Multiple access contd.

ALOHA recap

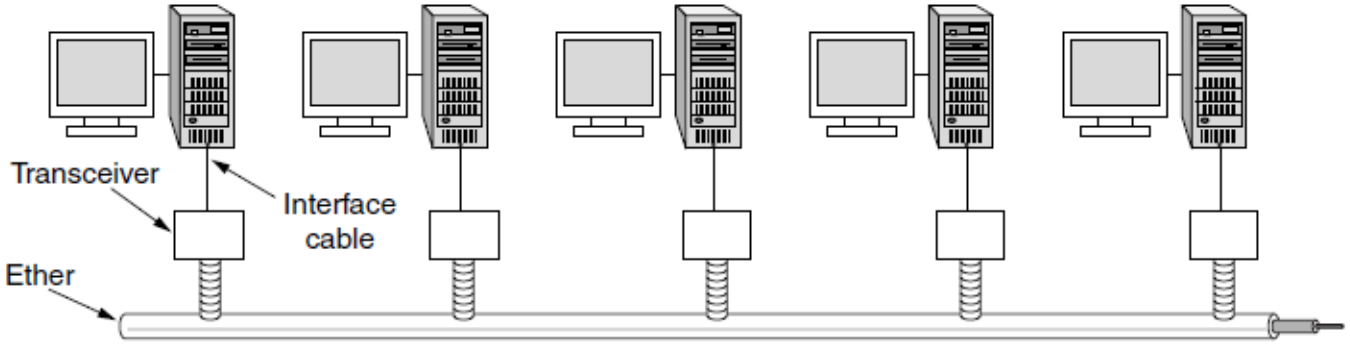
1. Send when you have to
2. If no ack, wait for a random time and send again

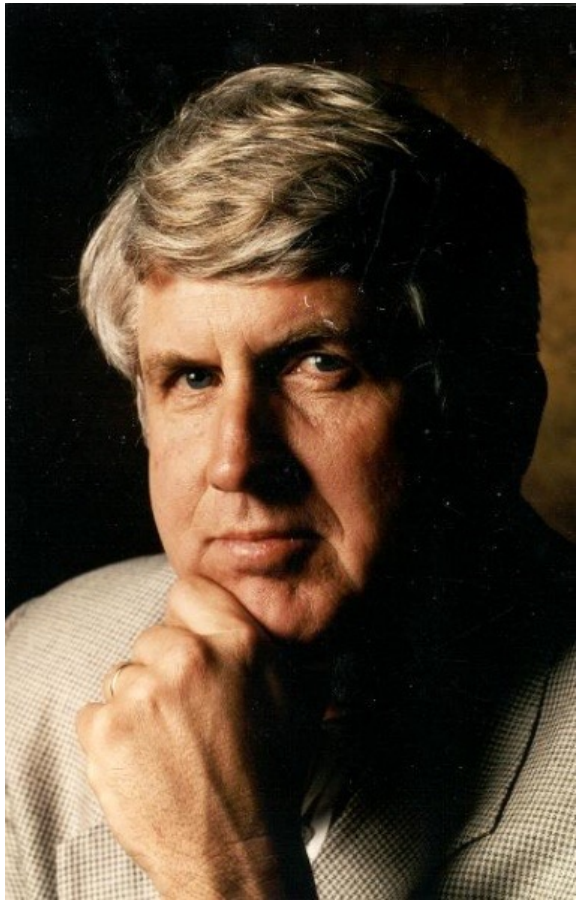
Super simple, but low efficiency

Classic Ethernet

ALOHA inspired Bob Metcalfe to invent Ethernet for LANs in 1973

- Nodes share 10 Mbps coaxial cable
- Hugely popular in 1980s, 1990s
- Turing award in 2023





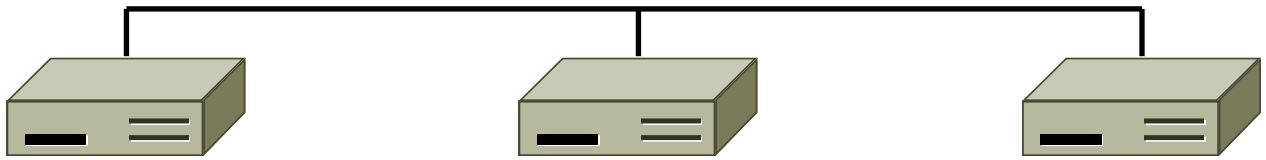
: © 2009 IEEE

CSMA (Carrier Sense Multiple Access)

- Improve ALOHA by listening for activity before we send (Doh!)
  - Easy with wires, recently made possible for wireless
- So does this eliminate collisions?
  - Why or why not?

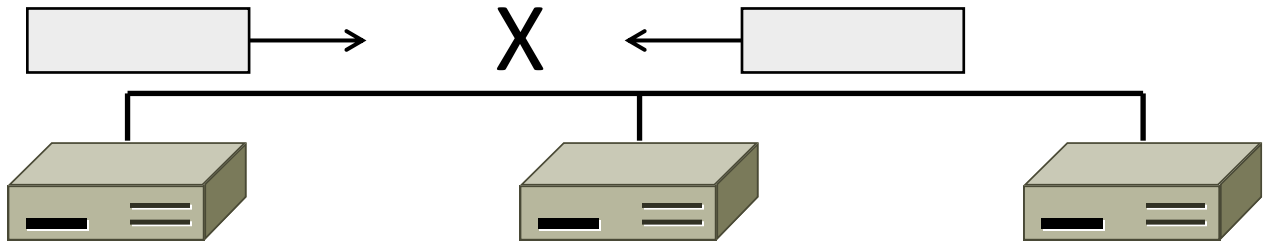
CSMA (2)

- Still possible to listen and hear nothing when another node is sending because of delay



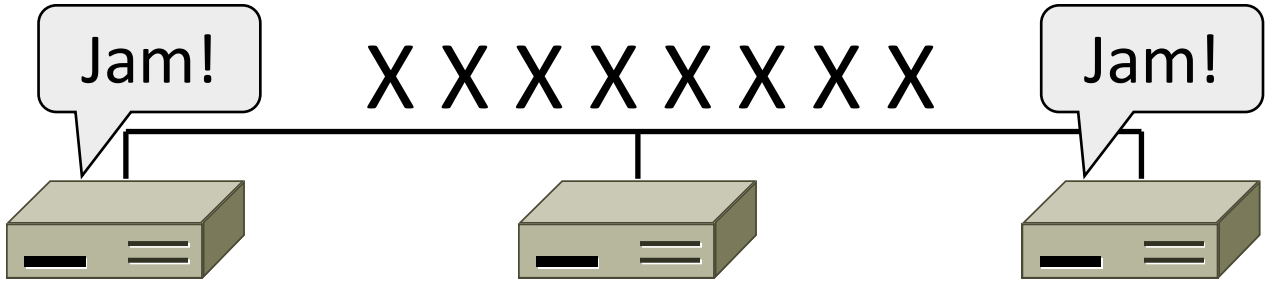
CSMA (3)

- CSMA is a good defense against collisions only when BD is small



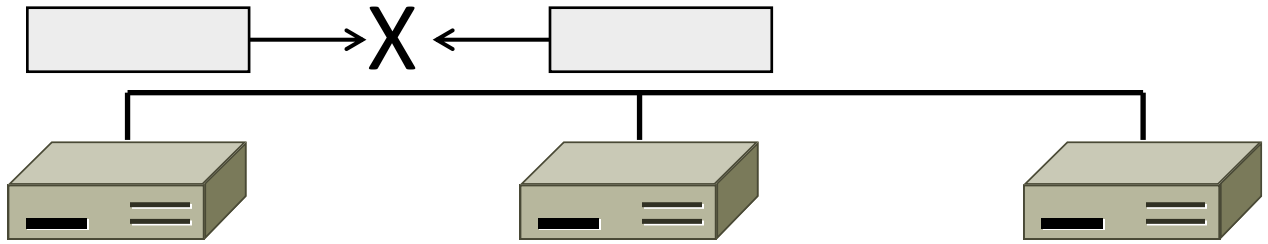
CSMA/CD (with Collision Detection)

- Can reduce the cost of collisions by detecting them and aborting (Jam) the rest of the frame time
  - Again, easy with wires, recently made possible for wireless



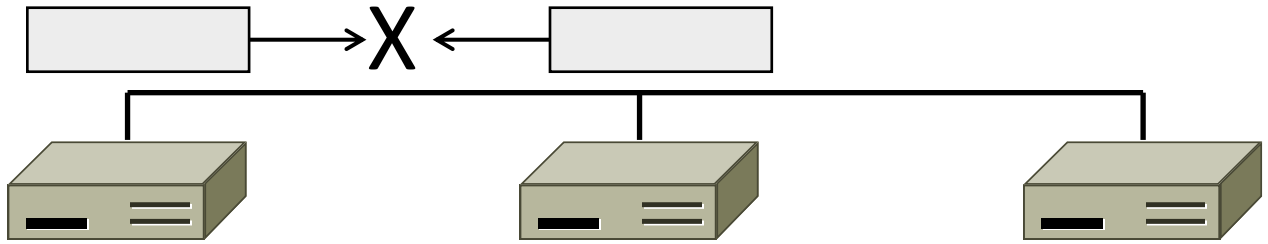
CSMA/CD Complications

- Everyone who collides needs to know it happened
  - How long do we need to wait to know there wasn't a JAM?



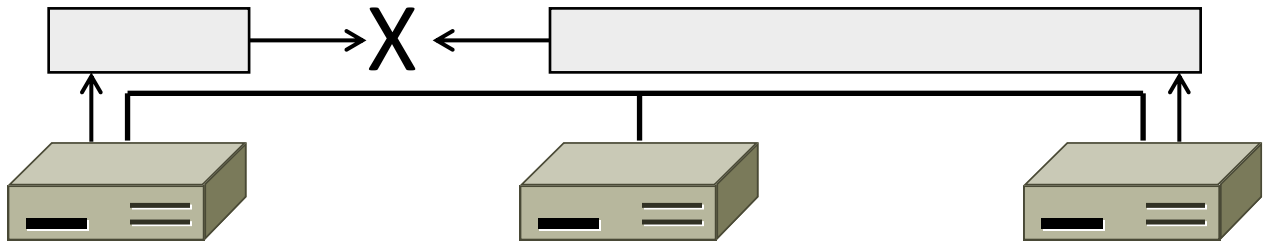
CSMA/CD Complications

- Everyone who collides needs to know it happened
  - How long do we need to wait to know there wasn't a JAM?
  - Time window in which a node may hear of a collision (transmission + jam) is 2D seconds



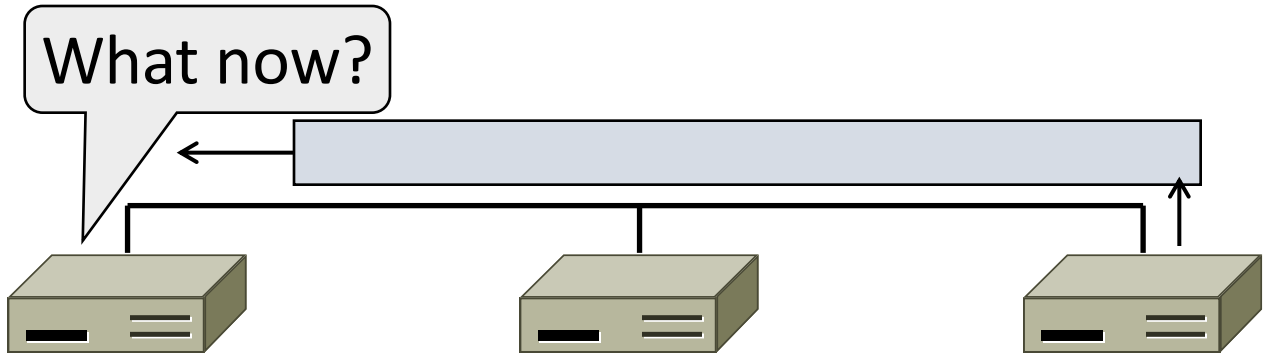
CSMA/CD Complications (2)

- Impose a minimum frame length of 2D seconds
  - So node can't finish before collision
  - Ethernet minimum frame is 64 bytes – Also sets maximum network length (500m w/ coax, 100m w/ Twisted Pair)



CSMA "Persistence"

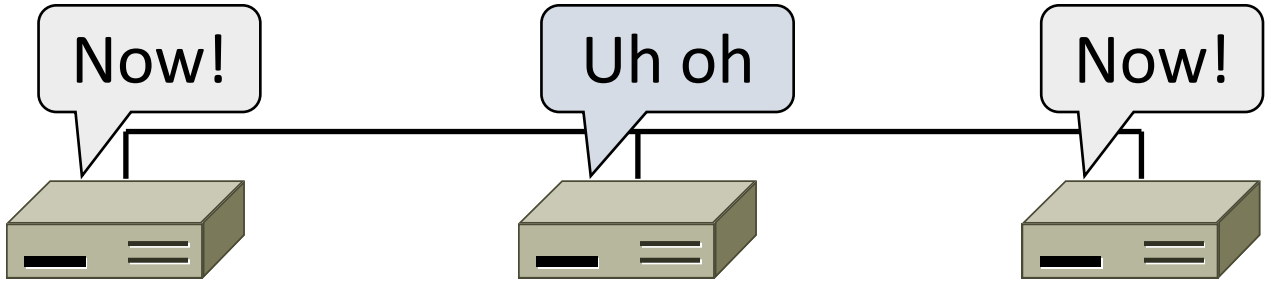
- What should a node do if another node is sending?



- Idea: Wait until it is done, and send

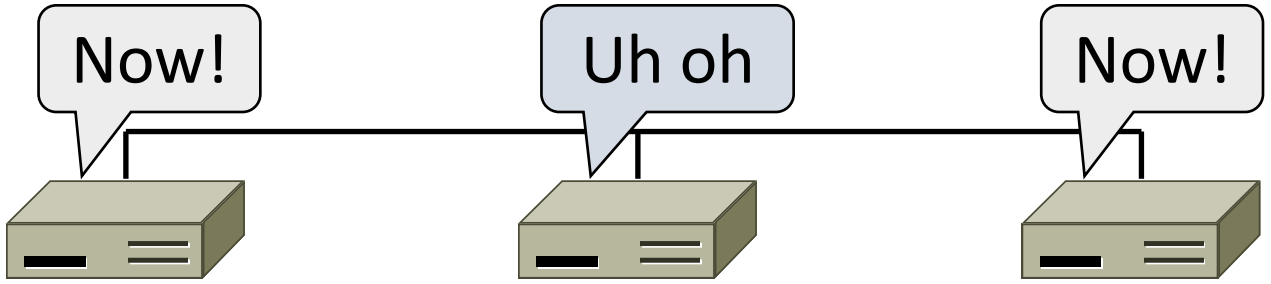
CSMA "Persistence" (2)

- Problem is that multiple waiting nodes will queue up then collide
  - More load, more of a problem



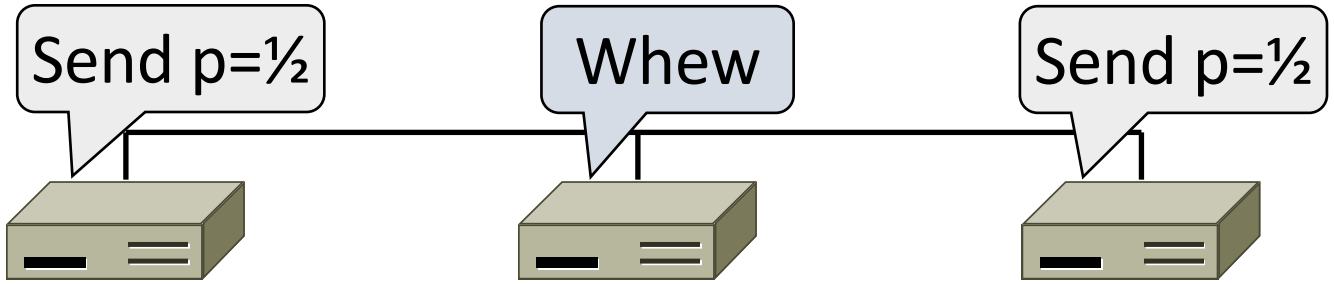
CSMA "Persistence" (2)

- Problem is that multiple waiting nodes will queue up then collide
  - Ideas?



CSMA "Persistence" (3)

- Intuition for a better solution
  - If there are N queued senders, we want each to send next with probability 1/N

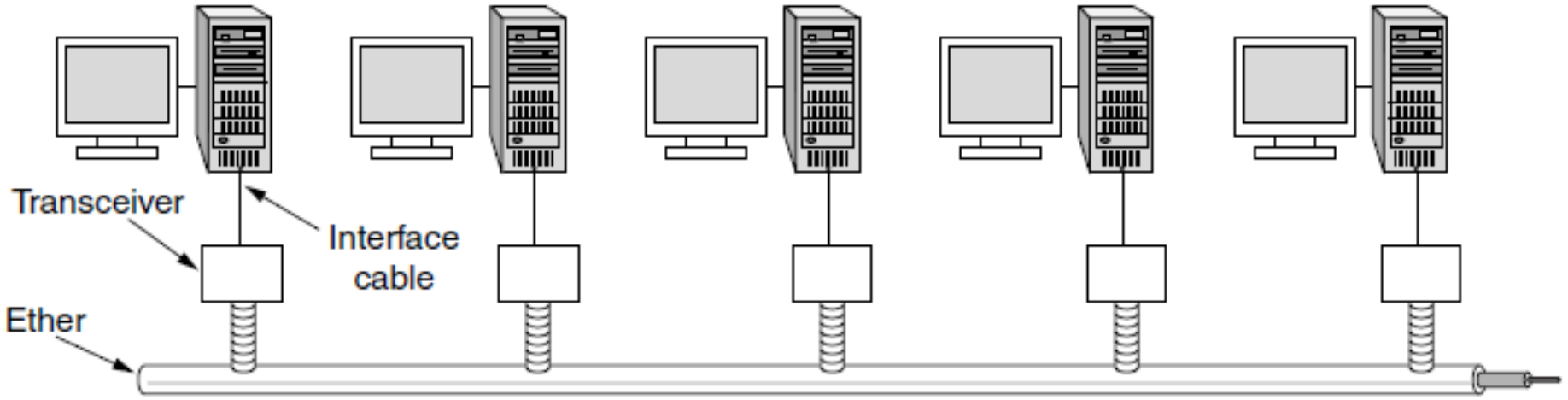


Binary Exponential Backoff (BEB)

- Cleverly estimates the probability
  - 1st collision, wait 0 or 1 frame times
  - 2nd collision, wait from 0 to 3 times
  - 3rd collision, wait from 0 to 7 times …
- BEB doubles interval for each successive collision
  - Quickly gets large enough to work
  - Very efficient in practice

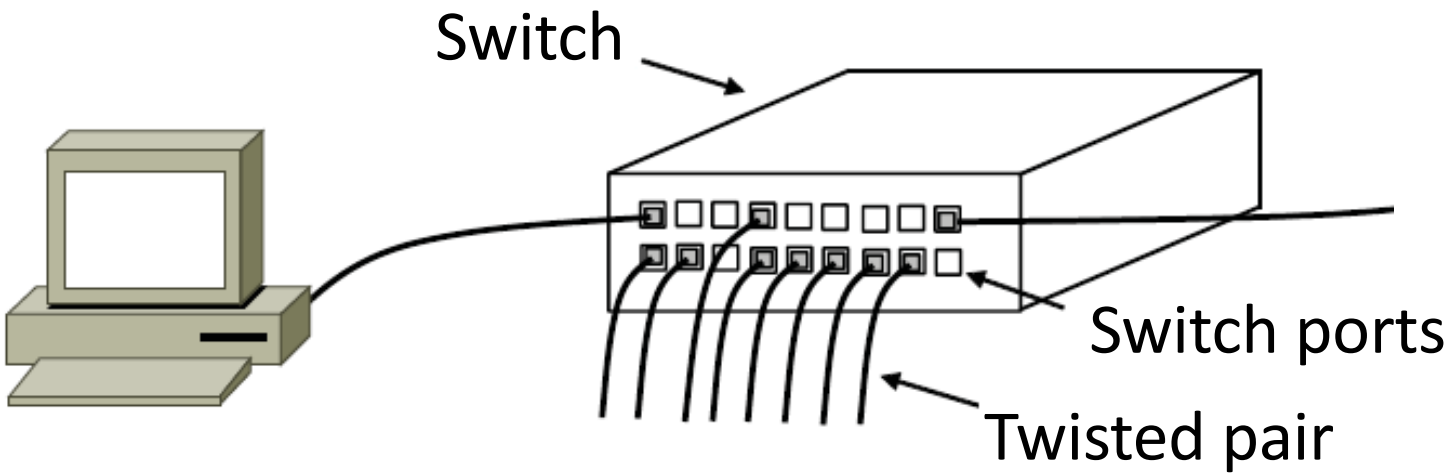
Classic Ethernet, or IEEE 802.3

- Most popular LAN of the 1980s, 1990s
  - 10 Mbps over shared coaxial cable
  - Multiple access with persistent CSMA/CD with BEB



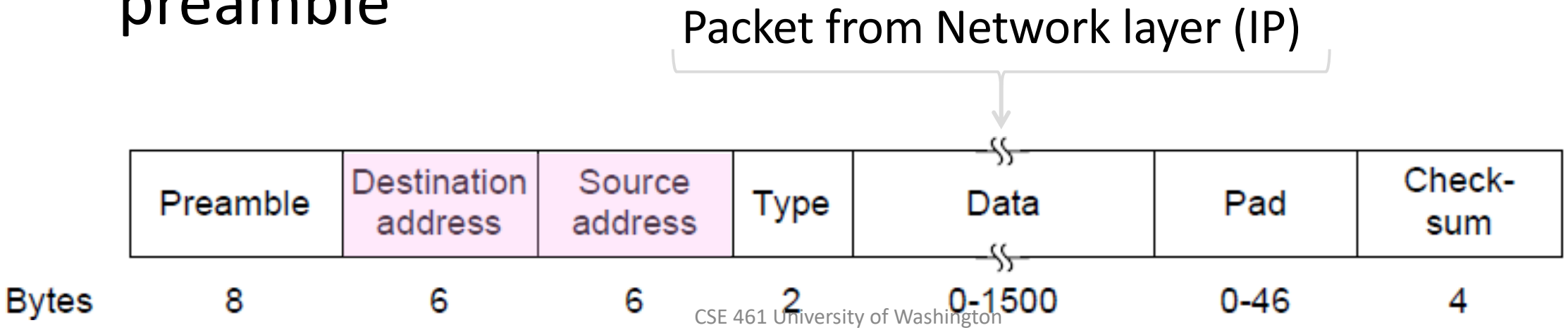
Modern Ethernet

- Based on switches, not multiple access, but still called Ethernet



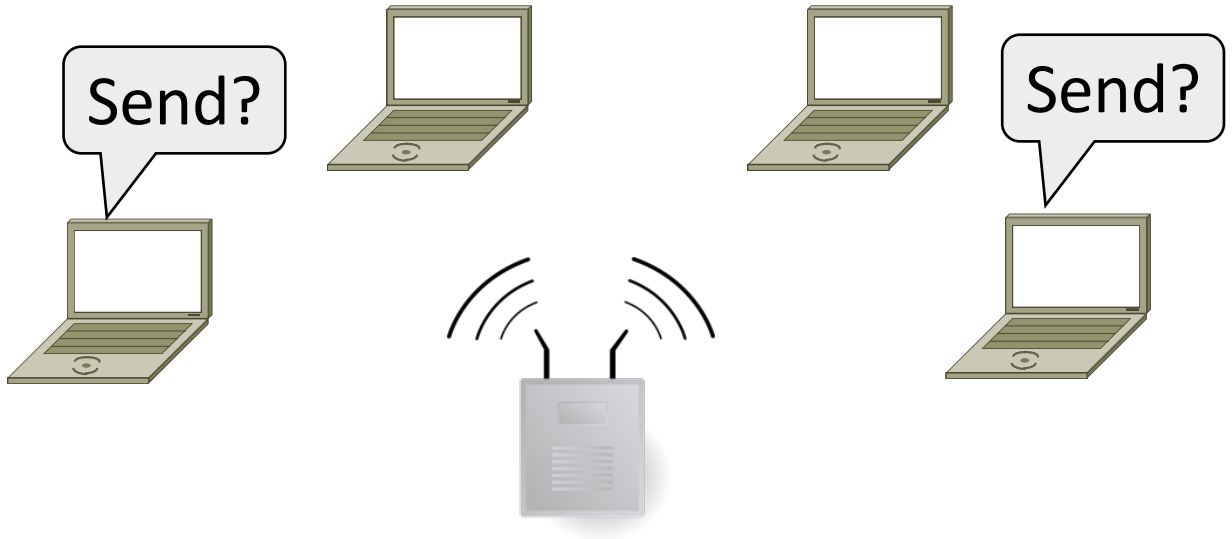
Ethernet Frame Format

- Has addresses to identify the sender and receiver
- CRC-32 for error detection; no ACKs or retransmission
- Start of frame identified with physical layer preamble



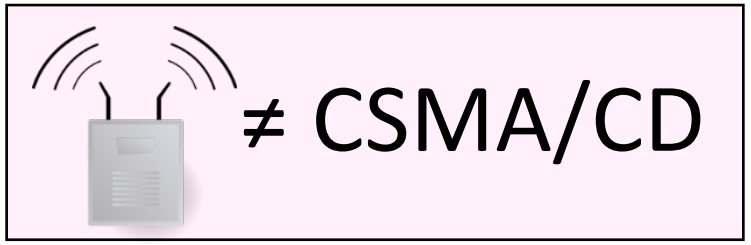
Wireless MACs

- How do wireless nodes share a single link? (Yes, this is WiFi!)
  - Build on our simple, wired model



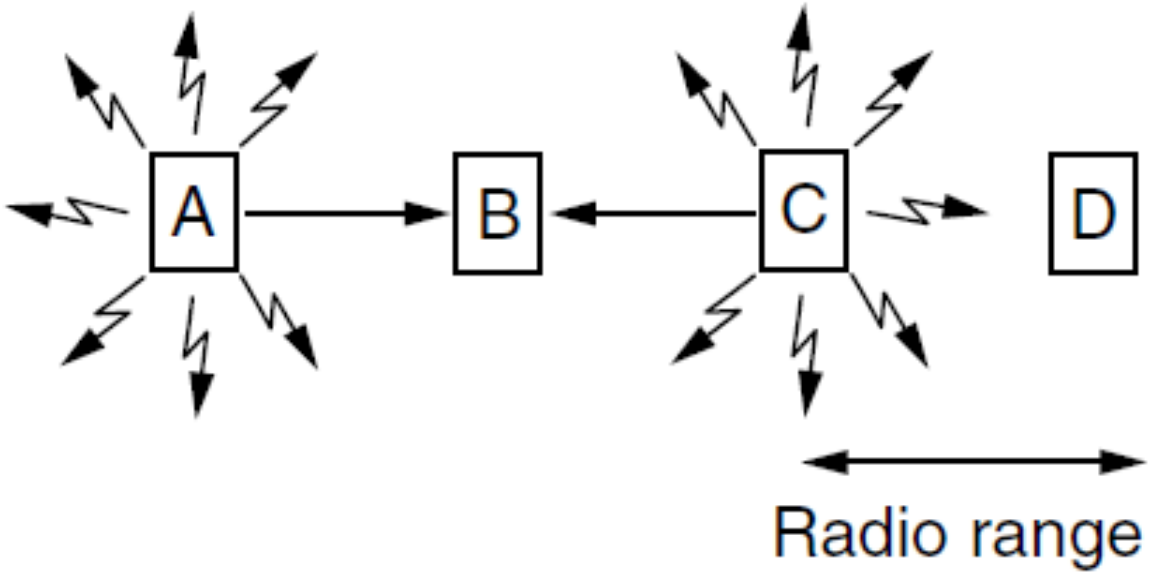
Wireless Complications

- Wireless is more complicated than wired (surprise!)
  1. Media is infinite – can't Carrier Sense
  2. Nodes usually can't hear while sending – can't Collision Detect



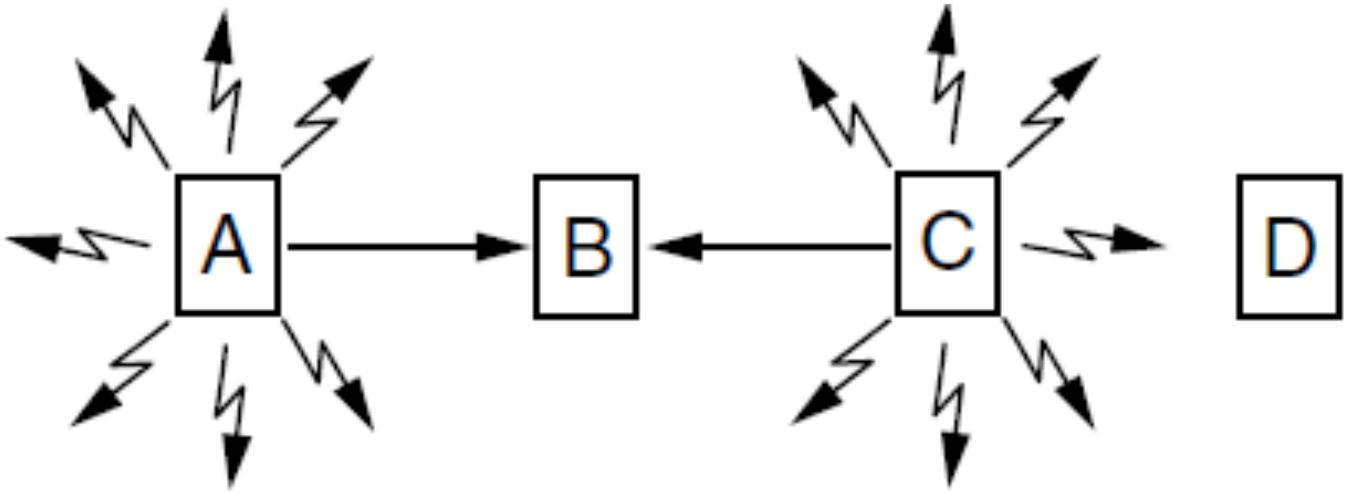
No CS: Different Coverage Areas

- Wireless signal is broadcast and received nearby, where there is sufficient SNR



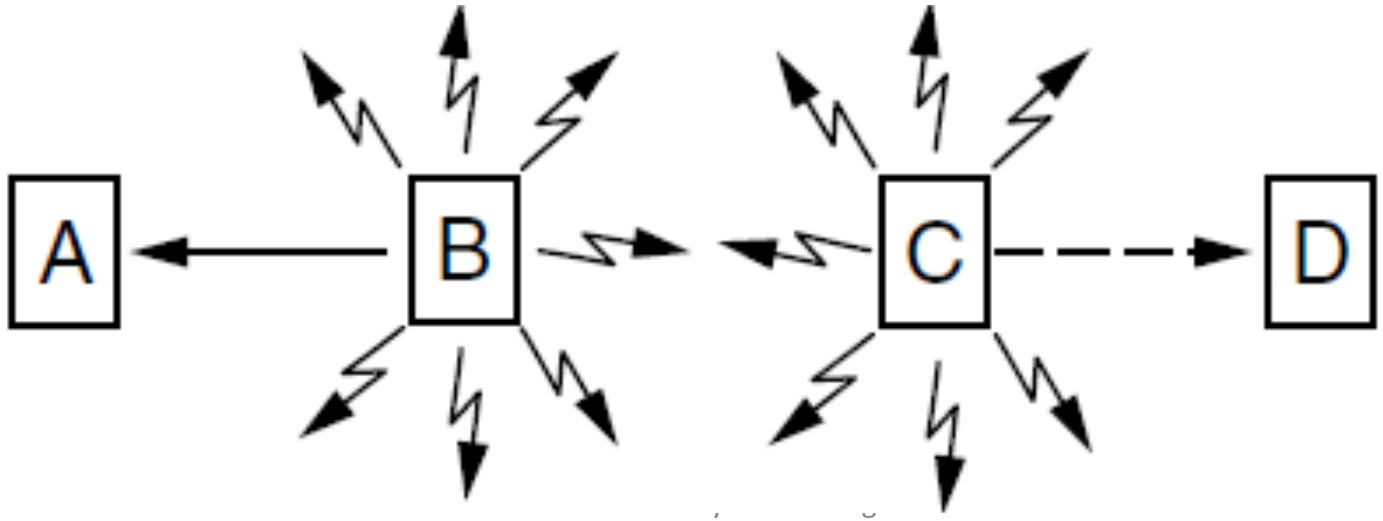
No CS: Hidden Terminals

- Node C is a hidden terminal when A sends to B
  - Similarly, A is a hidden terminal when C sends to B
  - A, C can't hear each other (to coordinate) yet collide at B
  - We want to avoid the inefficiency of collisions



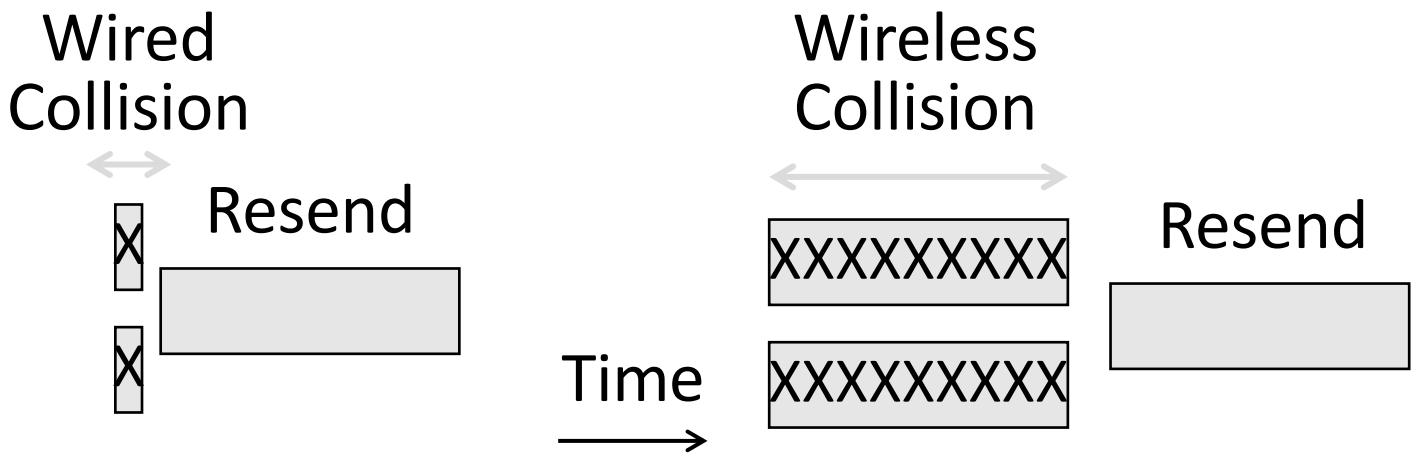
No CS: Exposed Terminals

- B, C are exposed terminals when sending to A, D
  - Can hear each other yet don't collide at receivers A and D
  - We want to send concurrently to increase performance



Nodes Can't Hear While Sending

- With wires, detecting collisions (and aborting) lowers their cost
- With wireless, more wasted time



Wireless Problems:

- Ideas?

MACA: Multiple Access w/ Collision Avoidance

- MACA uses a short handshake instead of CSMA (Karn, 1990)
  - 802.11 uses a refinement of MACA (later)

- Protocol rules:
  1. A sender node transmits a RTS (Request-To-Send, with frame length)
  2. The receiver replies with a CTS (Clear-To-Send, with frame length)
  3. Sender transmits the frame while nodes hearing the CTS stay silent

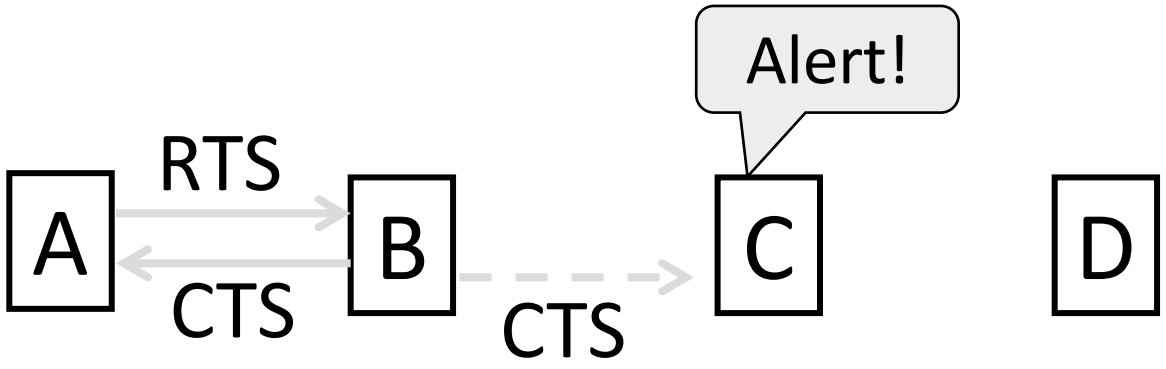
- Collisions on the RTS/CTS are still possible, but less likely

MACA – Hidden Terminals

- A→B with hidden terminal C
  1. A sends RTS, to B

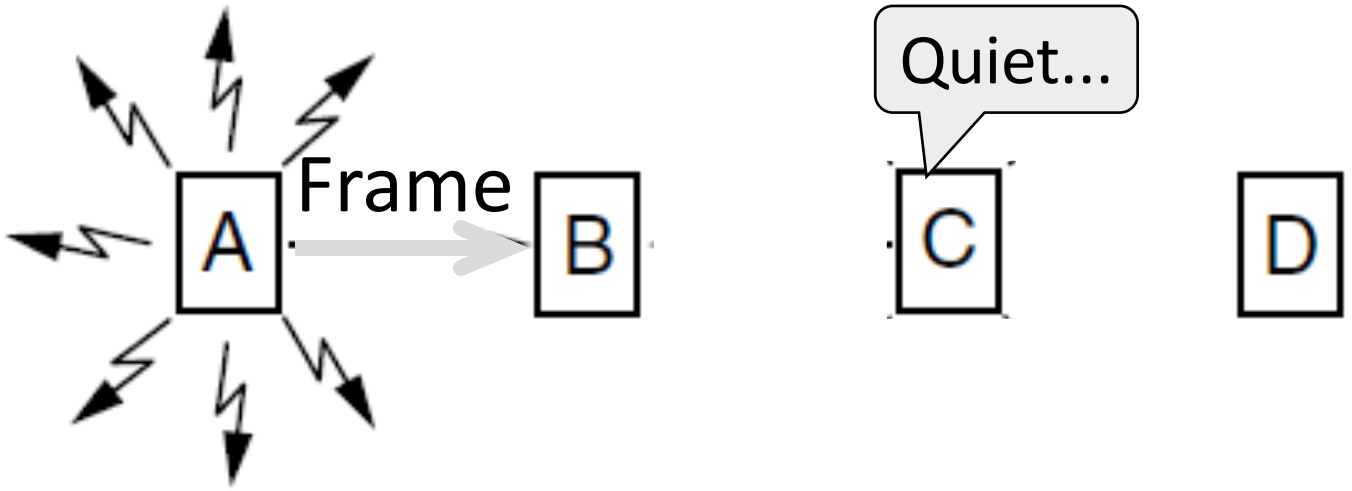
MACA – Hidden Terminals (2)

- A→B with hidden terminal C
  2. B sends CTS to A, and C overhears



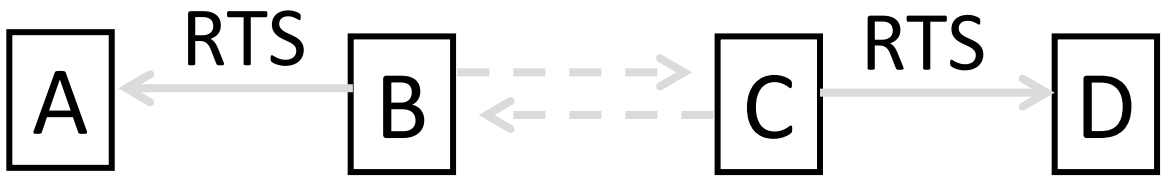
MACA – Hidden Terminals (3)

- A→B with hidden terminal C
  3. A sends frame while C defers



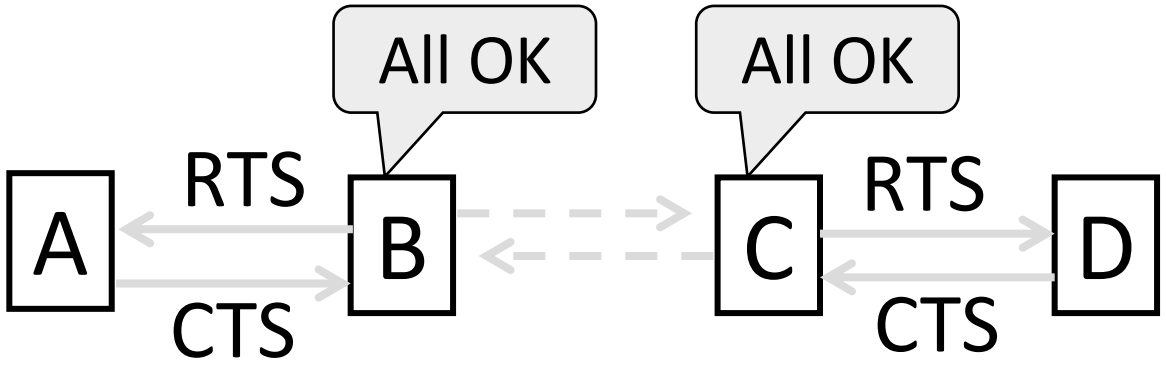
MACA – Exposed Terminals

- B→A, C→D as exposed terminals
  - B and C send RTS to A and D



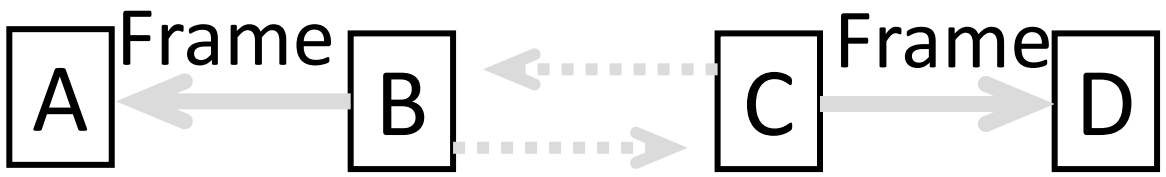
MACA – Exposed Terminals (2)

- B→A, C→D as exposed terminals
  - A and D send CTS to B and C



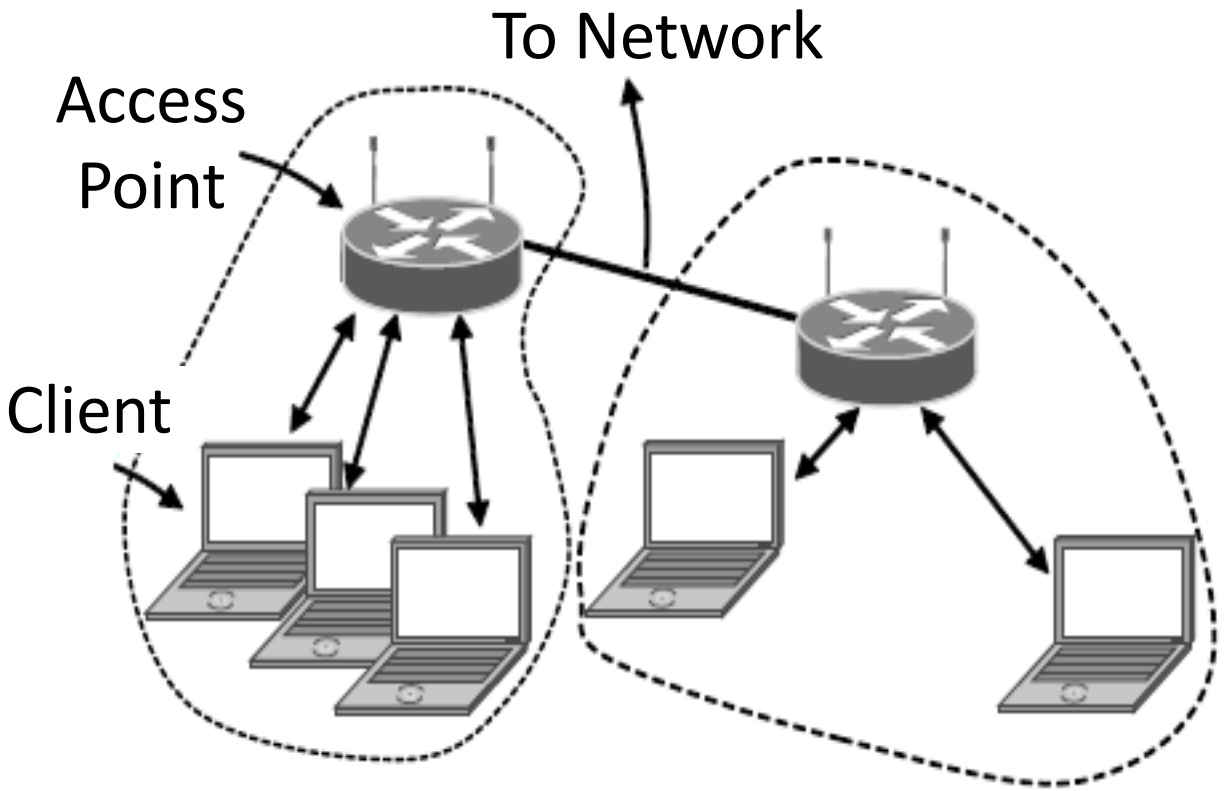
MACA – Exposed Terminals (3)

- B→A, C→D as exposed terminals
  - A and D send CTS to B and C



802.11, or WiFi

- Very popular wireless LAN started in the 1990s
- Clients get connectivity from a (wired) AP (Access Point)
- It's a multi-access problem ☺
- Various flavors have been developed over time
  - Faster, more features

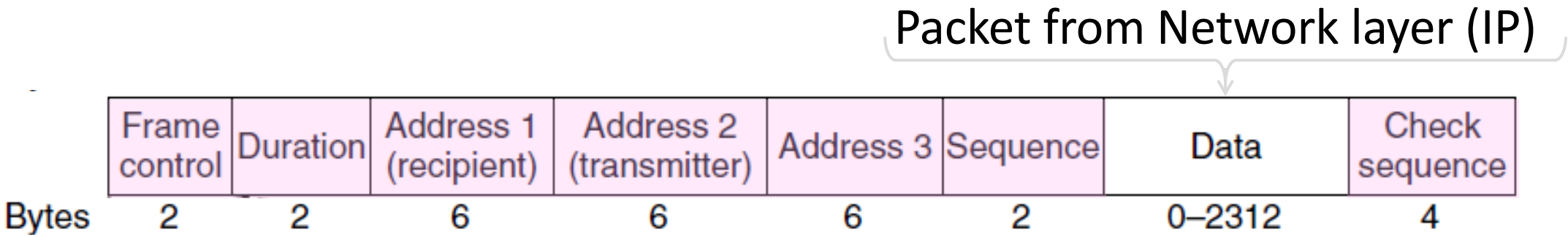


802.11 Physical Layer

- Uses 20/40 MHz channels on ISM (unlicensed) bands
  - 802.11b/g/n on 2.4 GHz
  - 802.11 a/n on 5 GHz
- OFDM modulation (except legacy 802.11b)
  - Different amplitudes/phases for varying SNRs
  - Rates from 6 to 54 Mbps plus error correction
  - 802.11n uses multiple antennas
    - Lots of fun tricks here

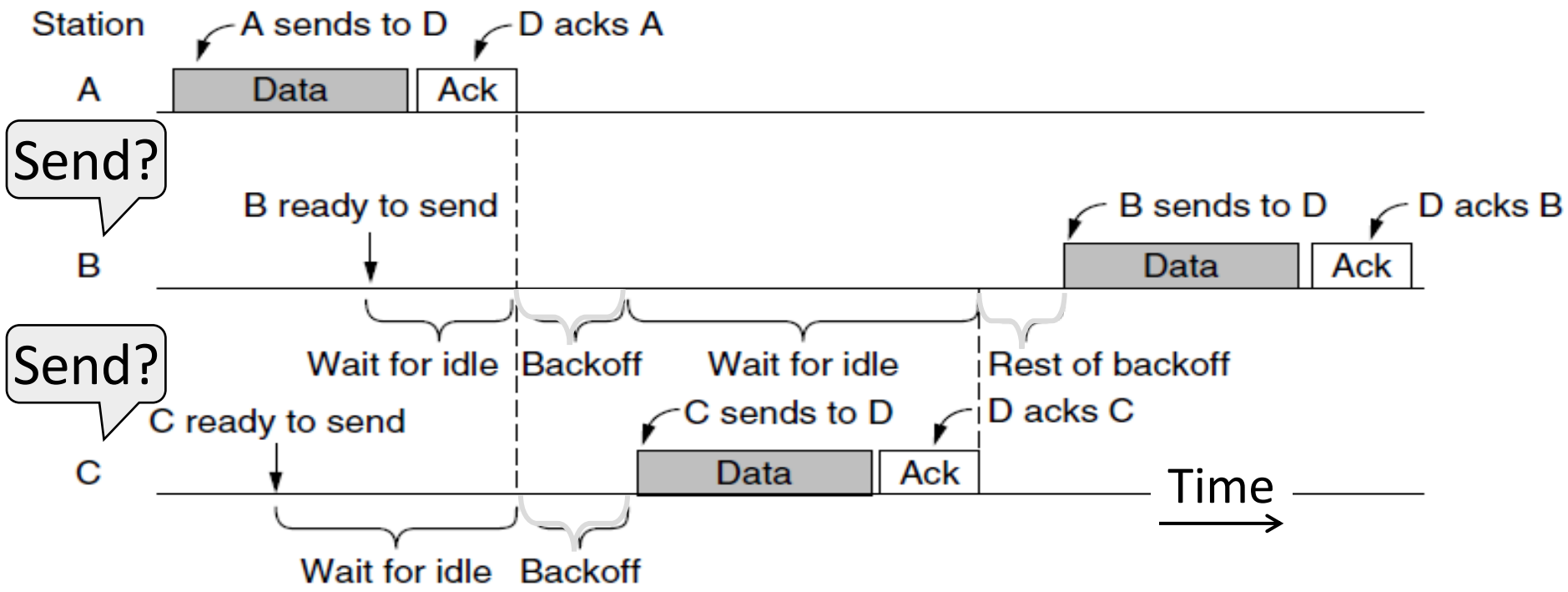
802.11 Link Layer

- Multiple access uses CSMA/CA (next); RTS/CTS optional
- Frames are ACKed and retransmitted with ARQ
- Funky addressing (three addresses!) due to AP
- Errors are detected with a 32-bit CRC
- Many, many features (e.g., encryption, power save)



802.11 CSMA/CA for Multiple Access

- Still using BEB!



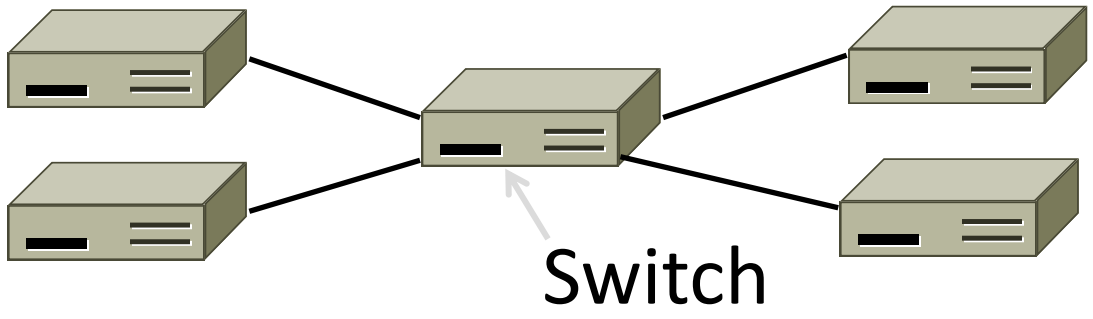
Recap: MAC layer ideas

- Random wait times upon collisions
- Carrier sense
  - Persistence
- Collision detection
- Binary exponential backoff
- RTS-CTS for hidden and exposed terminals

Link Layer: Switching

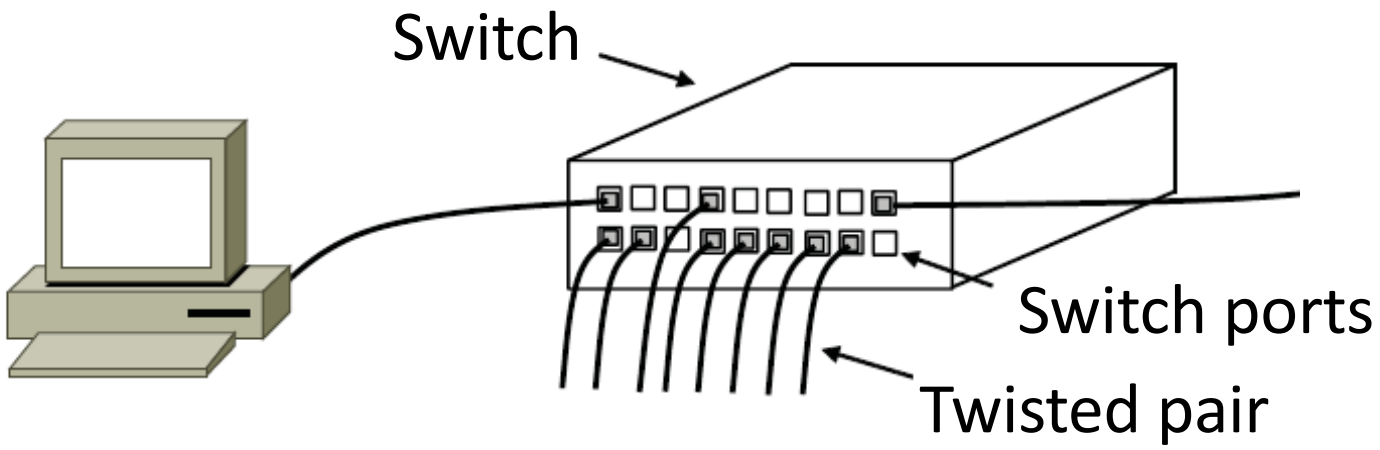
Switching

- How do we connect nodes with a switch instead of multiple access
  - Uses multiple links/wires
  - Basis of modern (switched) Ethernet



Switched Ethernet

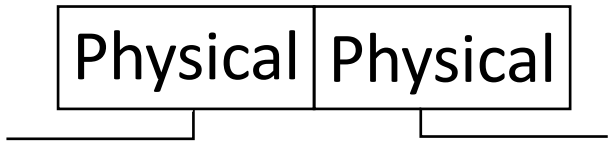
- Hosts are wired to Ethernet switches with twisted pair
  - Switch serves to connect the hosts
  - Wires usually run to a closet



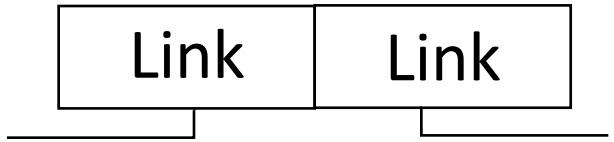
What's in the box?

- Remember from protocol layers:

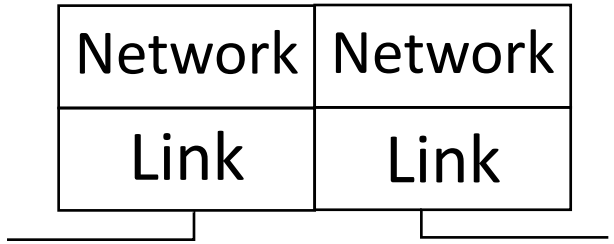
Hub, or repeater



Switch



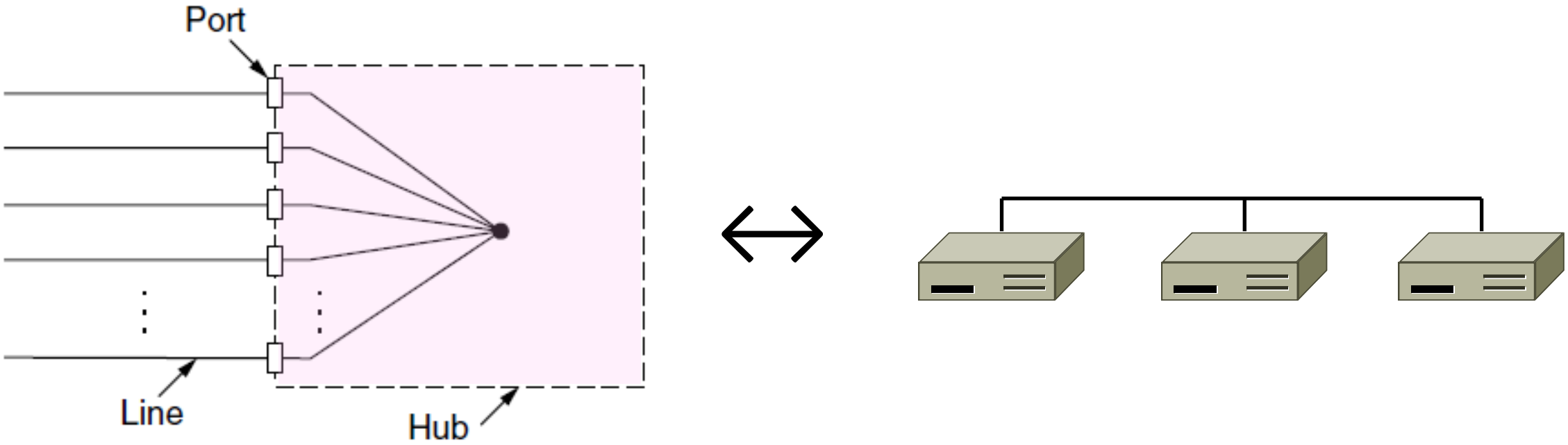
Router



All look like this:

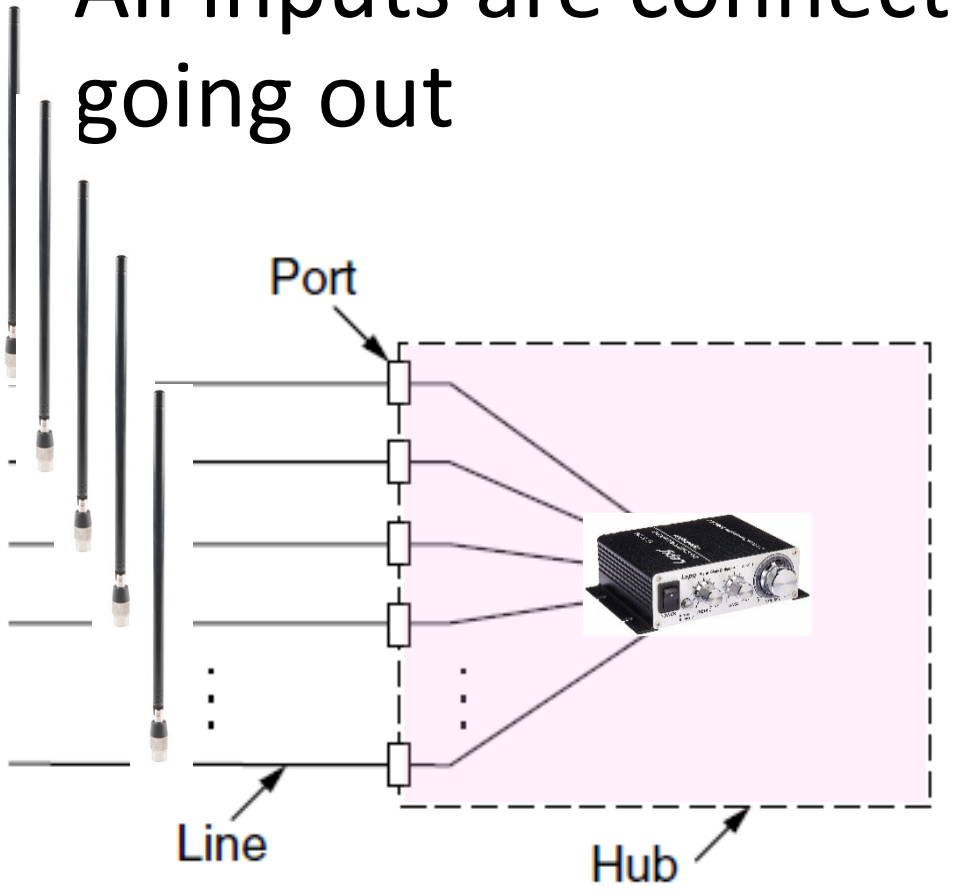
Inside a Hub

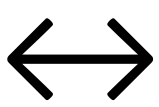
- All ports are wired together; more convenient and reliable than a single shared wire

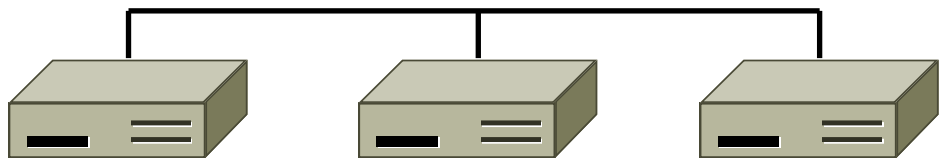


Inside a Repeater

- All inputs are connected; then amplified before going out

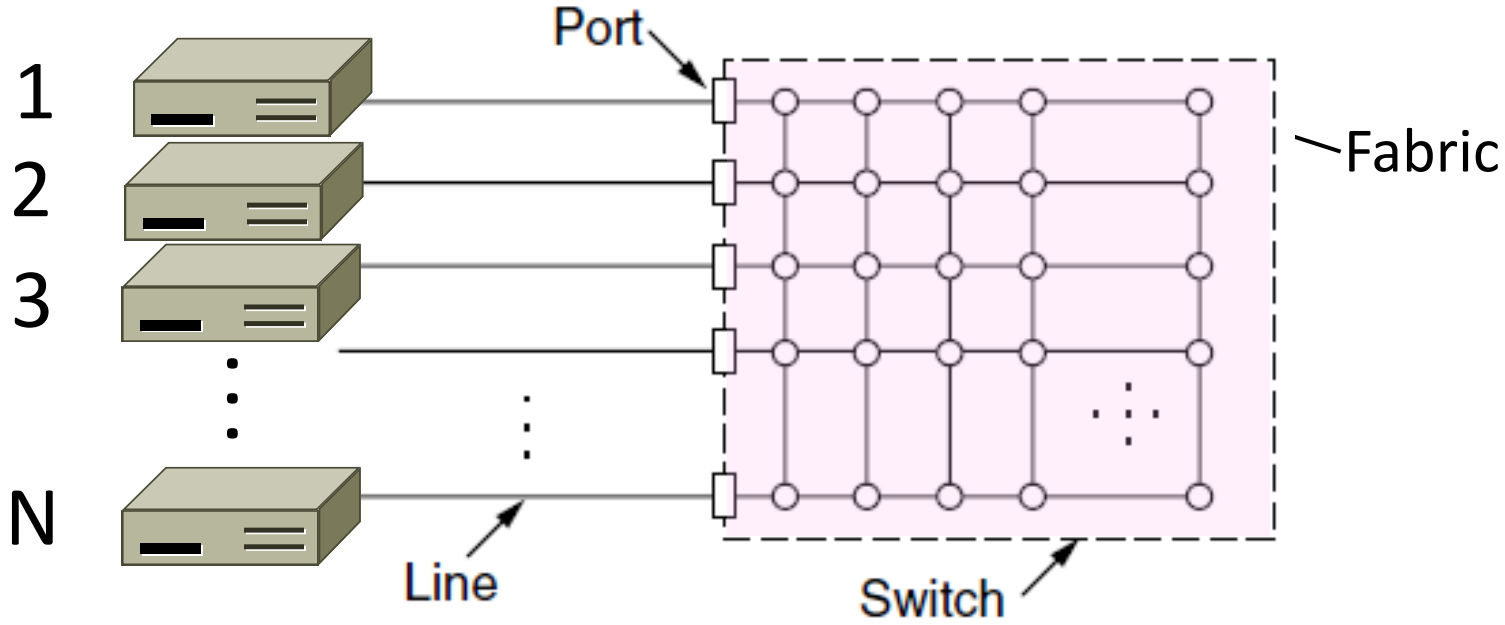






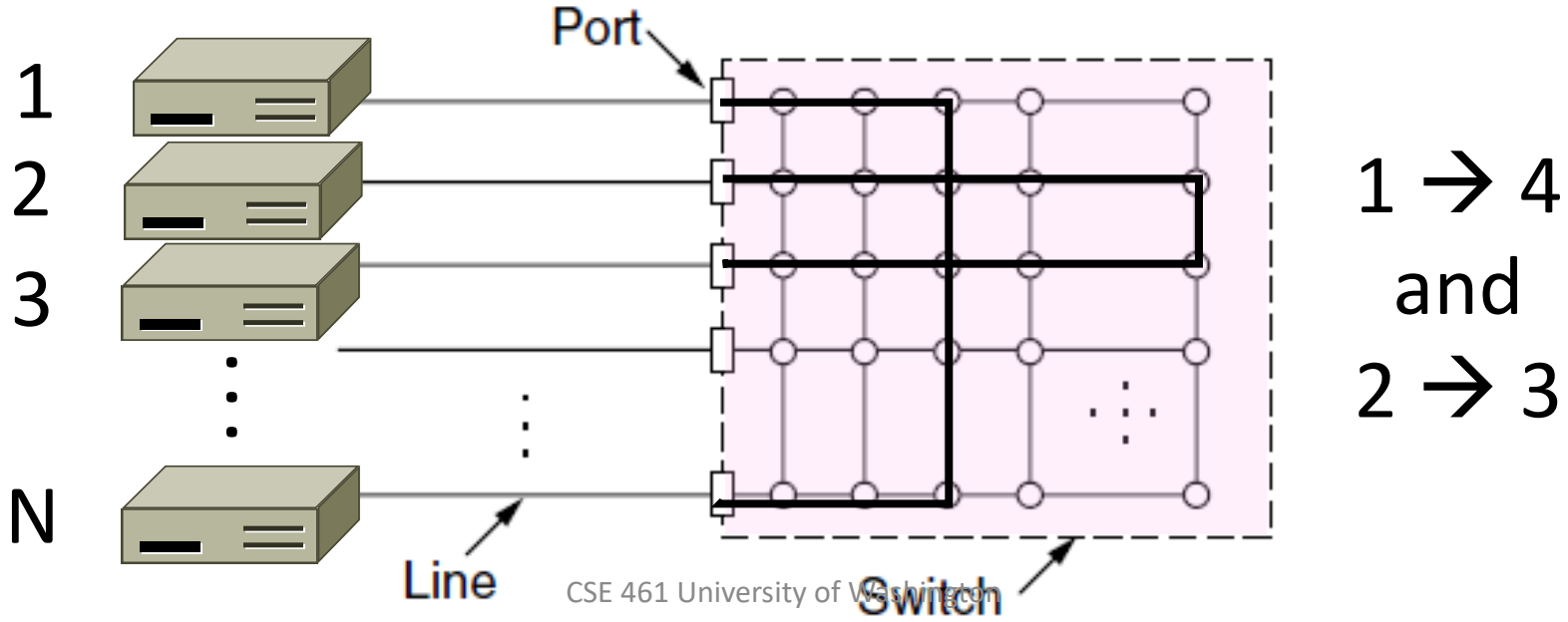
Inside a Switch

- Uses frame addresses (MAC addresses in Ethernet) to connect input port to the right output port; multiple frames may be switched in parallel



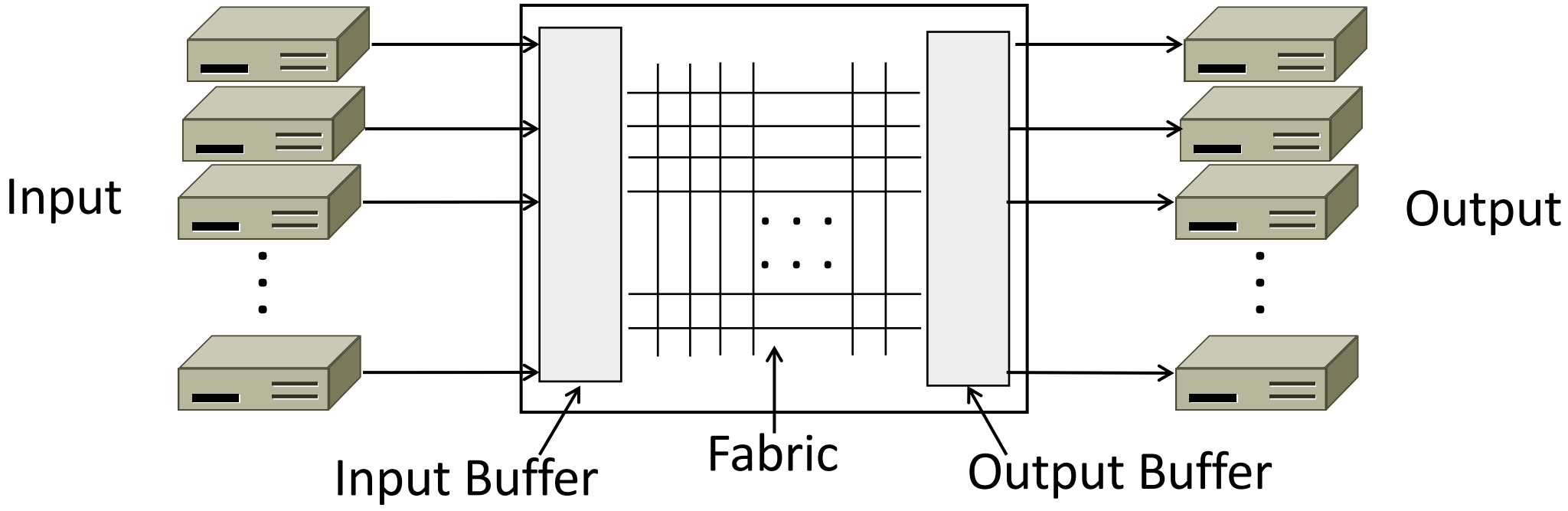
Inside a Switch (2)

- Port may be used for both input and output (full-duplex)
  - Just send, no multiple access protocol



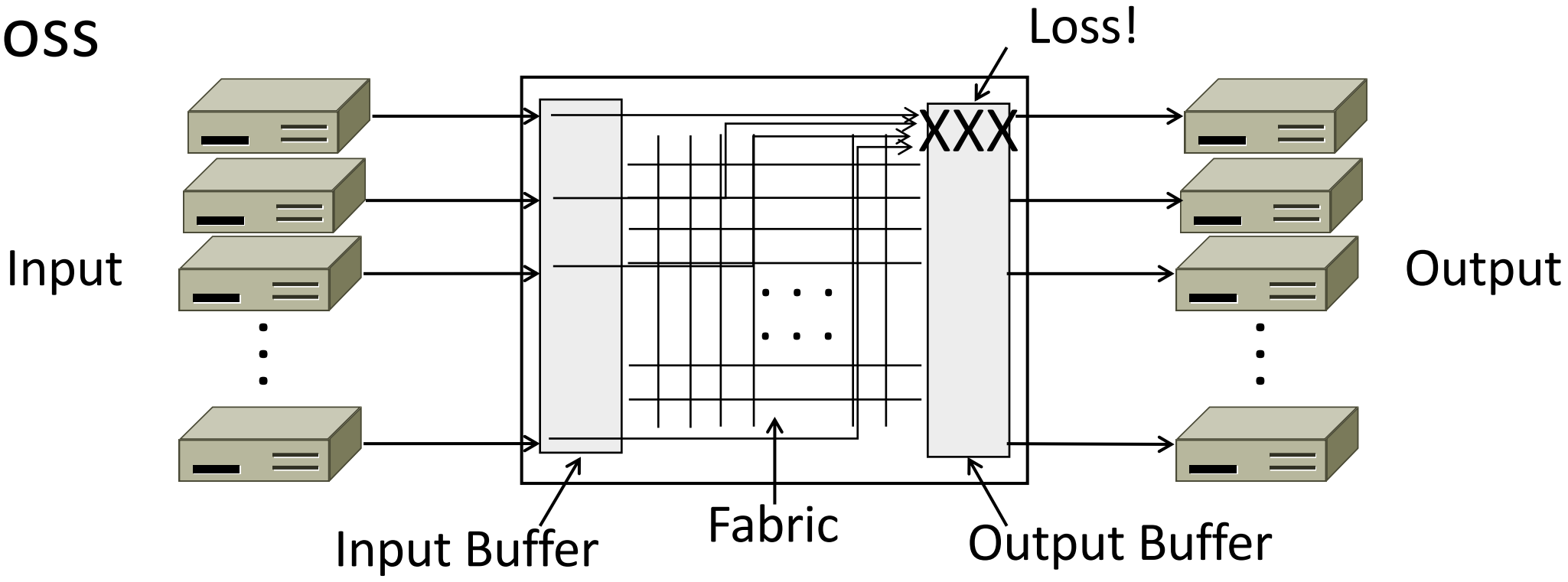
Inside a Switch (3)

- Need buffers for multiple inputs to send to one output



Inside a Switch (4)

- Sustained overload will fill buffer and lead to frame loss



Advantages of Switches

- Switches and hubs (mostly switches) have replaced the shared cable of classic Ethernet
  - Convenient to run wires to one location
  - More reliable; wire cut is not a single point of failure that is hard to find
- Switches offer scalable performance
  - E.g., 100 Mbps per port instead of 100 Mbps for all nodes of shared cable / hub