EN.601.414/614 Computer Networks

Data Link Layer

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Fall 2020 (TuTh 1:30-2:45pm on Zoom)

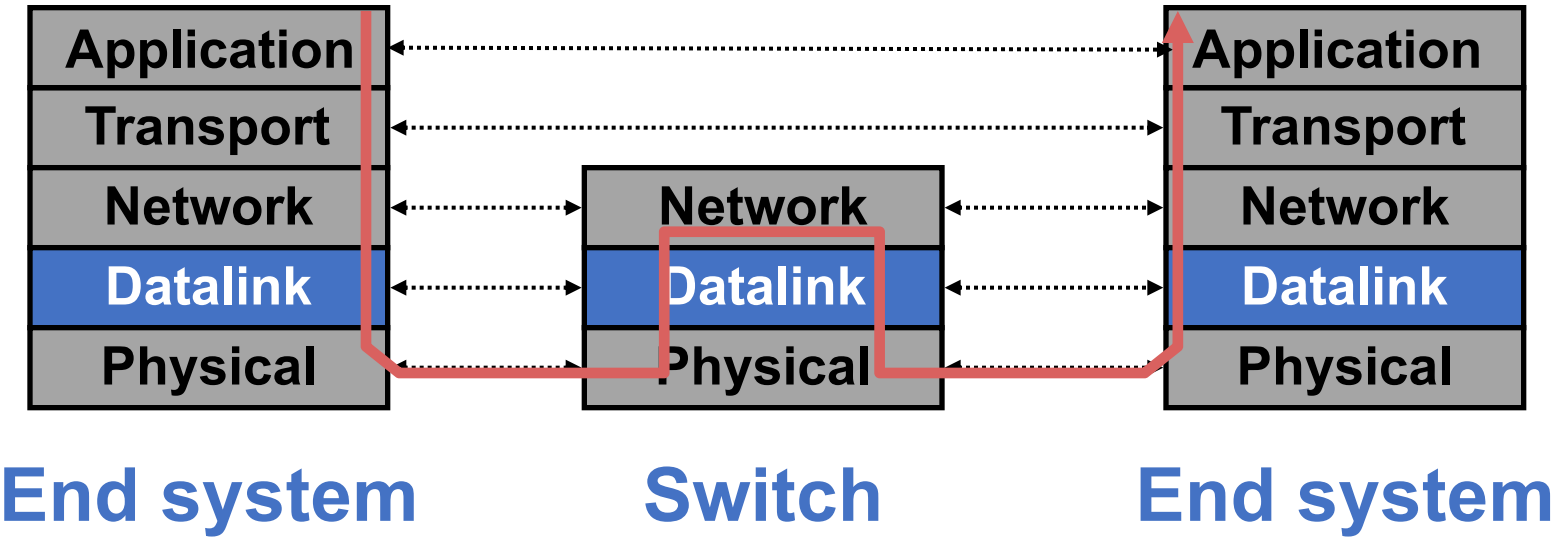
https://github.com/xinjin/course-net

Agenda

- **Data link layer**

Data link layer

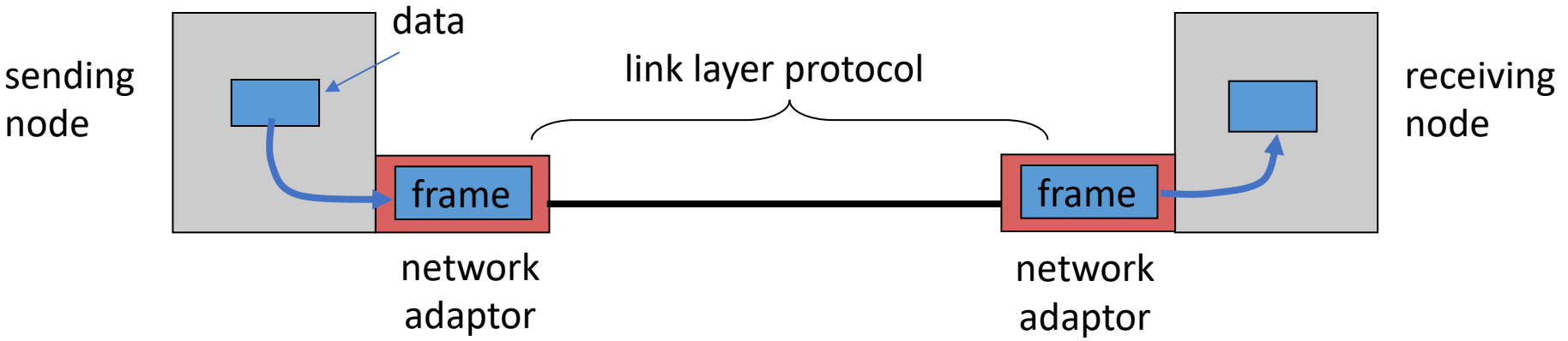
- **Present everywhere**
- **Transfers data between adjacent nodes or between nodes on the same local area network**



Data link layer

- **Provides four primary services**
  - Framing
    - Encapsulates network layer data
  - Link access
    - Medium access control (MAC) protocol defines when to transmit frames
  - Reliable delivery
    - Primarily for mediums with high error rates (e.g., wireless)
  - Error detection and correction

Packets are now “frames”



- **Frames encapsulate network layer packets**
- **Link layer protocols are implemented in h/w**
- **Frame formats can change based on link layer protocol**

Point-to-point vs. broadcast medium

- **Point-to-point: dedicated pairwise communication**
  - E.g., long-distance fiber link
  - E.g., Point-to-point link b/n Ethernet switch and host
- **Broadcast: shared wire or medium**
  - Traditional Ethernet (pre ~2000)
  - 802.11 wireless LAN

Multiple access algorithm

- **Context: a shared broadcast channel**
  - Must avoid having multiple nodes speaking at once
    - Otherwise, collisions lead to garbled data
  - Need distributed algorithm to determine which node can transmit
- **Three classes of techniques**
  - Channel partitioning: divide channel into pieces
  - Taking turns: scheme for deciding who transmits
  - Random access: allow collisions, and then recover
    - More in the Internet style!

Random access MAC protocols

- **When node has packet to send**
  - Transmit at full channel data rate **w/o** coordination
- **Two or more transmitting nodes ⇒ collision**
  - Data lost
- **Random access MAC protocol specifies**
  - How to detect and recover from collisions
- **Examples**
  - ALOHA and Slotted ALOHA
  - CSMA, CSMA/CD, CSMA/CA (wireless)

Ethernet

- **Invented as a broadcast technology**
  - Hosts share channel
  - Each packet received by all attached hosts
  - CSMA/CD for media access control
- **Modern Ethernets are "switched" (later)**
  - Point-to-point links between switches and between a host and switch
  - No sharing $\Rightarrow$ no CSMA/CD
    - Uses "self learning" and "spanning tree" algorithms for routing

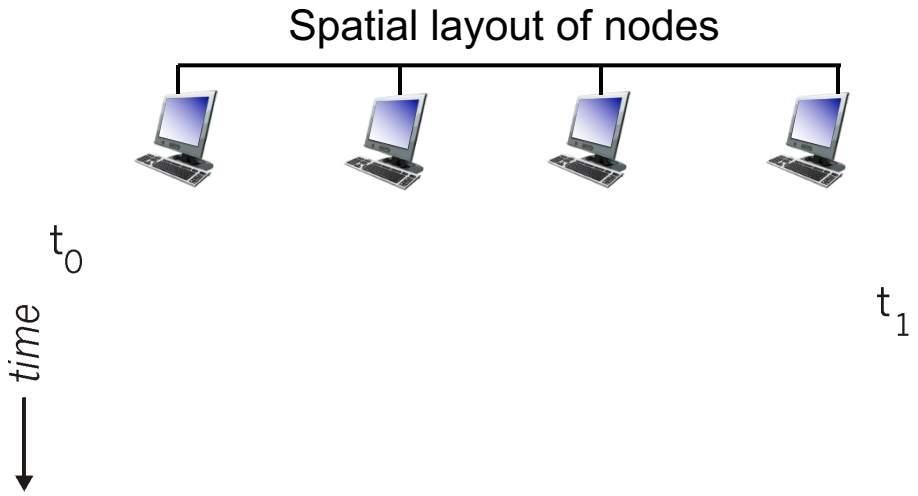
CSMA (Carrier Sense Multiple Access)

- **CSMA: listen before transmit**
  - If channel sensed idle: transmit entire frame
  - If channel sensed busy, defer transmission
- **Human analogy: don't interrupt others!**
- **Does not eliminate all collisions**
  - Why?

CSMA collisions

- **Propagation delay: two nodes may not hear each other before sending**

- **CSMA reduces but does not eliminate collisions**
- **Collision: entire packet transmission time wasted**
  - Distance and propagation delay affect collision probability



CSMA/CD (Collision Detection)

- **CSMA/CD: carrier sensing, deferral as in CSMA**
  - Collisions detected within short time
  - Colliding transmissions aborted, reducing wastage
- **Collision detection easy in wired (broadcast) LANs**
  - Compare transmitted, received signals
- **Collision detection difficult in wireless LANs**
  - Later!

Three key ideas of random access

- **Carrier sense**
  - Listen before speaking and don't interrupt
  - Checking if someone else is already sending data
  - … and waiting till the other node is done
- **Collision detection**
  - If someone else starts talking at the same time, stop
    - Make sure everyone knows there was a collision!
  - Realizing when two nodes are transmitting at once
  - …by detecting that the data on the wire is garbled

Three key ideas of random access

- **Randomness**
  - Don’t start talking again right away
  - Waiting for a random time before trying again

How long should you wait?

- **Should it be immediate?**
- **Should it be a random number with a fixed distribution?**

Ethernet: CSMA/CD Protocol

- **Carrier sense: wait for link to be idle**
- **Collision detection: listen while transmitting**
  - No collision: transmission is complete
  - Collision: abort transmission & send jam signal
- **Random access: binary exponential back-off**
  - After collision, wait a random time before retrying
  - After m^{th} collision, choose K randomly from {0, …, 2^m-1}
    - Wait for K*512 bit times before trying again
    - If transmission occurring when ready to send, wait until end of transmission (CSMA)

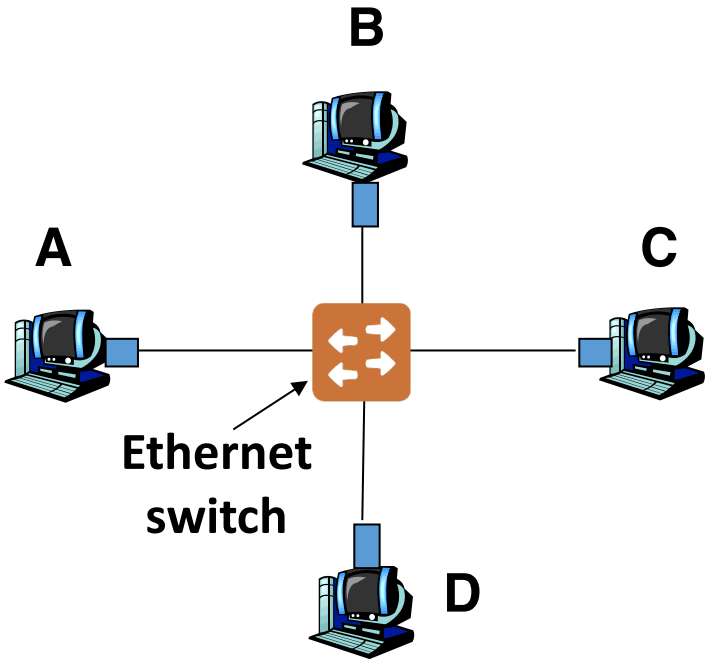
Switched Ethernet

Broadcast vs. switched Ethernet

- **Invented as a broadcast technology**
  - Hosts share channel
  - Each packet received by all attached hosts
  - CSMA/CD for media access control
- **Modern Ethernets are "switched"**
  - Point-to-point links between switches and between a host and switch
  - No sharing $\Rightarrow$ no CSMA/CD
    - Uses "self learning" and "spanning tree" algorithms for routing

Why switched Ethernet?

- **Enables concurrent communication**
  - Host A can talk to C, while B talks to D
  - No collisions and no need for CSMA/CD
  - No constraints on link lengths, etc.

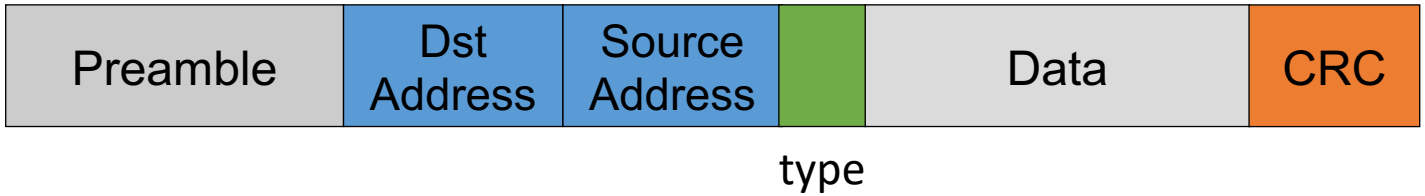


Topics

- **Frames and framing**
- **Addressing**
- **Routing**
- **Forwarding**
- **Discovery**

Ethernet “Frames”

- **Encapsulates IP datagram**



- **Preamble: 7 bytes for clock synchronization and 1 byte to indicate start of frame**
- **Addresses: 6 bytes**
- **Type: 2 bytes, higher-layer protocol (e.g., IP)**
- **Data payload: max 1500 bytes, min 46 bytes**
- **CRC: 4 bytes for error detection**

Framing frames

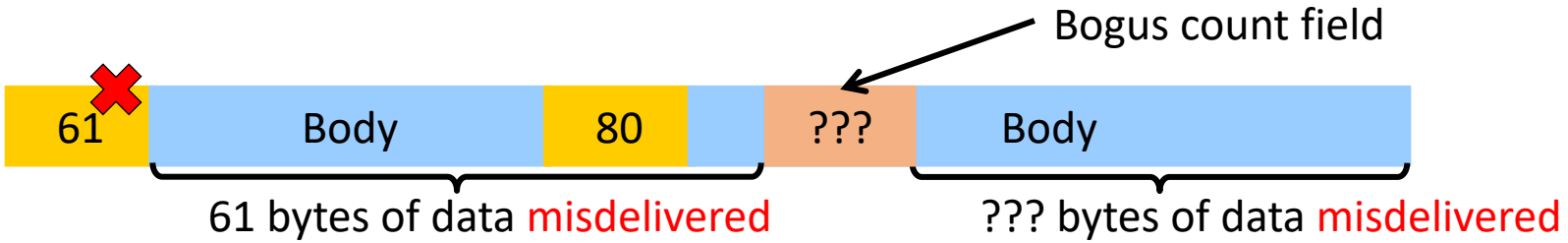
- **Physical layer puts bits on a link**
- **But, two hosts connected on the same physical medium need to be able to exchange frames**
  - Service provided by the link layer
  - Implemented by the network adaptor
- **Framing problem: how does the link layer determine where each frame begins and ends?**

Simple approach: Count bytes

- **Sender includes number of bytes in header**

  - Receiver extracts this number of bytes of body

- **What if the Count field is corrupted?**



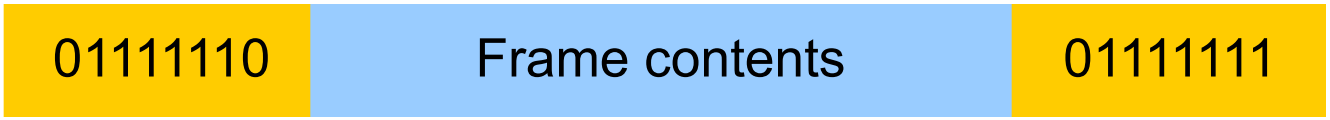
  - L2 will frame the wrong bytes → a framing error
  - CRC tells you to discard this frame, but what about the next one?

Desynchronization

- **Once framing on a link is desynchronized, it can stay that way**
- **Need a method to resynchronize**

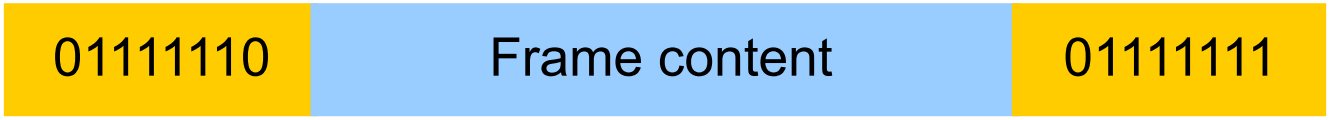
Framing with sentinel bits

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



- **What if sentinel occurs within frame?**
- **Solution: bit stuffing**
  - Sender always inserts a 0 after five 1s in the frame contents
  - Receiver always removes a 0 appearing after five 1s

When receiver sees five 1s…



- **If next bit 0, remove it; begin counting again**
  - Because this must be a stuffed bit; we can't be at beginning/end of frame (those had six or seven 1s)
- **If next bit 1 (i.e., we've seen six 1s) then:**
  - If following bit is 0, this is start of frame
    - Because the receiver has seen 01111110
  - If following bit is 1, this is end of frame
    - Because the receiver has seen 01111111

Example: sentinel bits

- **Original data, including start/end of frame:**
  - 01111110011111101111101111001**01111111**
- **Sender rule: five 1s → insert a 0**
  - After bit stuffing at the sender:
  - 01111110011111**0**10111110011111**0**001**01111111**
- **Receiver rule: five 1s and next bit 0 → remove 0**
  - 01111110011111101111101111001**01111111**

Topics

- Frames and framing
- **Addressing**
- **Routing**
- **Forwarding**
- **Discovery**

Medium Access Control (MAC) Address

- **MAC address**
  - Numerical address associated with a network adapter
  - Flat name space of 48 bits (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 the IEEE
    - First 24 bits (e.g., 00-15-C5-**-**-**)
  - Adapter: assigned by the vendor from its block
    - Last 24 bits

MAC address vs. IP address

MAC Addresses

- Hard-coded when adapter is built
- Flat name space of 48 bits (e.g., 00-0E-9B-6E-49-76)
- Like a social security number
- Portable, and can stay the same as the host moves
- Used to get packet between interfaces on same network

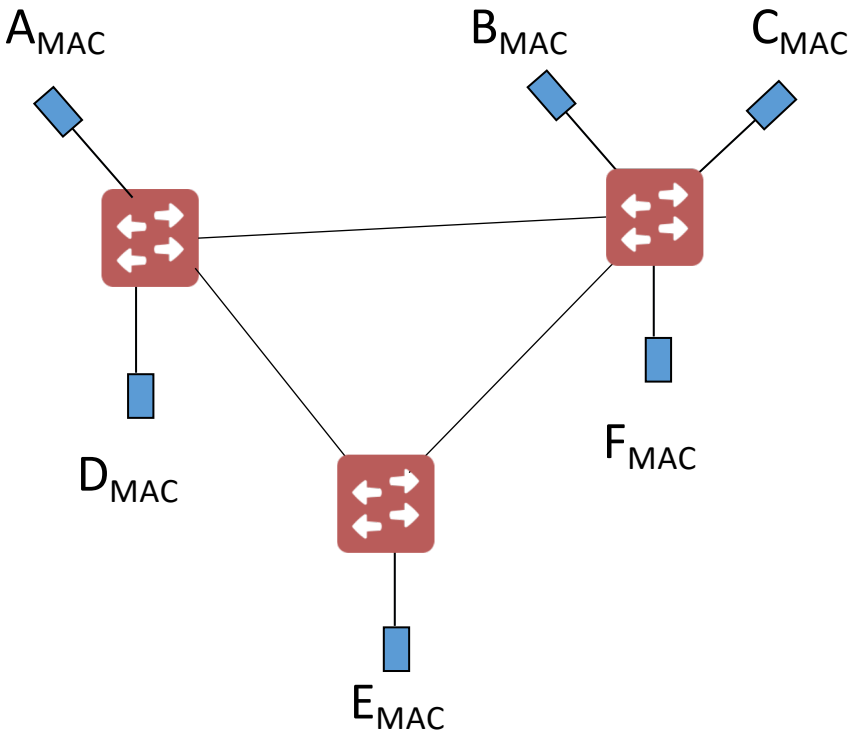
IP Addresses

- Configured, or learned dynamically
- Hierarchical name space of 32 bits (e.g., 12.178.66.9)
- Like a postal mailing address
- Not portable, and depends on where the host is attached
- Used to get a packet to destination IP subnet

Topics

- Frames and framing
- Addressing
- **Routing**
- **Forwarding**
- **Discovery**

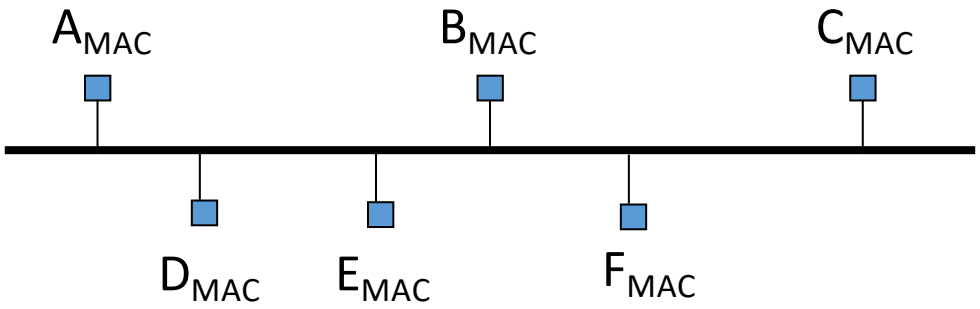
Routing with switched Ethernet?



Why does Ethernet not use LS/DV?

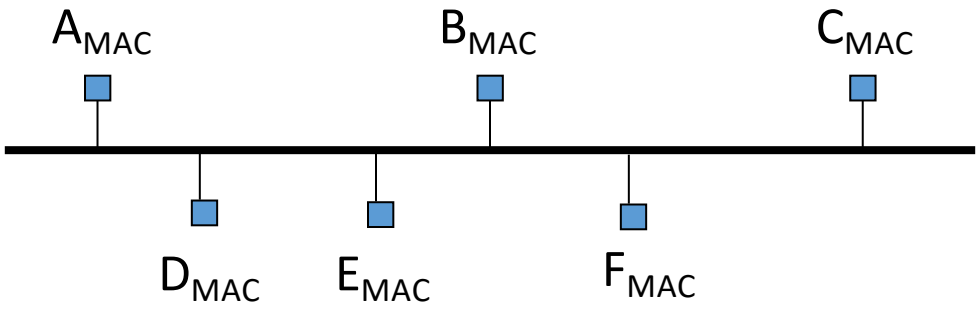
- **Concerns over scalability**
  - Flat MAC addresses cannot be aggregated like IP addresses
- **Legacy**

“Routing” with 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)

“Routing” with broadcast Ethernet

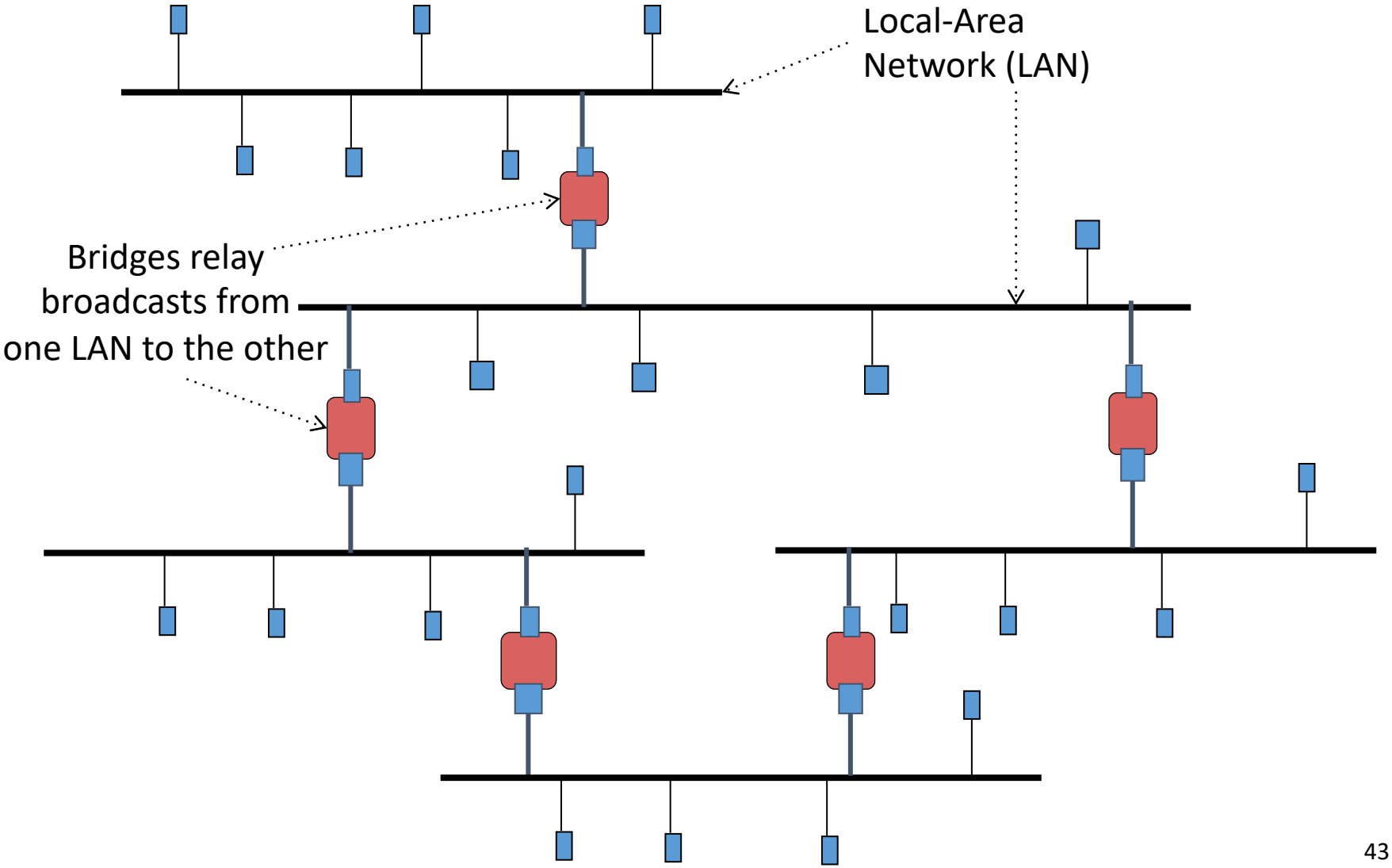


- **Ethernet is “plug-n-play”**
- **A new host plugs into the Ethernet and is good to go**
  - No configuration by users or network operators
  - Broadcast as a means of bootstrapping communication

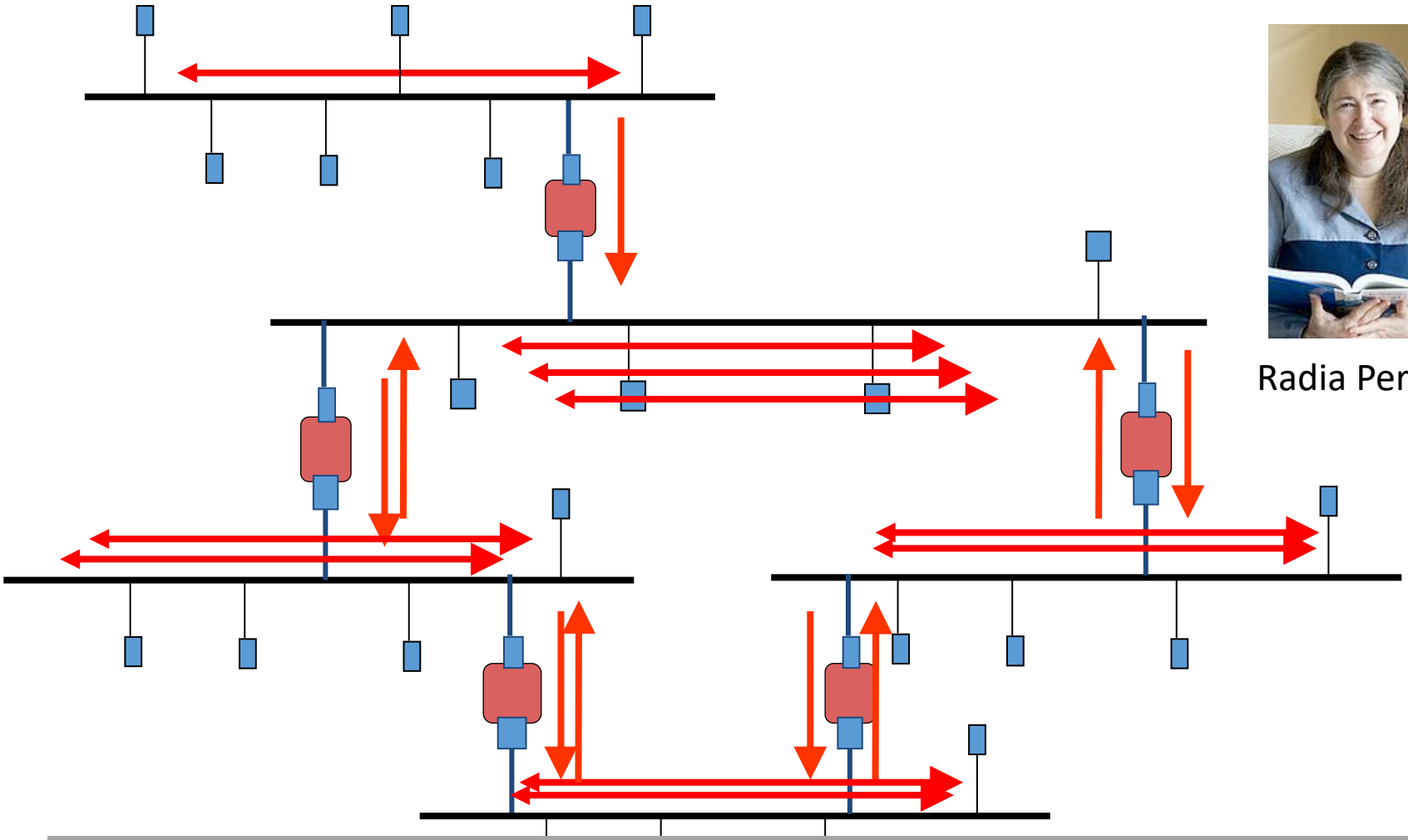
Why does Ethernet not use LS/DV?

- **Concerns over scalability**
  - Flat MAC addresses cannot be aggregated like IP addresses
- **Legacy**
  - Backward compatibility with broadcast Ethernet
  - Desire to maintain Ethernet's plug-n-play behavior

Routing in extended LANs



The “broadcast storm” problem



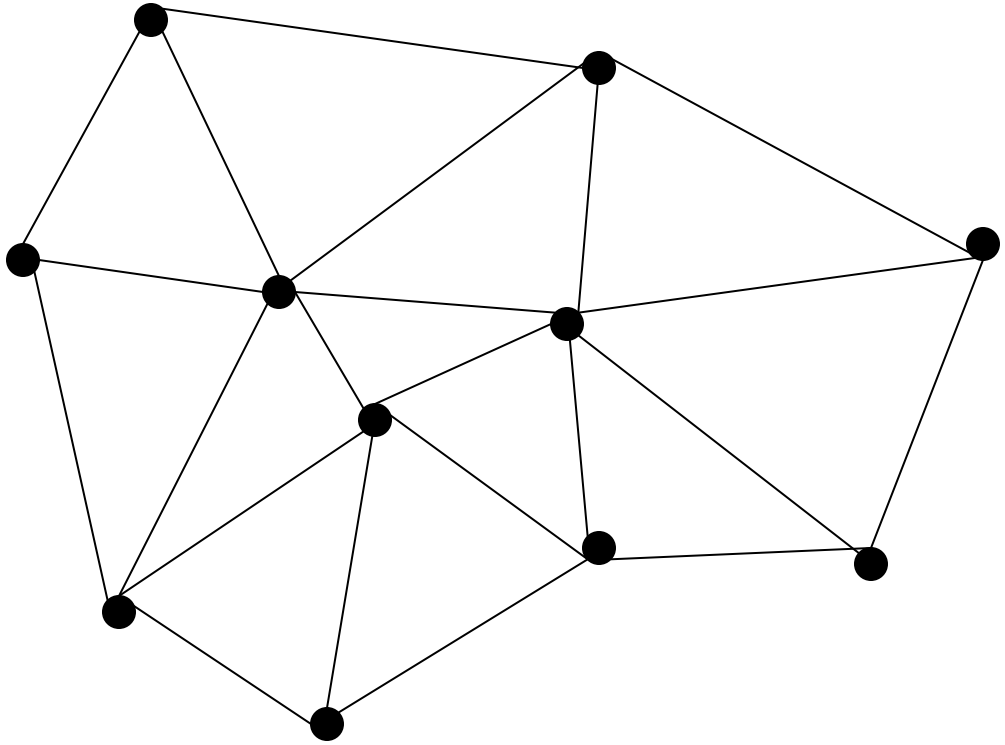
Radia Perlman

Perlman’s idea: eliminate loops in the topology

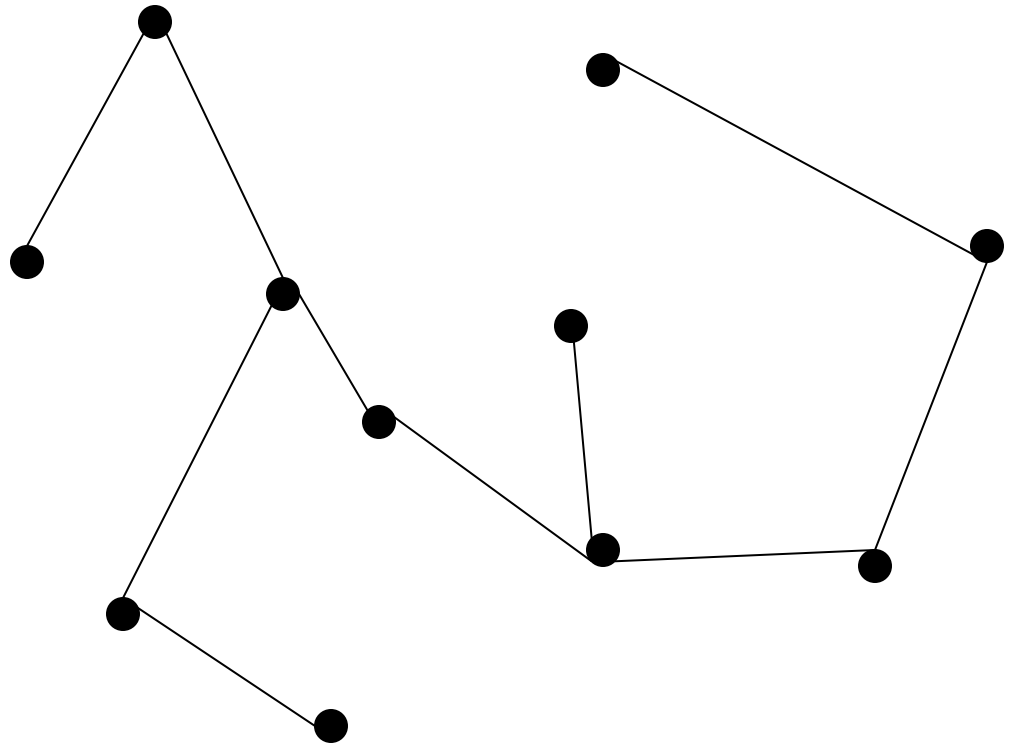
Easiest way to avoid loops

- **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

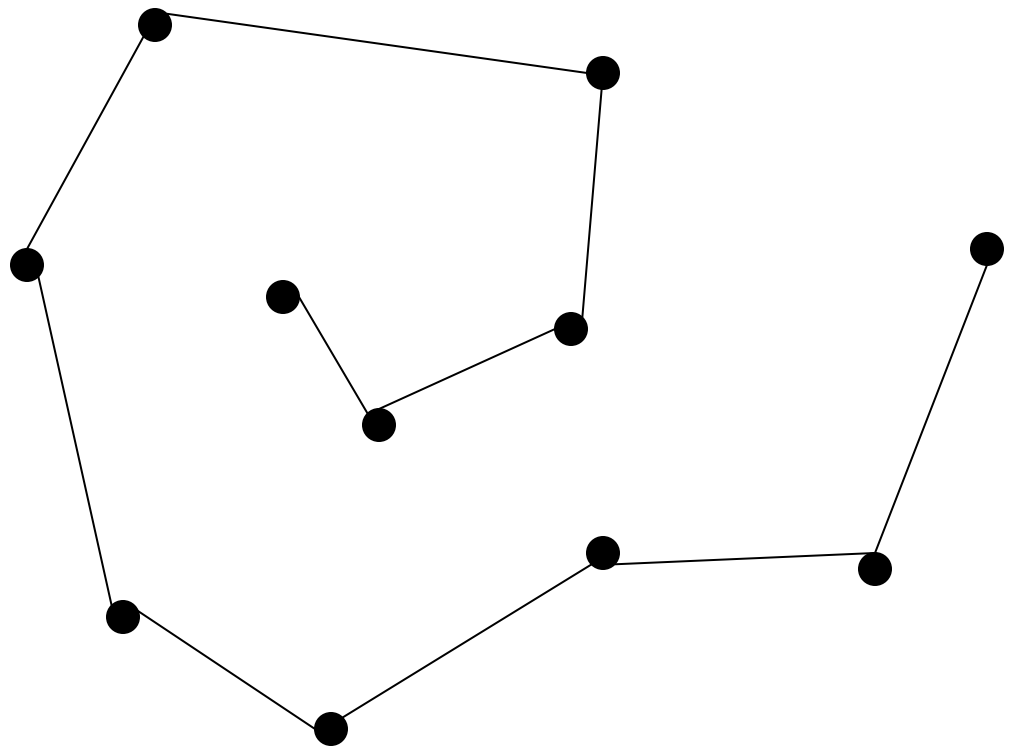
Consider a graph



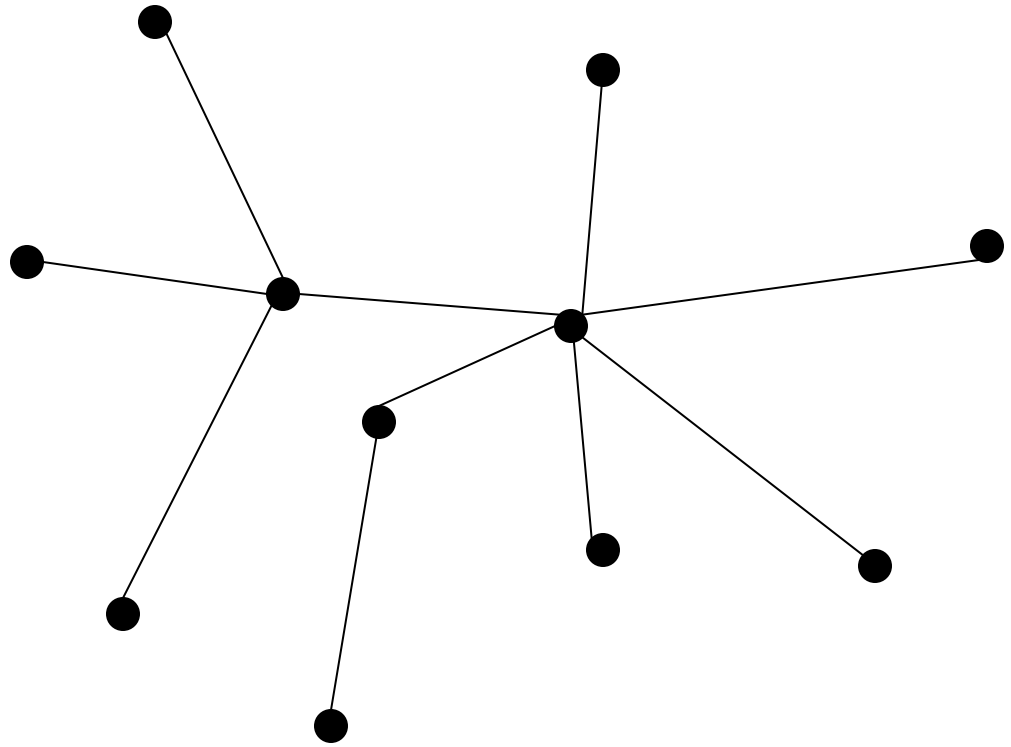
A spanning tree



Another spanning tree



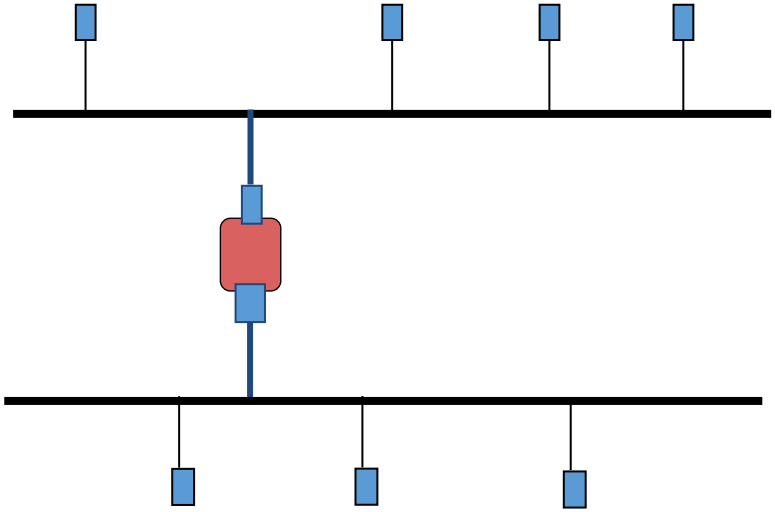
Yet another spanning tree

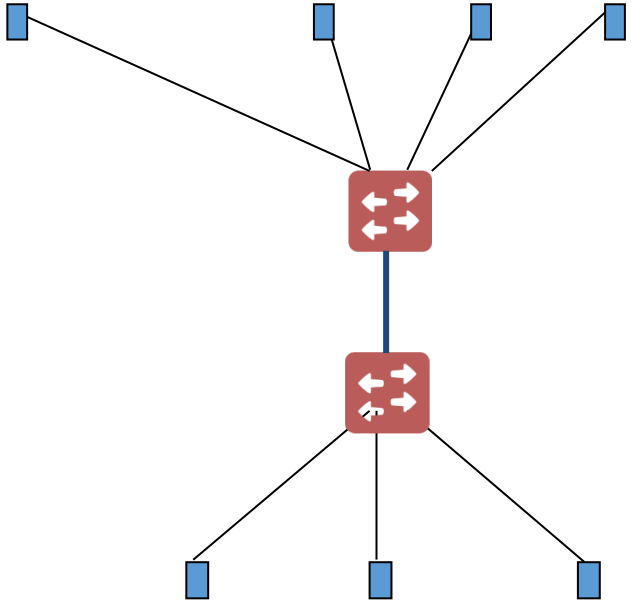


Spanning tree protocol (Perlman'85)

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

From extended LANs to switched Ethernet





Switched Ethernet

- **Constraints (for backward compatibility)**
  - ➢No changes to end-hosts
  - ➢Maintain plug-n-play aspect
- **Earlier Ethernet achieved plug-n-play by leveraging a broadcast medium**
  - ➢Can we do the same in a switched topology?

Group Discussion

- **Topic: Ethernet routing**
  - How does Ethernet do routing? What are the pros and cons of the approach?

- **Discuss in groups, and each group chooses a leader to summarize the discussion**
  - **Everyone should speak.**
  - **Turn on your audio and video. Do not mute.**

Summary

- **Data link layer transfers data between adjacent nodes or nodes connected to the same switch**
- **Ethernet evolved from a broadcast medium to switched**

- **Next week: Link layer wrap up + putting everything together**

Thanks!
Q&A