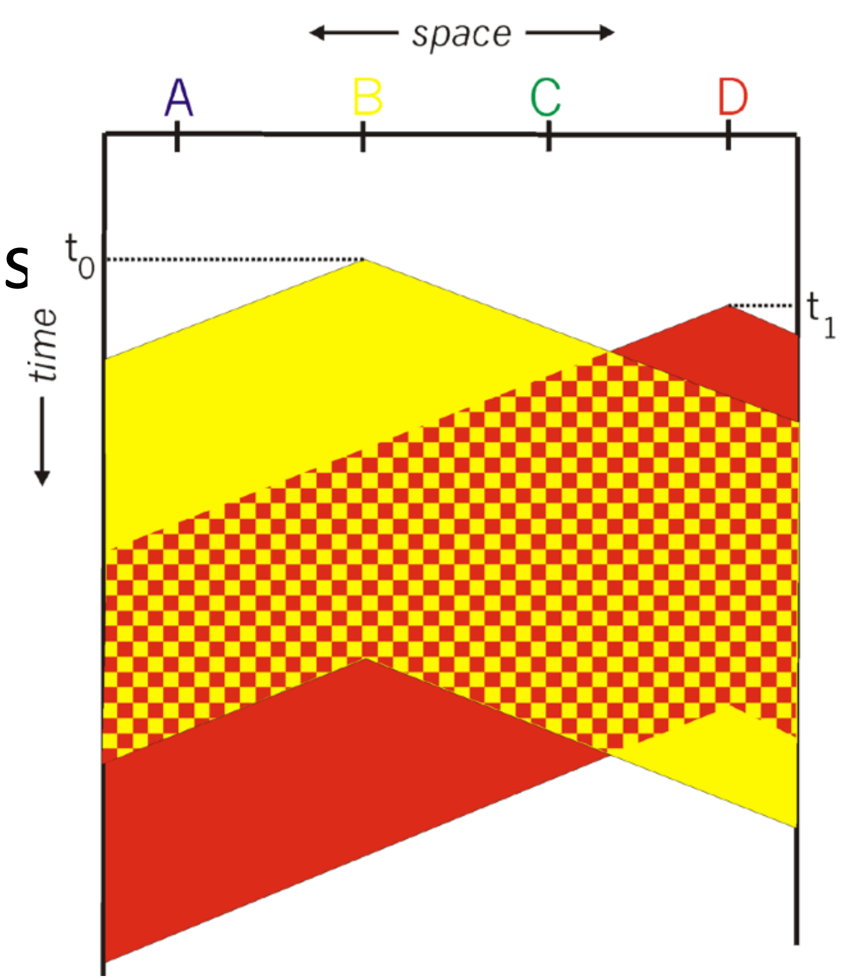
- **Three classes of techniques**
  - **Frequency-division multiple access**: coordinated sharing in space
  - **Time-division multiple access**: coordinated sharing in time
  - **Random access**: uncoordinated sharing
    - Detect collisions, and if needed, recover from collisions
    - **Carrier Sense Multiple Access (CSMA)**

Recap: CSMA (Carrier Sense Multiple Access)

- CSMA: **listen** before transmit
  - If channel sensed idle: transmit entire frame
  - If channel sensed busy: defer transmission

- Does this eliminate all collisions?
  - **No**, because of nonzero propagation delay

- Solution:
  - Include a **Collision Detection (CD)** mechanis
  - If a collision detected
    - Retransmit
    - **When to retransmit?**



Recap: Once a collision is detected …

- **When should the frame be retransmitted?**

- Immediately?
  - Every NIC would start sending immediately
  - Collision again!

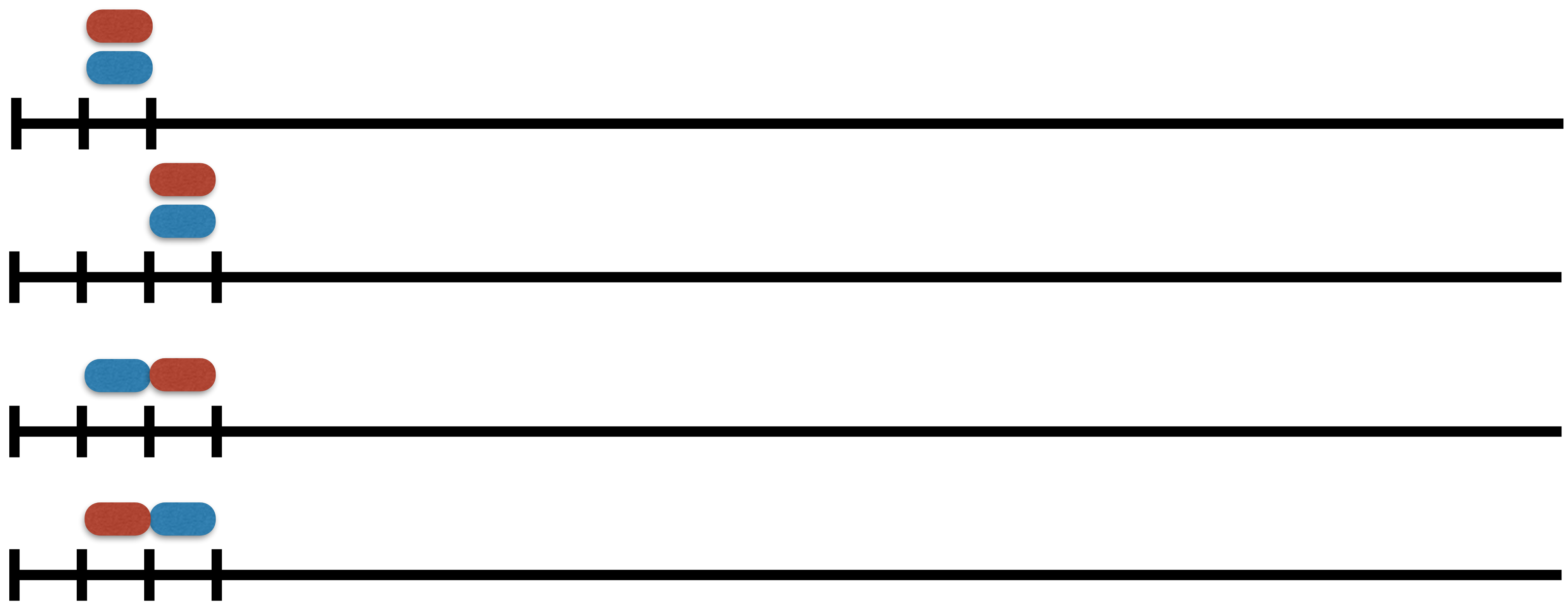
- Take turns?
  - Back to time division multiplexing
  - Problem?
    - Underutilization

Recap: CSMA/CD in one slide!

- **Carrier Sense: continuously listen to the channel**
  - If idle: start transmitting
  - If busy: wait until idle
- **Collision Detection: listen while transmitting**
  - No collision: transmission complete
  - Collision: abort transmission
- **When to retransmit?: exponential back off**
  - After collision, transmit after "waiting time"
  - After k collisions, choose "waiting time" from {0, …, 2^k-1)
  - Exponentially increasing waiting times
  - But also, exponentially larger success probability

Recap: Exponential Back-off: An example

Attempt 1: Suppose a collision happens



Attempt 2: Four possibilities

Success with Probability = 0.5

Group Exercise:

What is the success probability in attempt 3?

Answer: **0.75**

Questions?

Why Frames?

(Layering: Link Layer on top of Physical Layer)

Building Link Layer on top of Physical Layer

- Physical layer sends/receives bits on a link, and forwards to link layer

- View at the destination side physical layer:

  0101011001111110111111011111100101000111

- Challenge: how to take the above bits and convert to:

  0101011001111110111111011111100101000111

- **Problem**: how does the link layer separate data into correct "chunks"?
  - Chunks belonging to different applications

- Data link layer **interfaces** with **physical layer** using **frames**
  - Implemented by the network adaptor
  - **Finally: What are these frames?**

Frames

Identifying start/end of frames: Sentinel Bits

- Delineate frame with special "sentinel" bit pattern
    - e.g., **01111110** -> start, **01111111** -> end

01111110	**Frame contents**	**01111111**

- **Problem: what if the sentinel occurs within the frame?**

- Solution: **bit stuffing**
    - Sender always inserts a **0** after five **1**s in the frame content
    - Receiver always removes a **0** appearing after five **1**s

When Receiver sees five 1s…

01111110	**Frame contents**	**01111111**

- If next bit is 0, remove it, and begin counting again
    - Because this must be a stuffed bit
    - we can’t be at beginning/end of frame (those had six/seven 1s)

- If next bit is 1 (i.e., we have six 1s) then:
    - If following bit is 0, this is the start of the frame
        - Because the receiver has seen 01111110
    - If following bit is 1, this is the end of the frame
        - Because the receiver has seen 01111111

Example: Sentinel Bits

- Original data, including start/end of frame:

01111110011111101111110111110010111111

- Sender rule: five 1s -> insert a 0

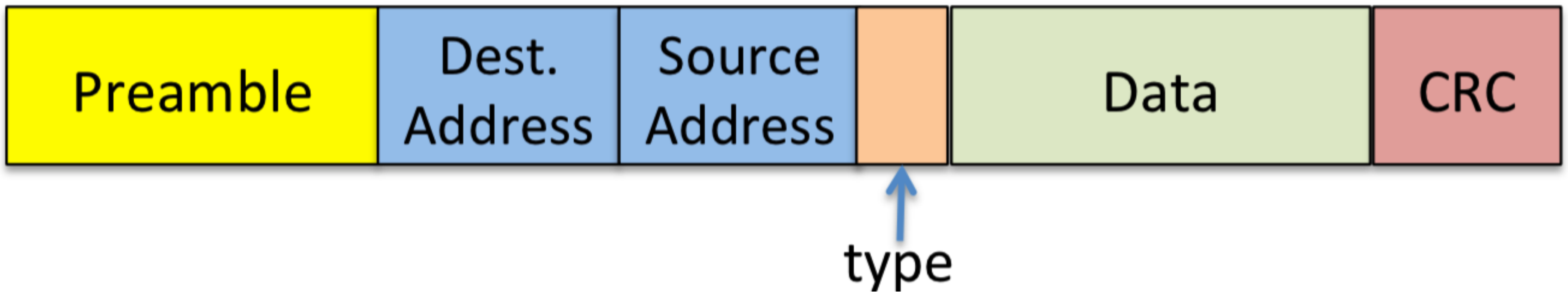
- After bit stuffing at the sender:

01111110011111010111110011111000101111111

- Receiver rule: five 1s and next bit 0 -> remove 0

01111110011111101111110111110010111111

Ethernet “Frames”



- **Preamble:**
  - 7 bytes for clock synchronization
  - 1 byte to indicate start of the frame
- **Names:** 6 + 6 bytes (MAC names/addresses)
- **Protocol type:** 2 bytes, indicating higher layer protocol (e.g., IP)
- **Data payload:** max 1500 bytes, minimum 46 bytes
- **CRC:** 4 bytes for error detection

What about source/destination Addresses?

- **Frames are at Layer-2**
  - **Thus, use Layer-2 addresses (MAC names/addresses)**

- **MAC name/address**
  - Numerical address associated with the network adapter
  - Flat namespace of 6 bytes (e.g., 00-15-C5-49-04-A9 in HEX)
  - Unique, hard coded in the adapter when it is built

- **Hierarchical Allocation**
  - Blocks: assigned to vendors (e.g., Dell) by IEEE
    - First 24 bits (e.g., 00-15-C5-**-**-**)
  - Adapter: assigned by the vendor from its block
    - Last 24 bits

Questions?

Putting it all together

(Traditional Ethernet)

Traditional Ethernet

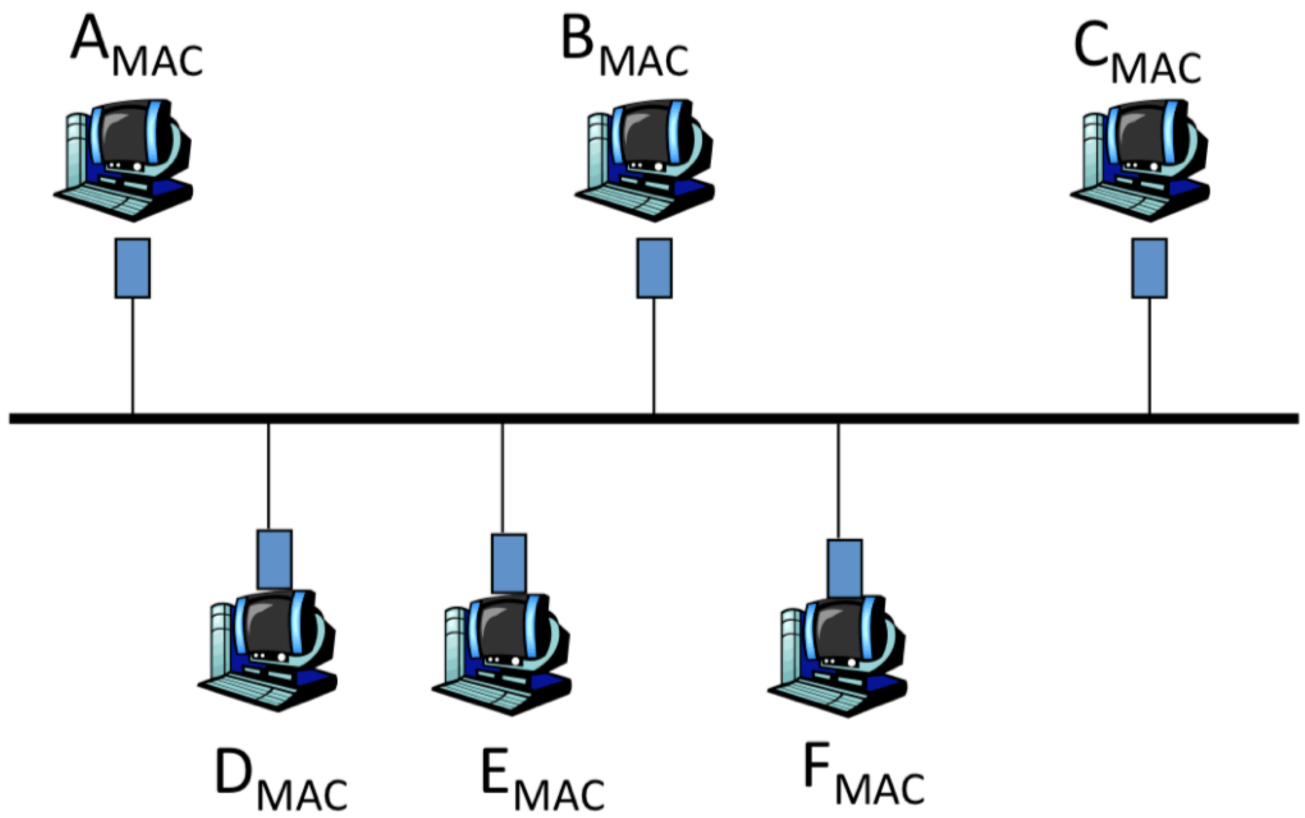
- **(Source) Link layer receives data from the network layer (more later)**

- **(Source) Link layer divides data into frames**
  - How does it know source/destination MAC names?
  - Source name is easy … destination name is tricky (more later)

- **(Source) Link layer passes the frame to physical layer**
  - Frames up the frames (using sentinel bits)
  - **And broadcasts on the broadcast Ethernet**

- **(EACH) physical layer regenerates the frame…**
  - And sends it up to the (destination) link layer ….
    - Which sends the data to the network layer …. **If and only if:**
      - destination name matches the receiver's MAC name
      - Or, the destination name is the broadcast address (FF:FF:FF:FF:FF:FF)

Traditional Ethernet



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

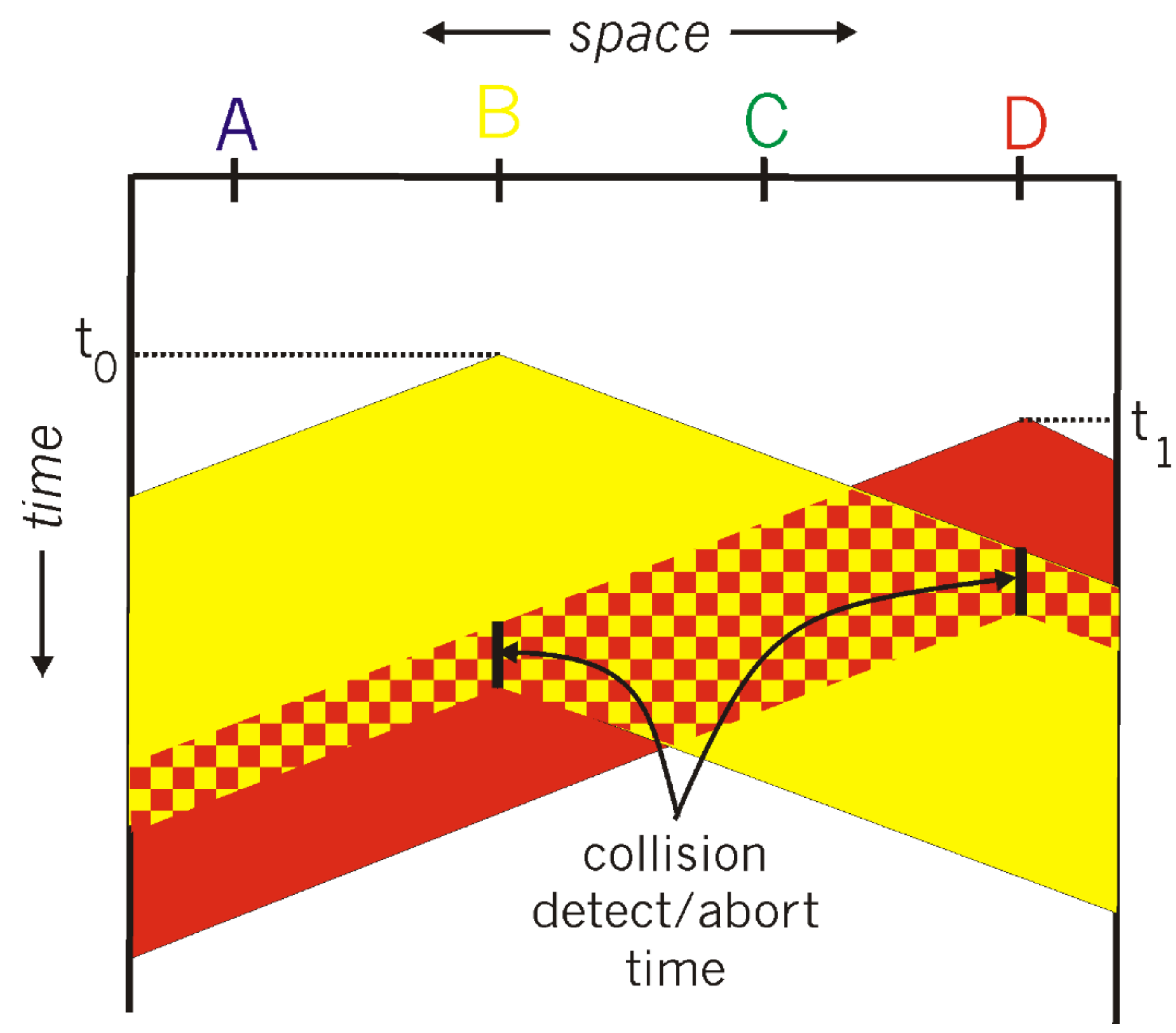
Questions?

WHY Switched Ethernet?

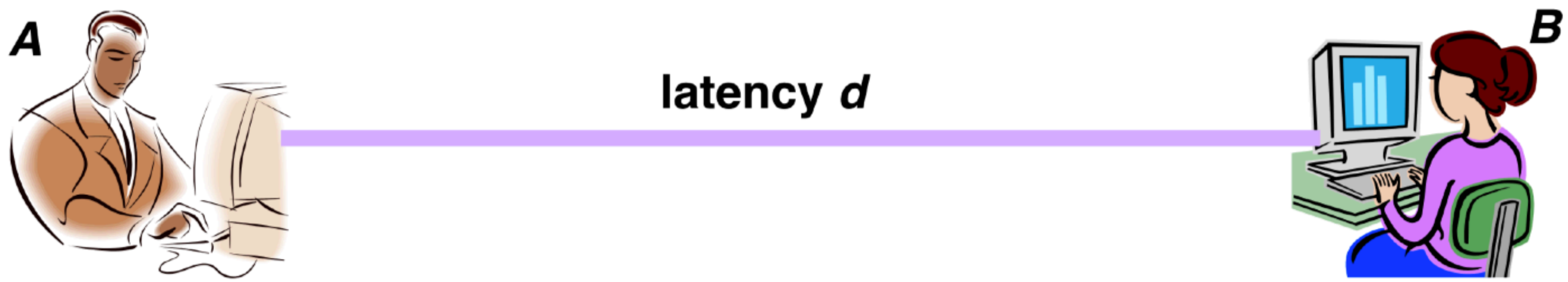
Collision Detection limits Ethernet scalability

- **B** and **D** can tell that collision occurred

- However, need restrictions on
  - **Minimum frame size**
  - **Maximum distance**

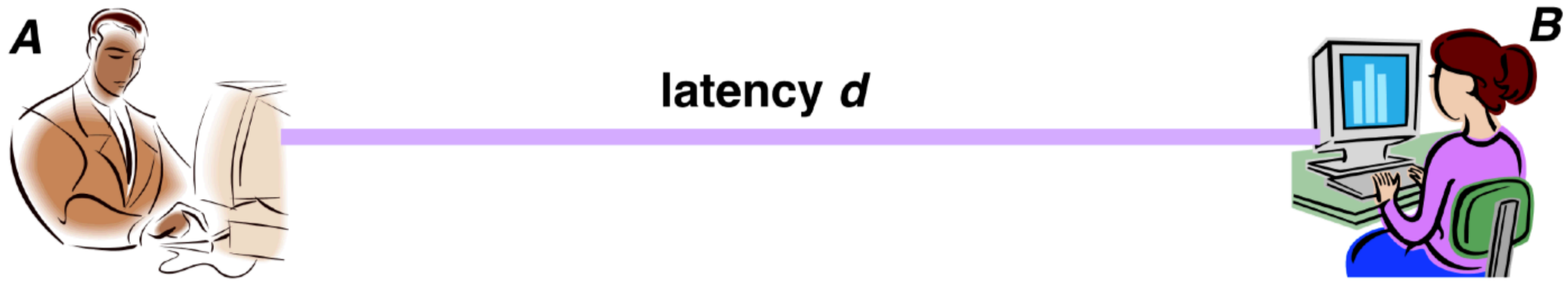


Limits on Traditional Ethernet Scalability



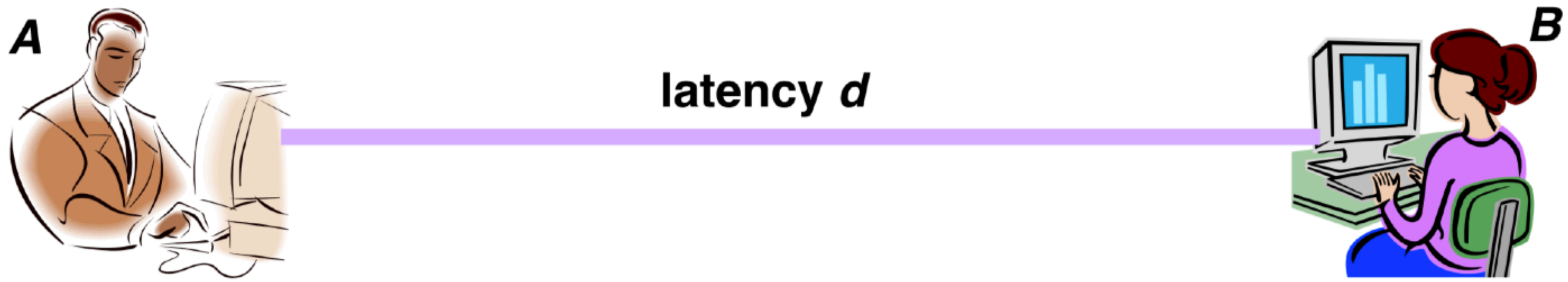
- **Latency depends on physical length of link**
  - Propagation delay
- **Suppose A sends a packet at time 0**
  - B sees an idle line at all times before **d**
  - … so B happily starts transmitting a packet
- **B detects a collision at time d**
  - But A can't see collision until **2d**
  - **A must have a frame size such that transmission time > 2d**
  - **Need transmission time > 2 * propagation delay**

Limits on Traditional Ethernet Scalability



- **Transmission time > 2 * propagation delay**
- **Requires either very large frames (underutilization) or small scale.**
    - **Example: consider 100 Mbps Ethernet**
    - **Suppose** minimum frame length: 512 bits (64 bytes)
        - Transmission time = 5.12 µsec
        - Thus, propagation delay < 2.56 µsec
        - Length < 2.56 µsec * speed of light
        - Length < 768m
- **Cannot scale beyond ~76.8m for 1Gbps and beyond ~7.68m for 10Gbps**

Limits on Traditional Ethernet Scalability



- Transmission time > 2 * propagation delay

- Cannot scale beyond ~76.8m for 1Gbps and beyond ~7.68m for 10Gbps

- This is WHY modern Ethernet networks are "switched"

Performance of CSMA/CD

- **Time spent transmitting a frame (collision)**
  - Proportional to distance d; why?

- **Time spent transmitting a frame (no collision)**
  - Frame length p divided by bandwidth b

- **Rough estimate for efficiency (K some constant)**

$$E \sim \frac{\frac{p}{b}}{\frac{p}{b} + Kd}$$

- Observations:
  - For large frames AND small distances, E ~ 1
  - **Right frame length depends on b, K, d**
  - **As bandwidth increases, E decreases**
    - That is why high-speed LANs are switched

Evolution

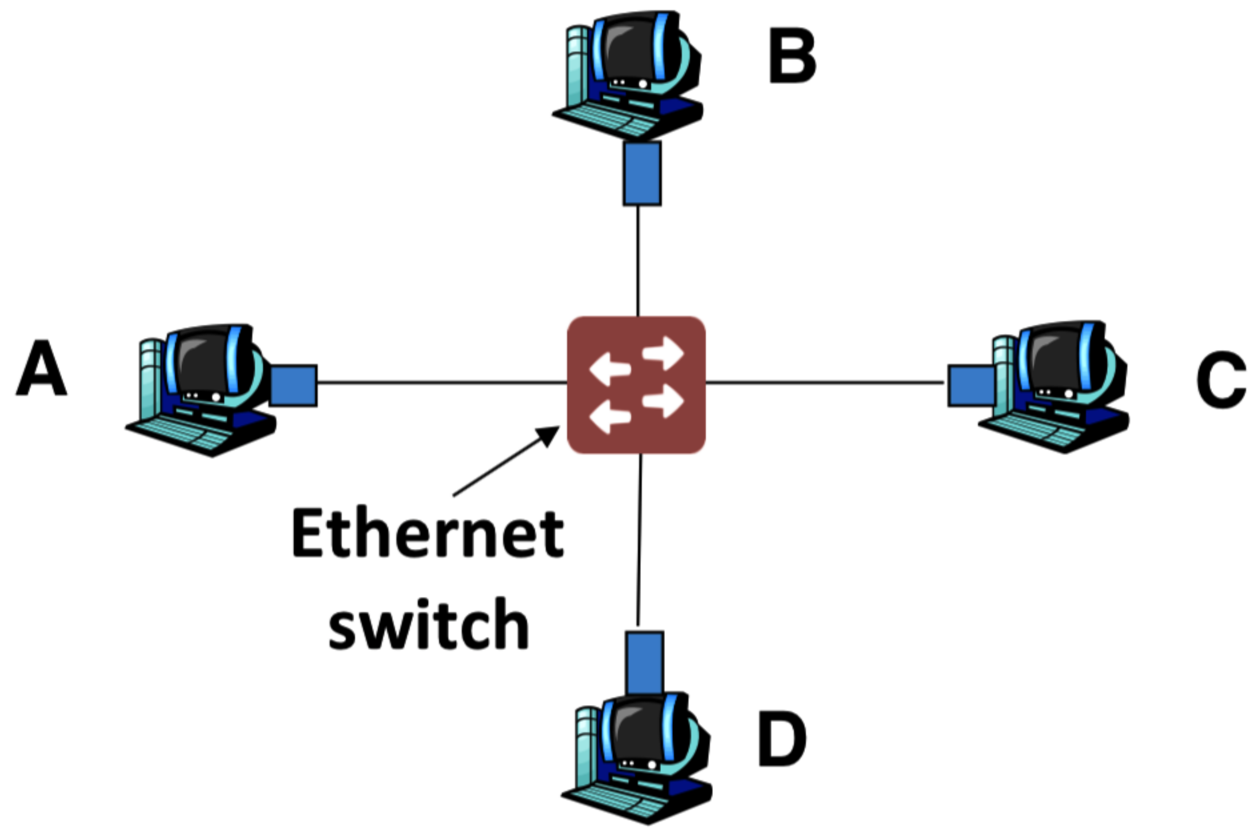
- **Ethernet was invented as a broadcast technology**
    - Hosts share channel
    - Each packet received by all attached hosts
    - CSMA/CD for access control

- **Current Ethernets are “switched”**
    - Point-to-point medium between switches;
    - Point-to-point medium between each host and switch
    - Sharing only when needed (using CSMA/CD)

Questions?

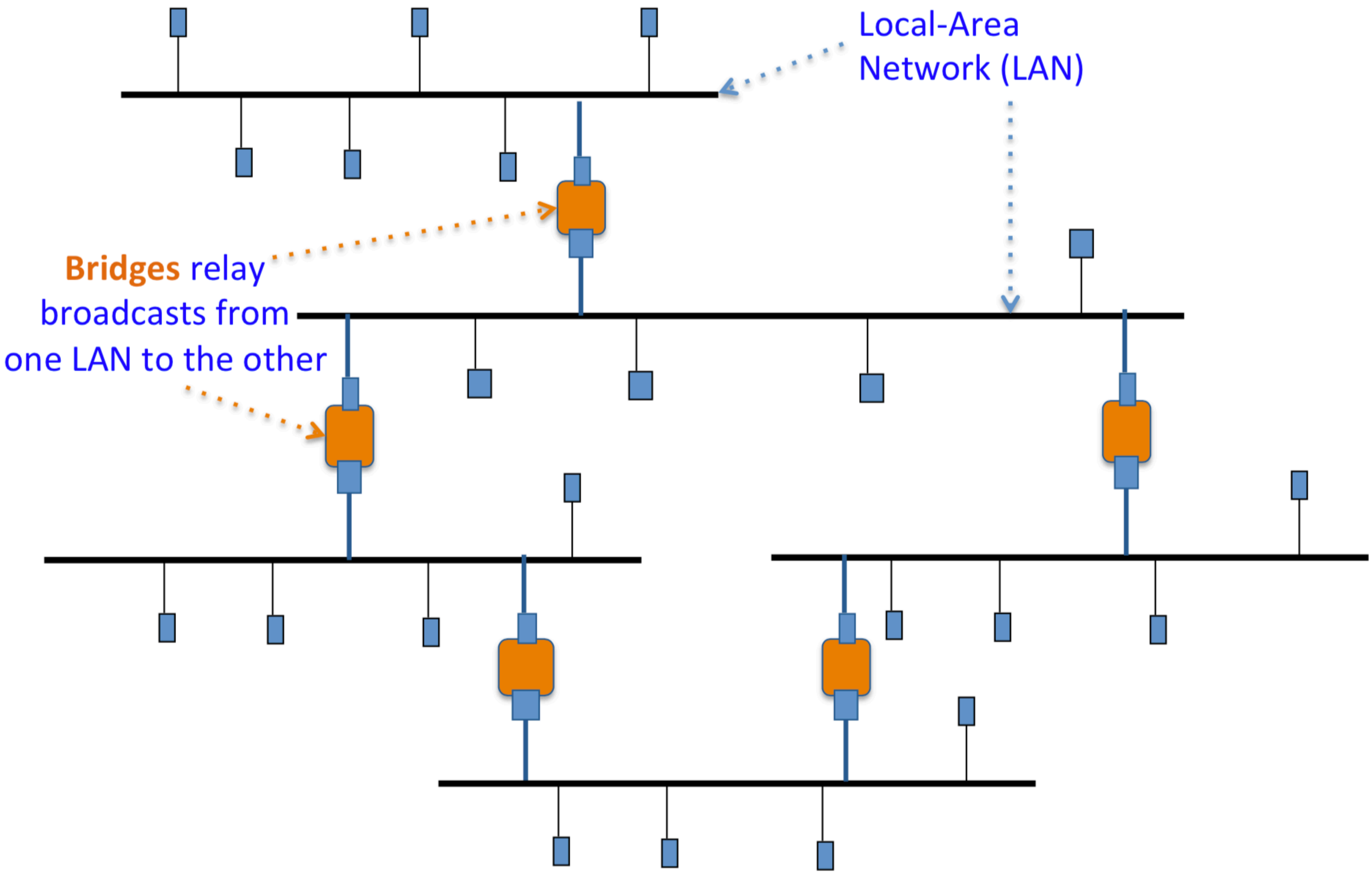
Switched Ethernet

Switched Ethernet

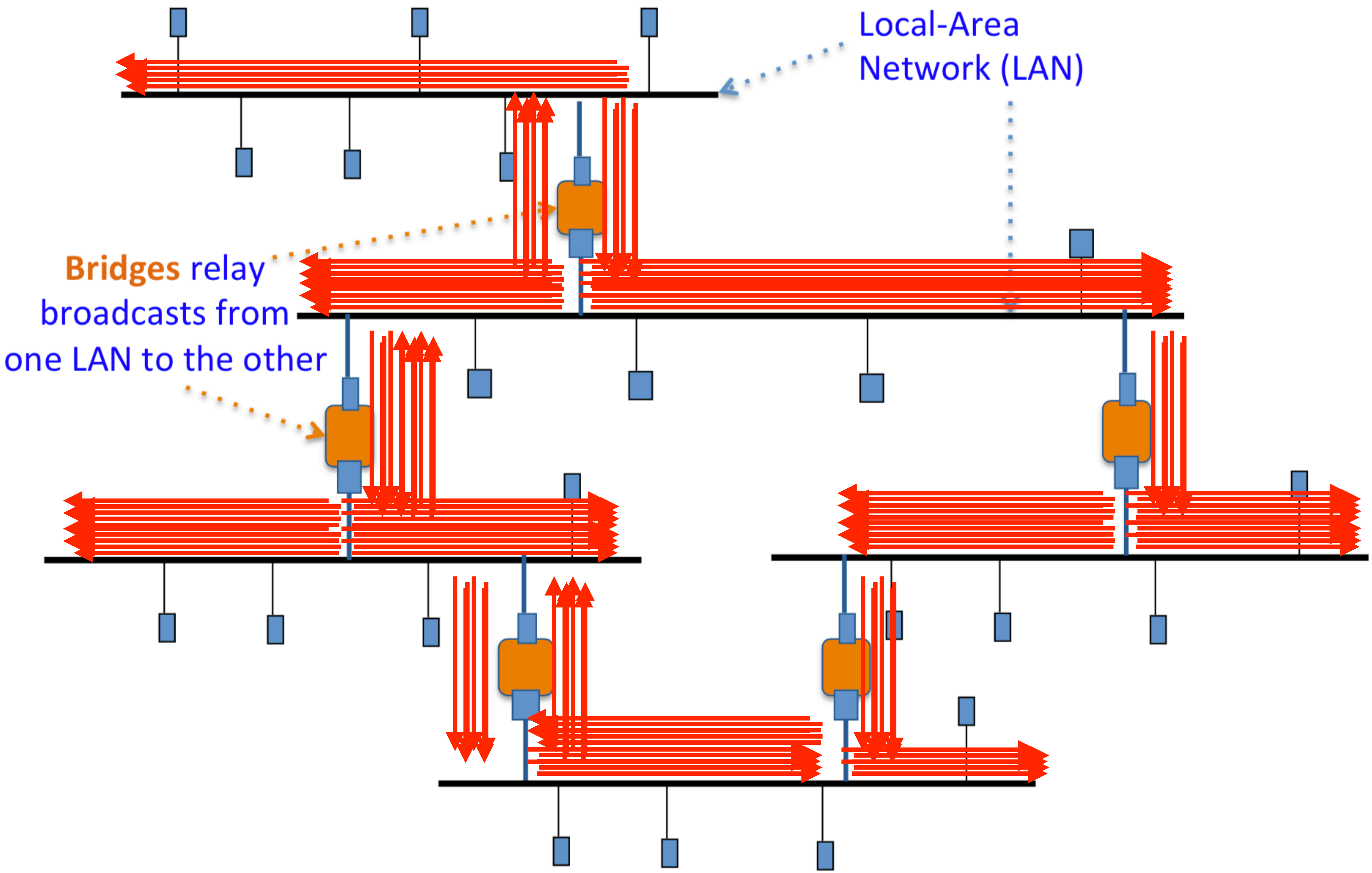


- Enables concurrent communication
  - Host A can talk to C, while B talks to D
  - No collisions -> no need for CSMA, CD
  - No constraints on link lengths or frame size

Routing in Switched Ethernet (Extended LANs)



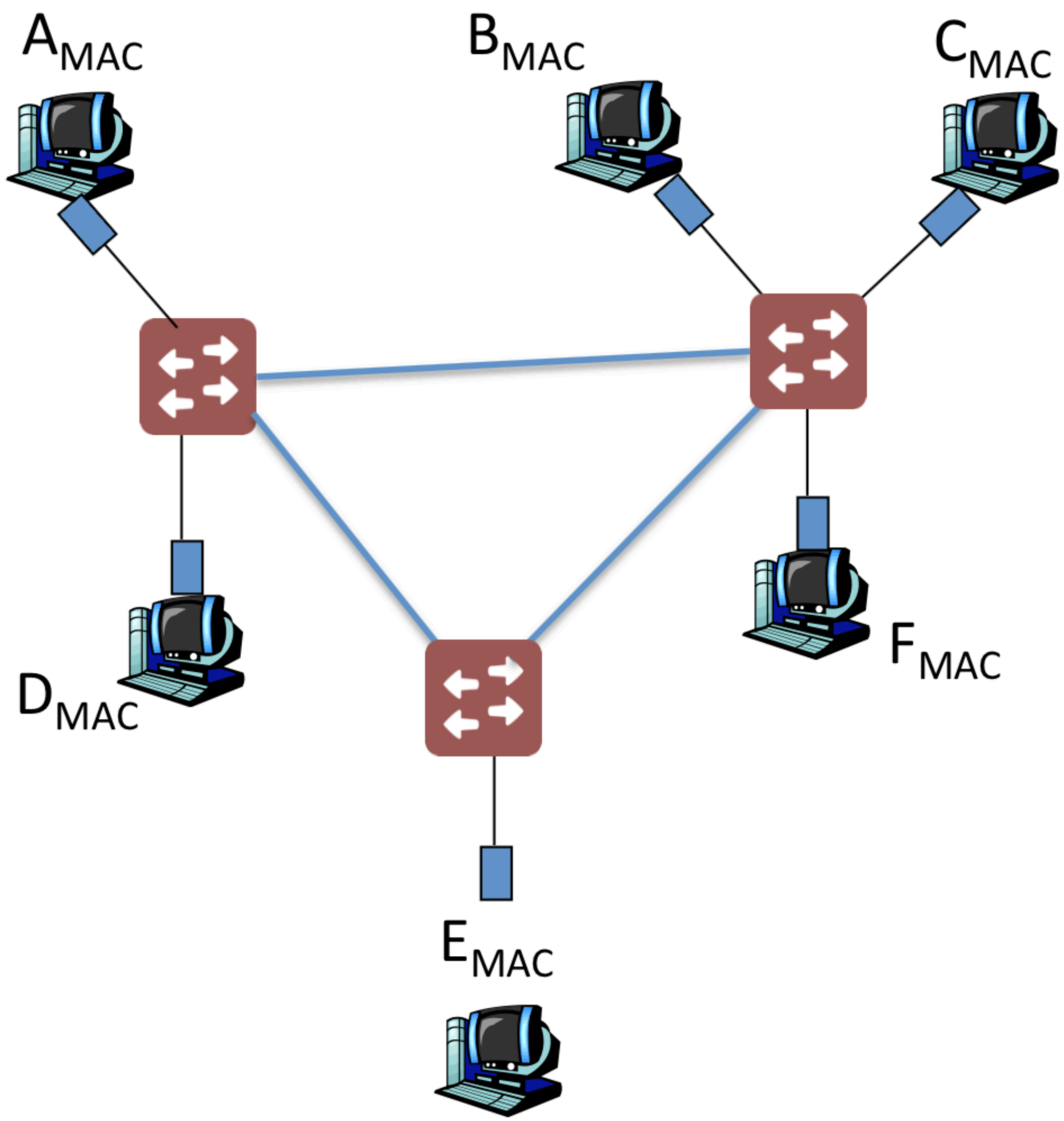
Naïvely Routing in "Extended LANs": Broadcast storm



How to avoid the Broadcast Storm Problem?

Get rid of the loops!

Lets get back to the graph representation!



Easiest Way to Avoid Loops

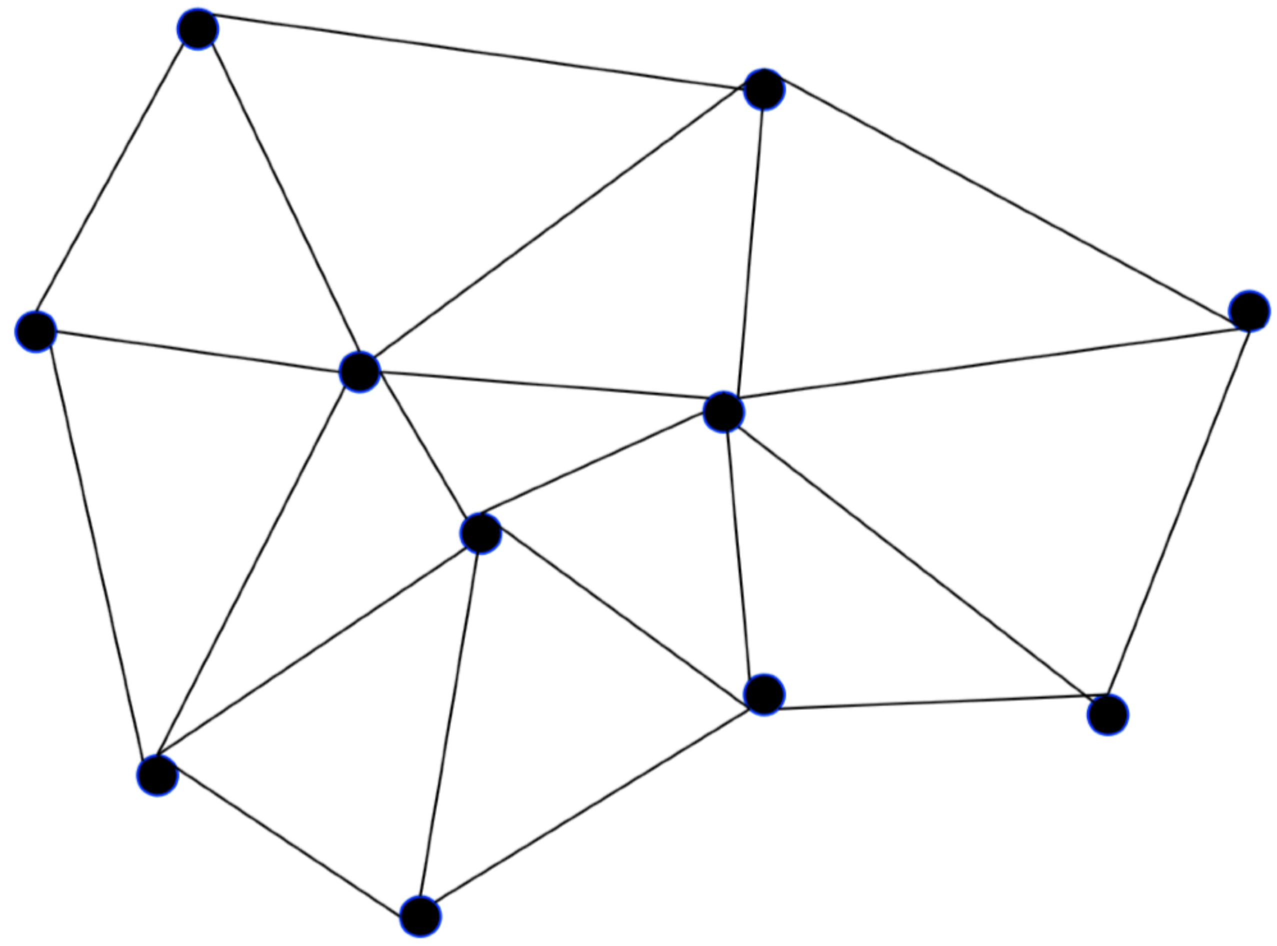
- Use a network topology (graph) where loop is impossible!

- Take arbitrary topology (graph)

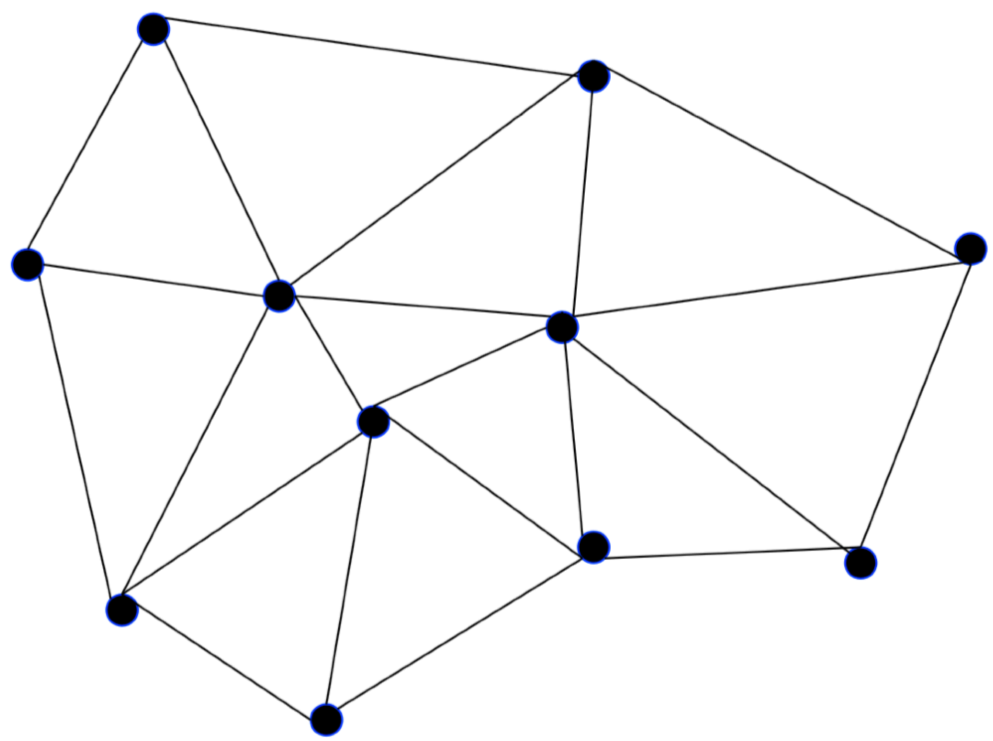
- **Build spanning tree**
    - **Subgraph that includes all vertices but contains no cycles**
    - Links not in the spanning tree are not used in forwarding frames

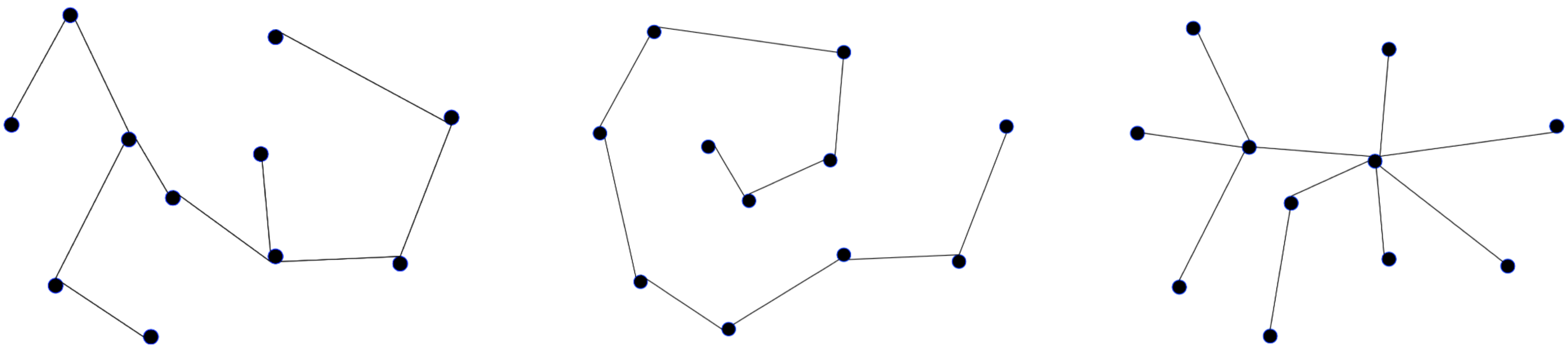
- Only one path to destinations on spanning trees
    - So don't have to worry about loops!

Consider Graph



Multiple Spanning Trees





Questions?

Spanning Tree Approach

- Take arbitrary topology
- Pick subset of links that form a spanning tree
- Only forward packets on the spanning tree
    - => No loops
    - => No broadcast storm

Spanning Tree Protocol

- Protocol by which bridges construct a spanning tree
- Nice properties
  - Zero configuration (by operators or users)
  - Self healing
- Still used today
- Constraints for backwards compatibility
  - No changes to end-hosts
  - Maintain plug-n-play aspect
- Earlier Ethernet achieved plug-n-play by leveraging a broadcast medium
  - Can we achieve plug-n-play for a switched topology?

Algorithm has Two Aspects…

- Pick a root:
    - Destination to which the shortest paths go
    - Pick the one with the smallest identifier (MAC name/address)

- Compute the shortest paths to the root
    - No shortest path can have a cycle
    - Only keep the links on the shortest path
    - 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 via neighbor switch with the “smallest” identifier

- **One could use any tie breaking system**
    - This is just an easy one to remember and implement

Constructing a Spanning Tree

- **Messages (Y,d,X)**
    - Proposing Y as the root
    - From node X
    - And advertising a distance d between X and Y
- Switches elect the node with smallest identifier (MAC address) as root
    - **Y** in messages
- Each switch determines if a link is on its shortest path to the root
    - If not, excludes it from the tree
    - **d** to **Y** in the message is used to determine this

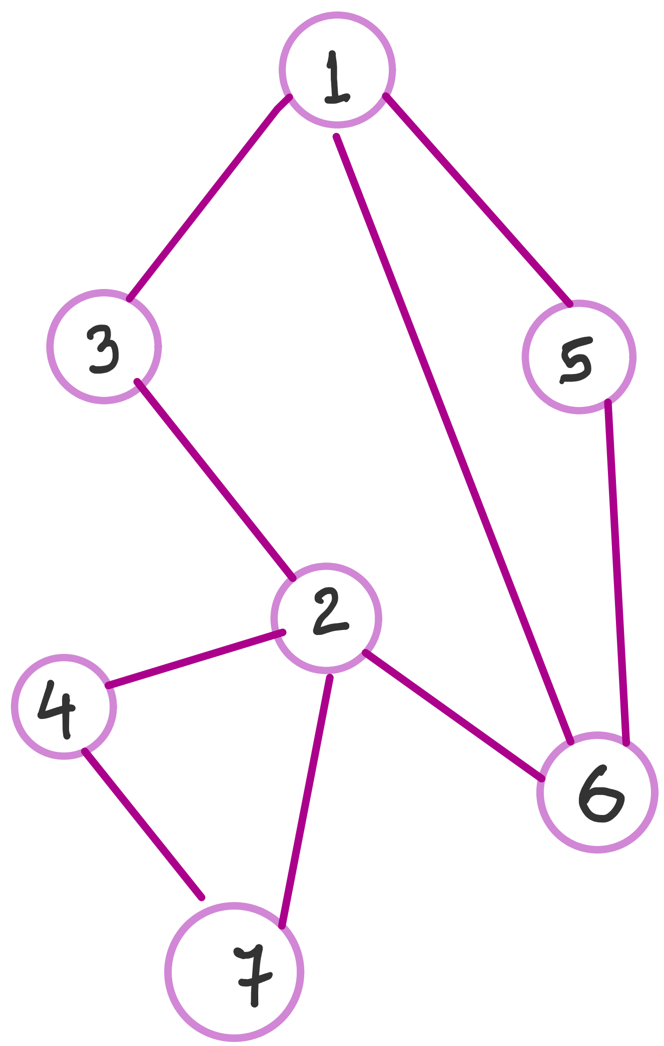
Steps in Spanning Tree Protocol

- **Messages (Y,d,X)**
  - Proposing root Y; from node X; advertising a distance d to Y
- Initially each switch proposes itself as the root
  - that is, switch X announces (X,0,X) to its neighbors
- Switches update their view
  - Upon receiving message (Y,d,Y) from Z, check Y's id
  - If Y's id < current root: set root = Y
  - Set next-hop = Z
- Switches compute their distance from the root
  - Add 1 to the shortest distance received from a neighbor
- If **root changed OR shortest distance to the root changed:**
  - send neighbors updated message (Y,d+1,X)

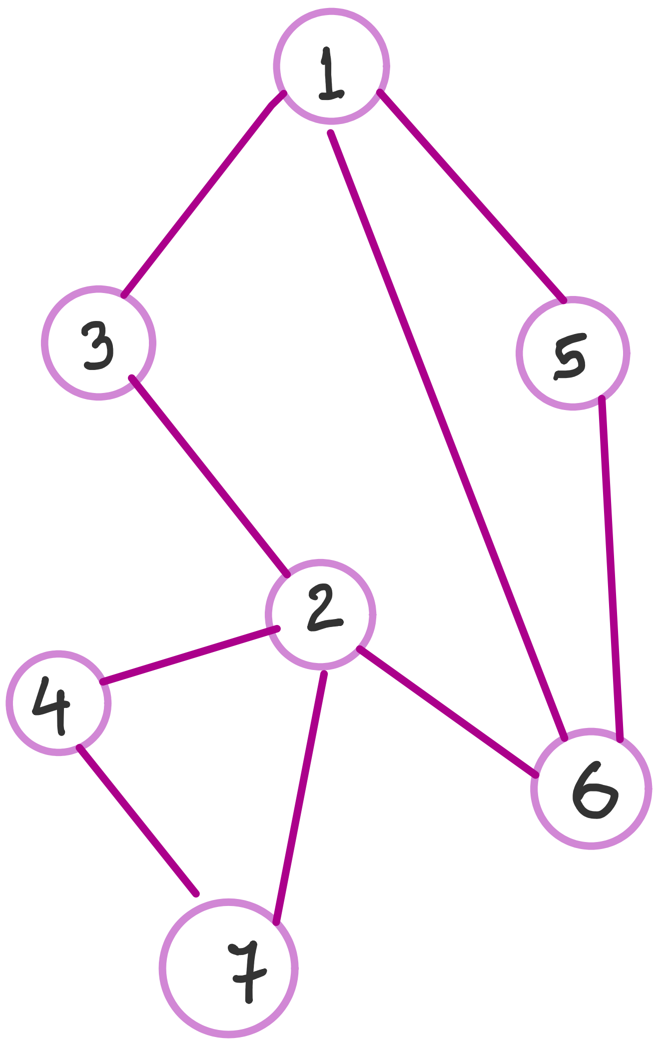
Group Exercise:

Lets run the Spanning Tree Protocol on this example

(assume all links have "distance" 1)

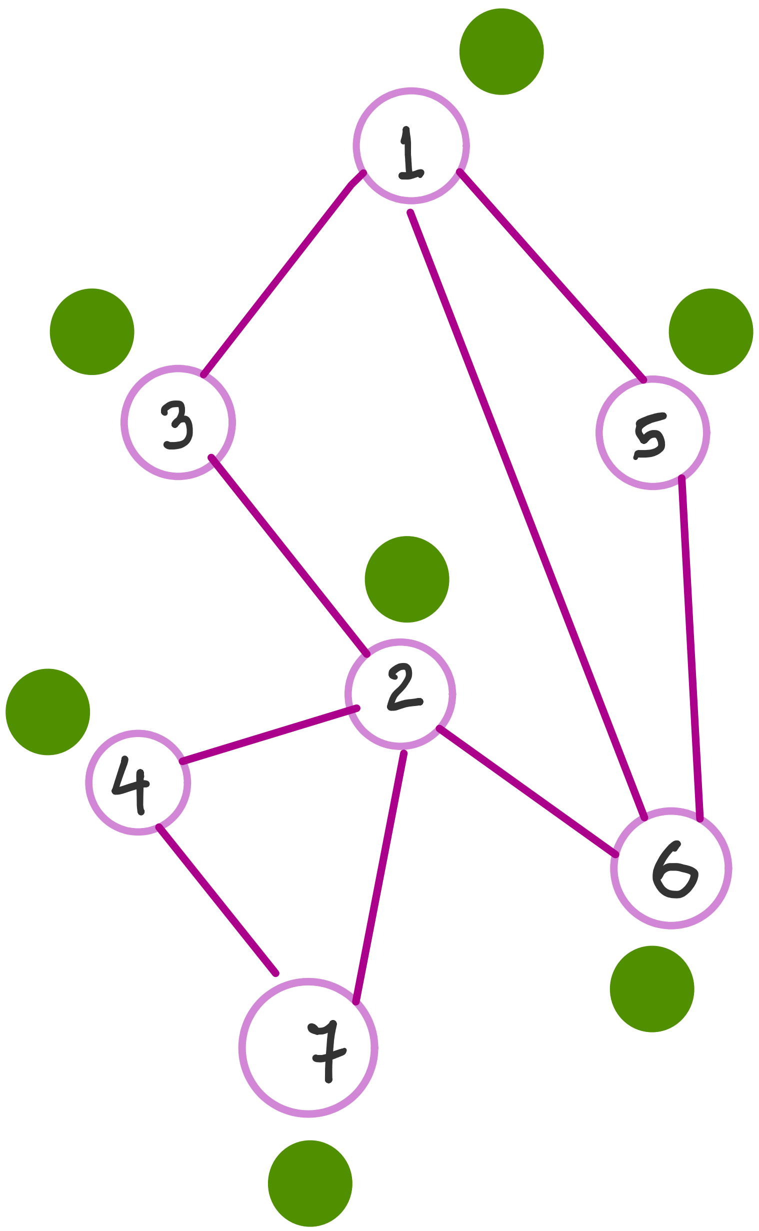


Round 1



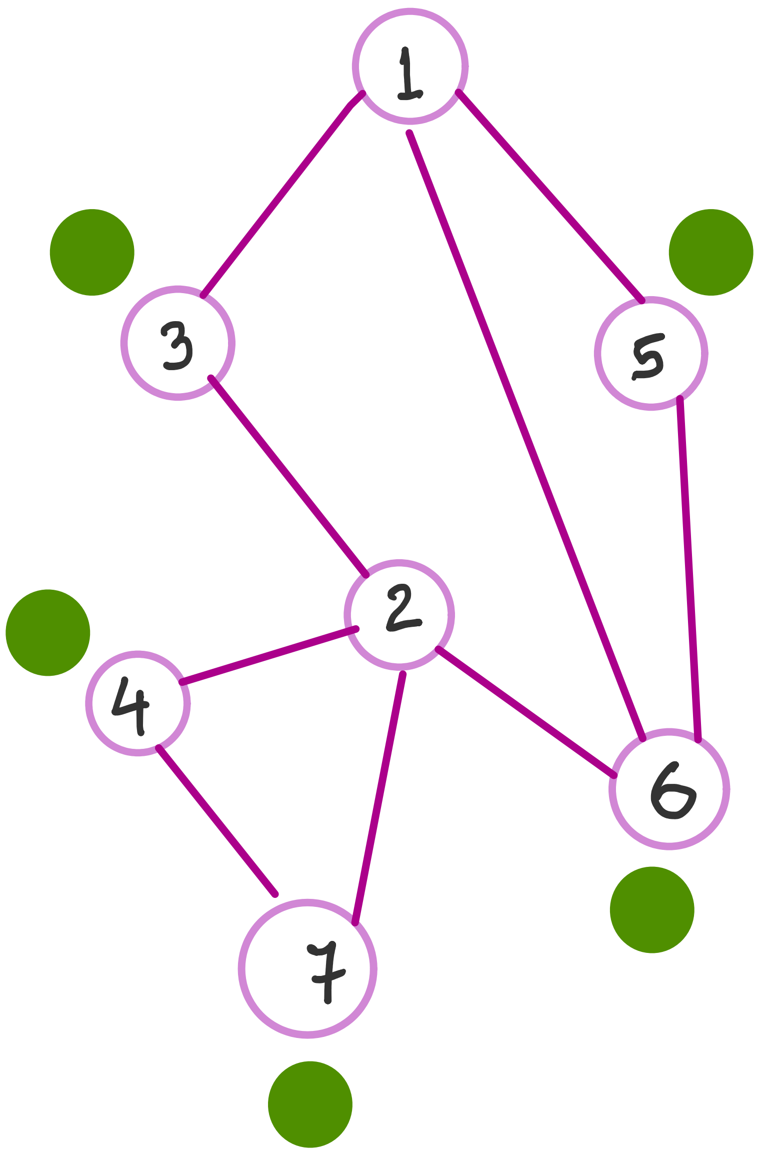
	Receive	Send	Next-hop
1		(1, 0, 1)	1
2		(2, 0, 2)	2
3		(3, 0, 3)	3
4		(4, 0, 4)	4
5		(5, 0, 5)	5
6		(6, 0, 6)	6
7		(7, 0, 7)	7

Round 2



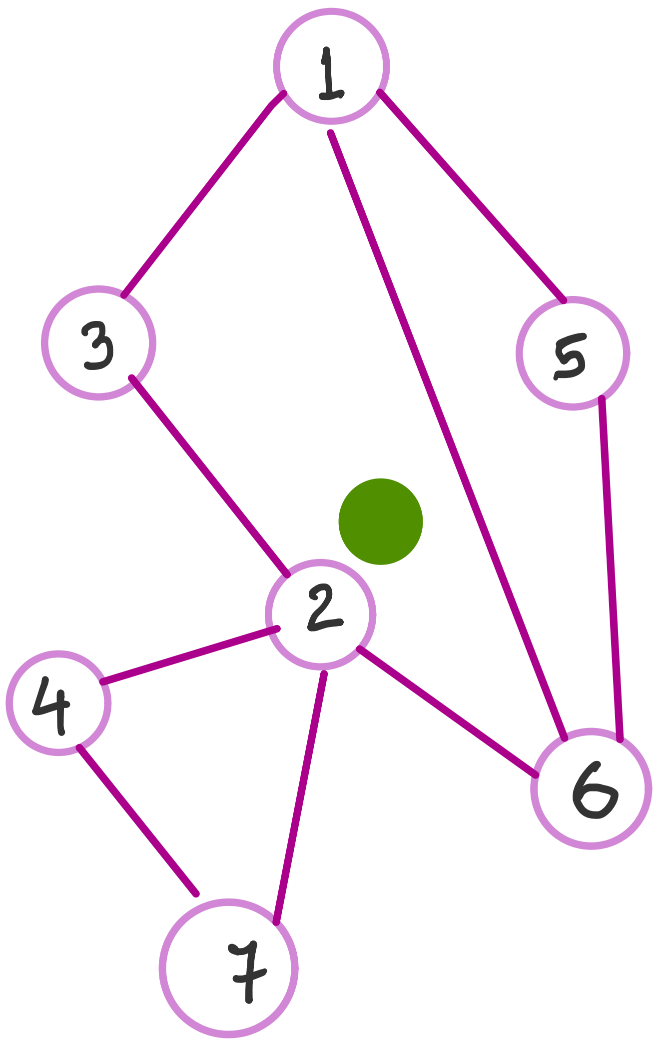
	Receive	Send	Next hop
1 (1, 0, 1)	(3, 0, 3), (5, 0, 5), (6, 0, 6)		1
2 (2, 0, 2)	(3, 0, 3), (4, 0, 4), (6, 0, 6), (7, 0, 7)		2
3 (3, 0, 3)	(1, 0, 1), (2, 0, 2)	**(1, 1, 3)**	**1**
4 (4, 0, 4)	(2, 0, 2), (7, 0, 7)	**(2, 1, 4)**	**2**
5 (5, 0, 5)	(1, 0, 1), (6, 0, 6)	**(1, 1, 5)**	**1**
6 (6, 0, 6)	(1, 0, 1), (2, 0, 2), (5, 0, 5)	**(1, 1, 6)**	**1**
7 (7, 0, 7)	(2, 0, 2), (4, 0, 4)	**(2, 1, 7)**	**2**

Round 3



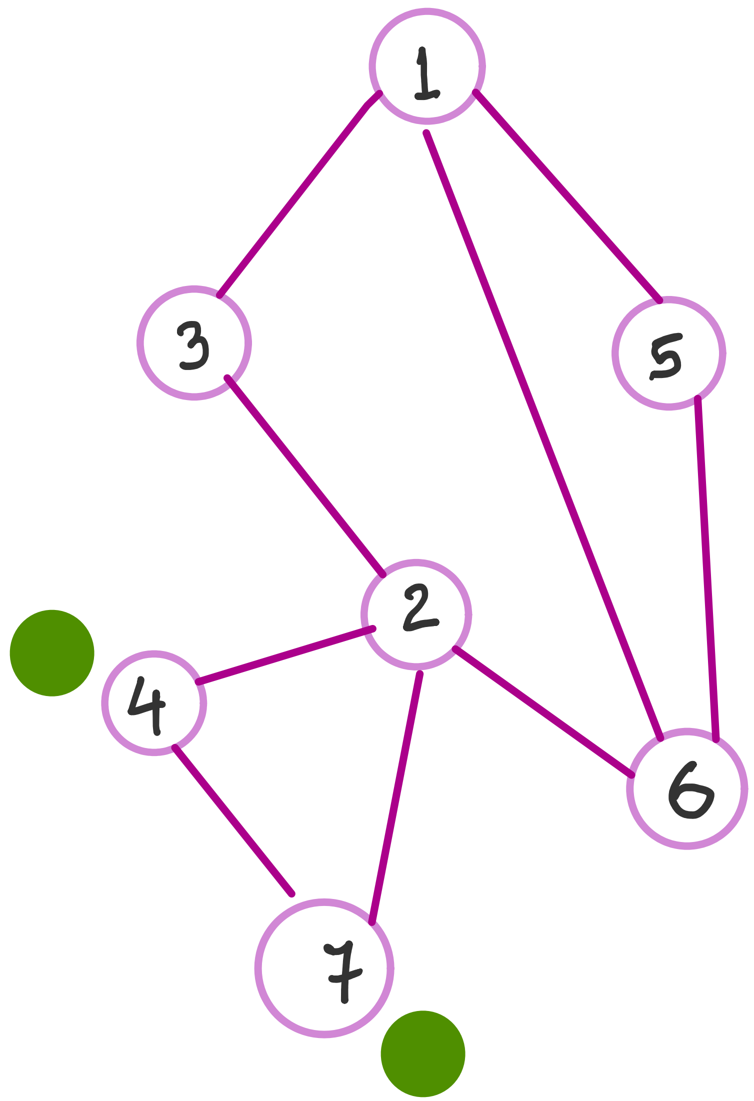
	Receive	Send	Next hop
1 (1, 0, 1)	(1, 1, 3), (1, 1, 5), (1, 1, 6)		1
2 (2, 0, 2)	(1, 1, 3), (2, 1, 4), (1, 1, 6), (2, 1, 7)	**(1, 2, 2)**	**3 (or 6)**
3 (1, 1, 3)			1
4 (2, 1, 4)	(2, 1, 7)		2
5 (1, 1, 5)	(1, 1, 6)		1
6 (1, 1, 6)	(1, 1, 5)		1
7 (2, 1, 7)	(2,1, 4)		2

Round 4



	Receive	Send	Next hop
1 (1, 0, 1)			1
2 (1, 2, 2)			3
3 (1, 1, 3)	(1, 2, 2)		1
4 (2, 1, 4)	(1, 2, 2)	**(1, 3, 4)**	**2**
5 (1, 1, 5)			1
6 (1, 1, 6)	(1, 2, 2)		1
7 (2, 1, 7)	(1, 2, 2)	**(1, 3, 7)**	**2**

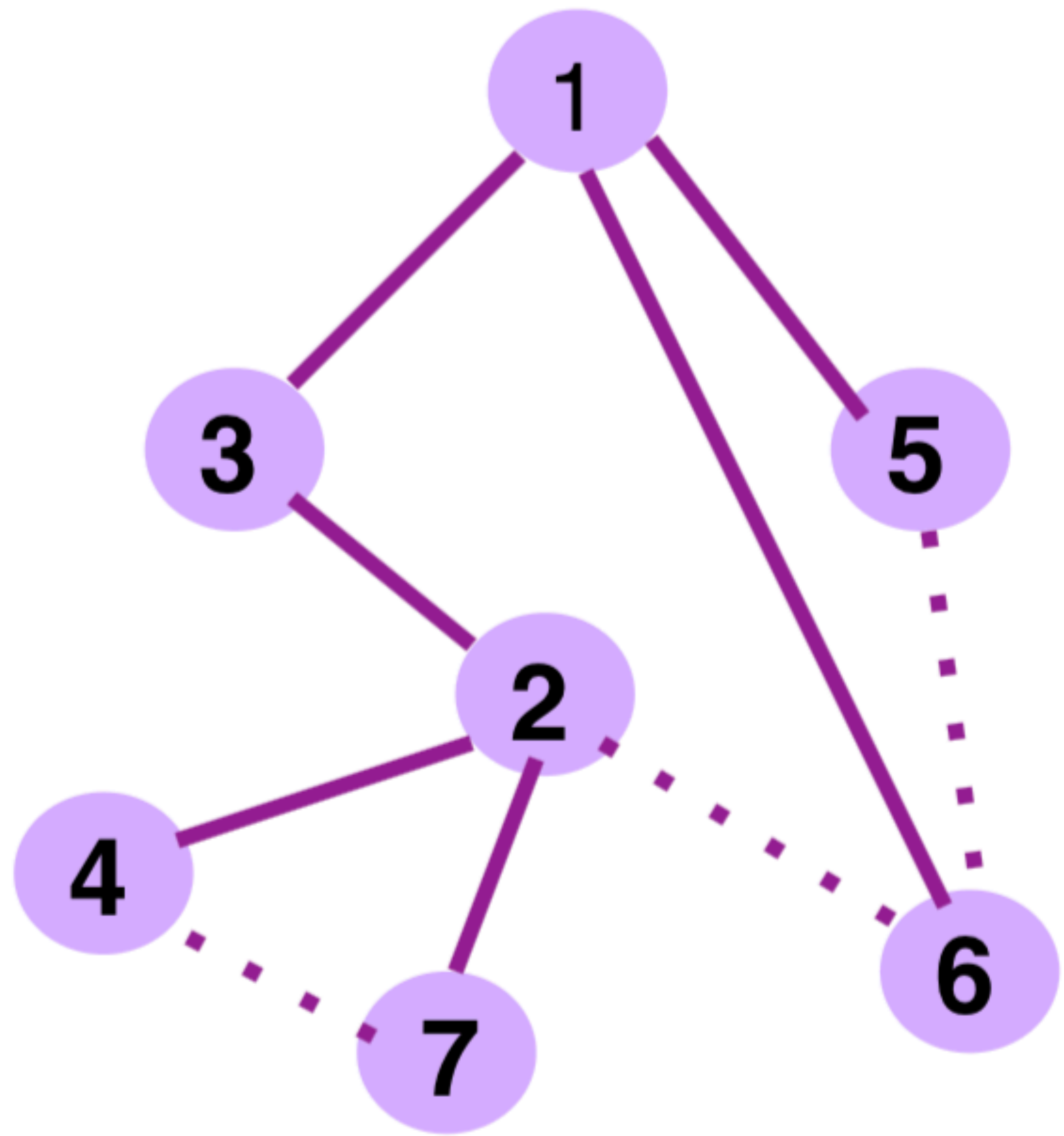
Round 5



	Receive	Send	Next hop
1 (1, 0, 1)			1
2 (1, 2, 2)	(1, 3, 4), (1, 3, 7)		3
3 (1, 1, 3)			1
4 (1, 3, 4)	(1, 3, 7)		2
5 (1, 1, 5)			1
6 (1, 1, 6)			1
7 (1, 3, 7)	(1, 3, 4)		2

After Round 5: We have our Spanning Tree

- 3-1
- 5-1
- 6-1
- 2-3
- 4-2
- 7-2



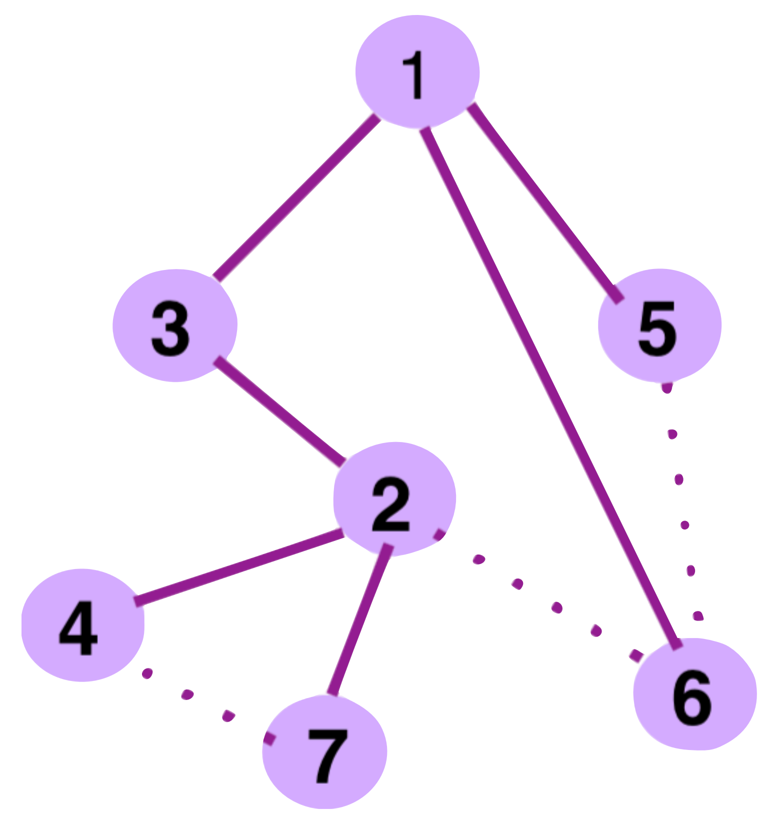
Questions?

Spanning Tree Protocol ++ (incorporating failures)

- Protocol must react to failures
  - Failure of the root node
  - Failure of switches and links
- **Root node sends periodic announcement messages**
  - Few possible implementations, but this is simple to understand
  - Other switches continue forwarding messages
- Detecting failures through timeout (soft state)
  - If no word from root, time out and send a (Y, 0, Y) message to all neighbors (in the graph)!
- **If multiple messages with a new root received, send message (Y, d, X) to the neighbor sending the message**

Suppose link 2-4 fails

- 4 will send (4, 0, 4) to all its neighbors
    - 4 will stop receiving announcement messages from the root
    - Why?
- At some point, 7 will respond with (1, 3, 7)
- 4 will now update to (1, 4, 4) and send update message
- New spanning tree!



Questions?

The end of Link Layer ….

And the beginning of network layer :-D