CSE160: Computer Networks

Lecture #05 – Multiplexing and Randomized Access

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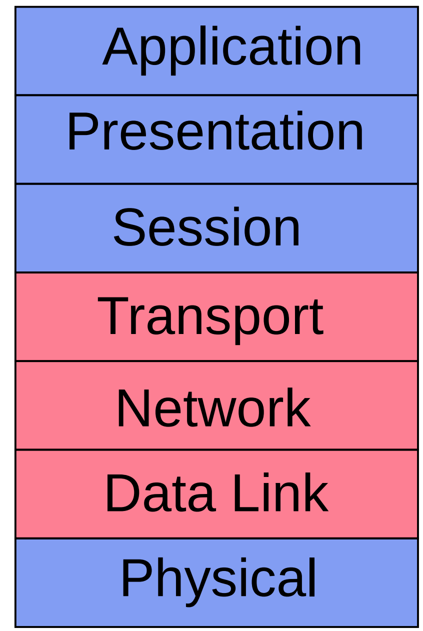
Last Time …

- Framing allows us to send full messages instead of bits
- Redundant bits are added to messages to protect against transmission errors
- Two recovery strategies are retransmissions (ARQ) and error correcting codes (FEC)
- The Hamming distance tells us how much error can safely be tolerated
- The optimal recovery strategy depends on the error expected in the channel and the app requirements



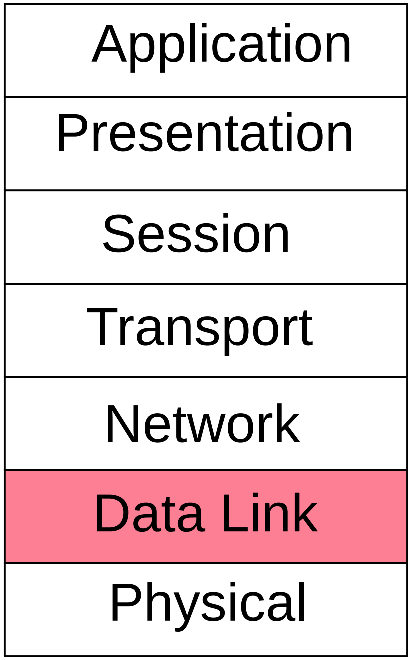
This Lecture

- Key Focus: How do multiple parties share a wire? We explore static and statistical multiplexing schemes

- This is the Medium Access Control (MAC) portion of the Link Layer

- Static Partitioning:
  1. TDM
  2. FDM

- Randomized access protocols:
  1. Aloha
  2. CSMA variants
  3. Classic Ethernet



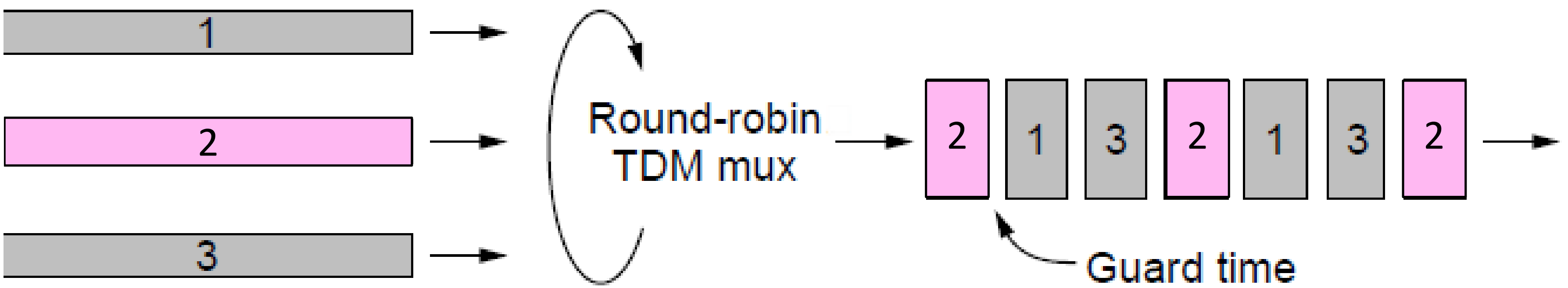
Multiplexing

- Multiplexing is the network word for the sharing of a resource

- Classic scenario is sharing a link among different users
  - Time Division Multiplexing (TDM)
  - Frequency Division Multiplexing (FDM)

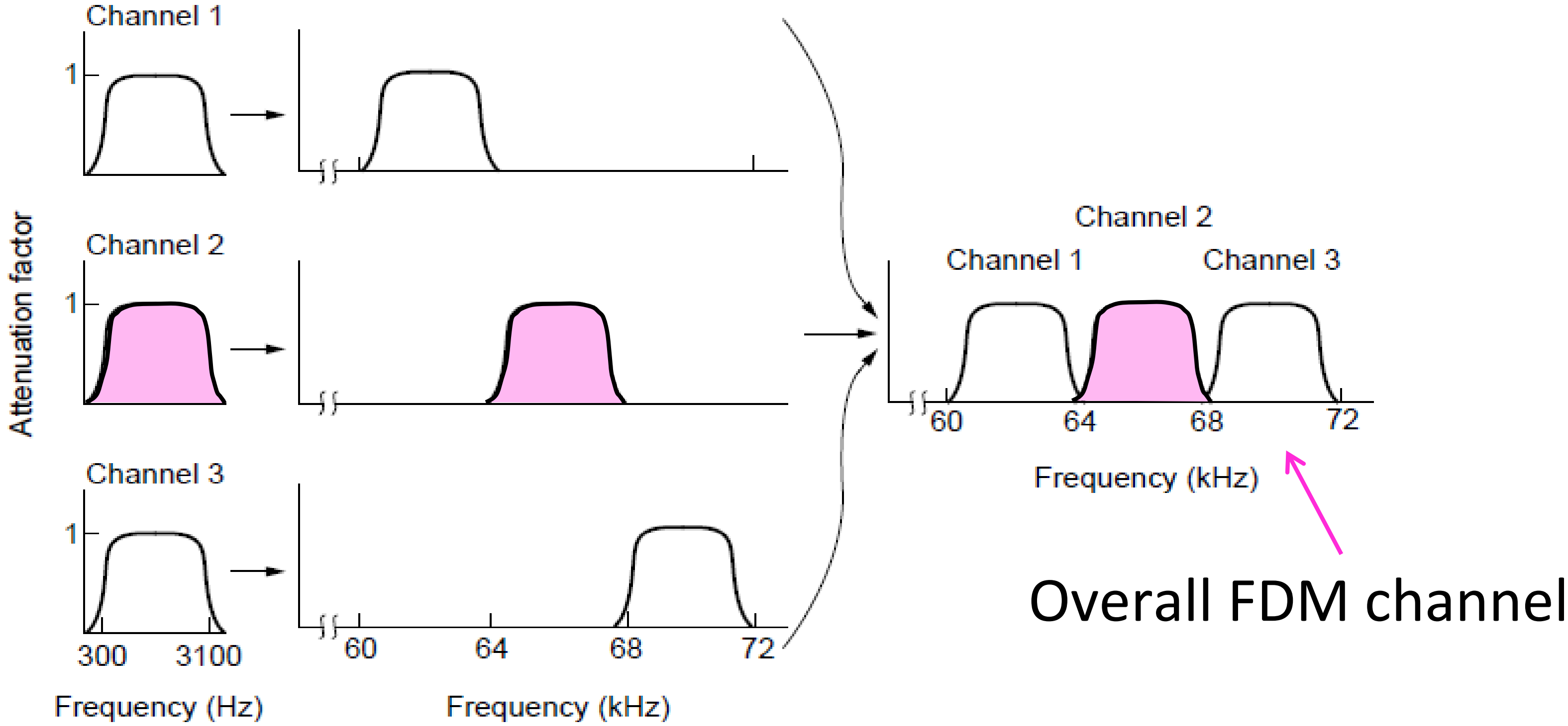
Time Division Multiplexing (TDM)

- Users take turns on a fixed schedule



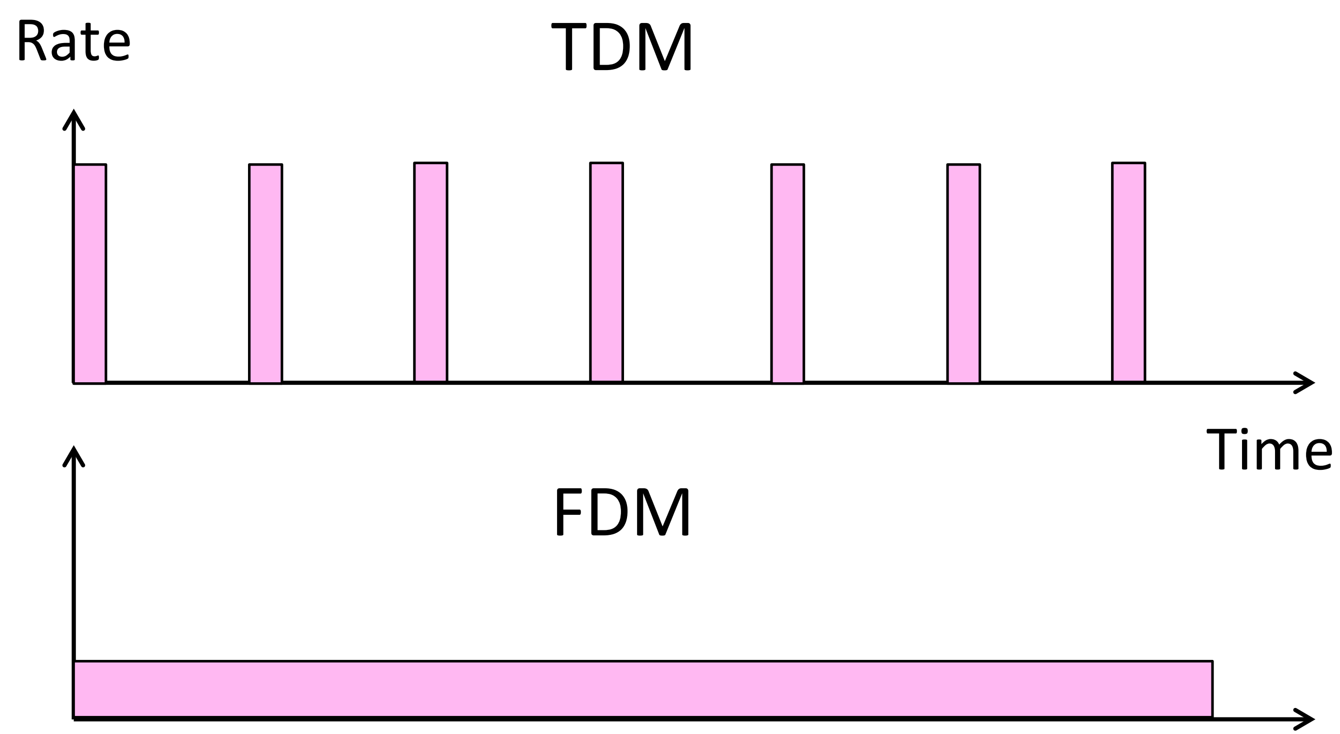
Frequency Division Multiplexing (FDM)

- Put different users on different frequency bands



TDM vs FDM

- In TDM, a user sends at a high rate a fraction of the time; in FDM, a user sends at a low rate all the time

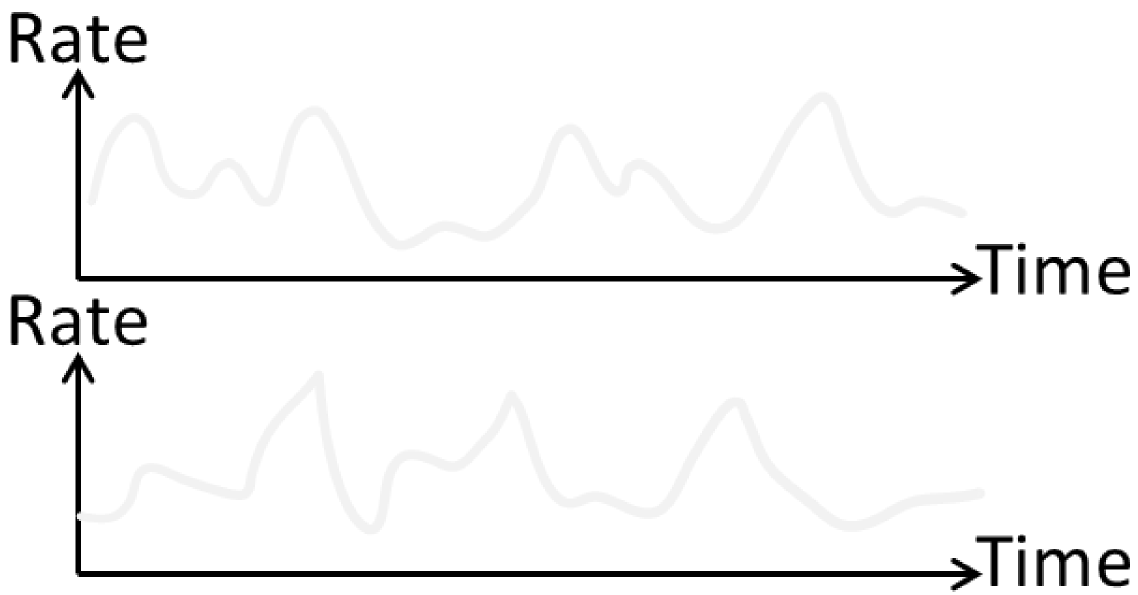


TDM/FDM Usage

- Statically divide a resource
  – Suited for continuous traffic, fixed number of users
- Widely used in telecommunications
  – TV (NTSC subcarrier freq. for video, color, and audio)
  – Stereo FM radio stations (FDM)
  – AN/UCC-4 (FDMA used by US Air Force to carry voice to DoD)
  – Long-distance voice used the L-Carrier (FDM)
  – PCM (digital transmission of phone calls over four-wire copper cables)
  – GSM (2G cellular) allocates calls using TDM within FDM
  – Synchronous Digital Hierarchy (SDH) over SONET

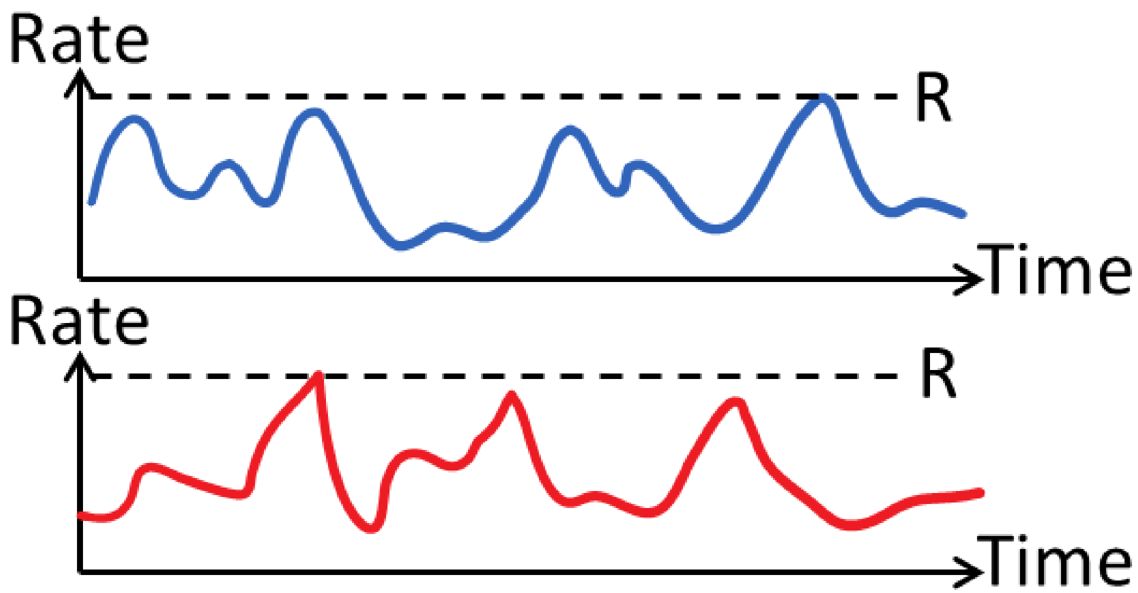
Multiplexing Network Traffic

- Network traffic is <u>bursty</u>
  - ON/OFF sources
  - Load varies greatly over time



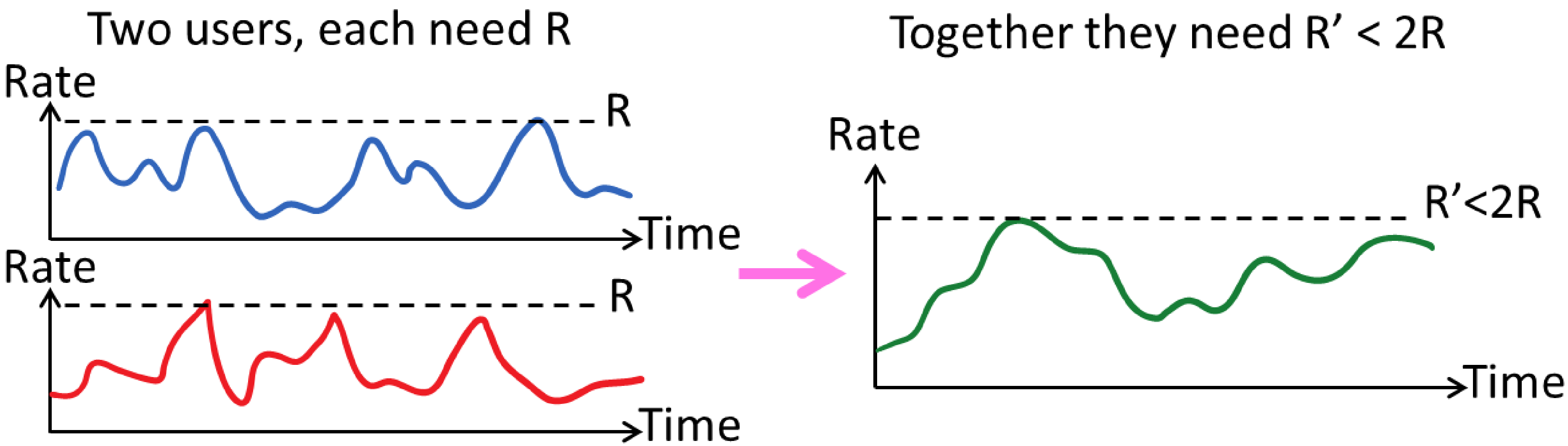
Multiplexing Network Traffic (2)

- Network traffic is <u>bursty</u>
  - Inefficient to always allocate user their ON needs with TDM/FDM



Multiplexing Network Traffic (2)

- <u>Multiple access</u> schemes multiplex users according to their demands – for gains of statistical multiplexing



Multiple Access

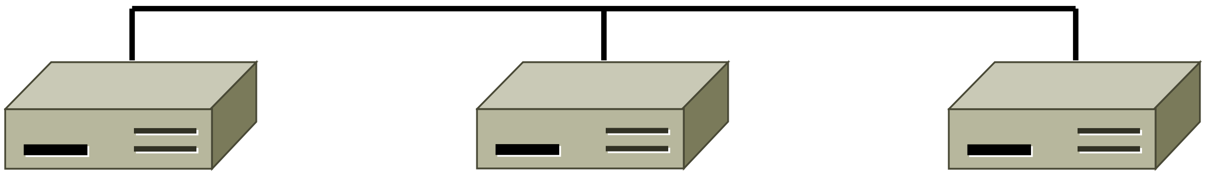
- We will look at two kinds of multiple access protocols

1. Randomized. Nodes randomize their resource access attempts
   - Good for low load situations

2. Contention-free. Nodes order their resource access attempts
   - Good for high load or guaranteed quality of service situations

Randomized Access

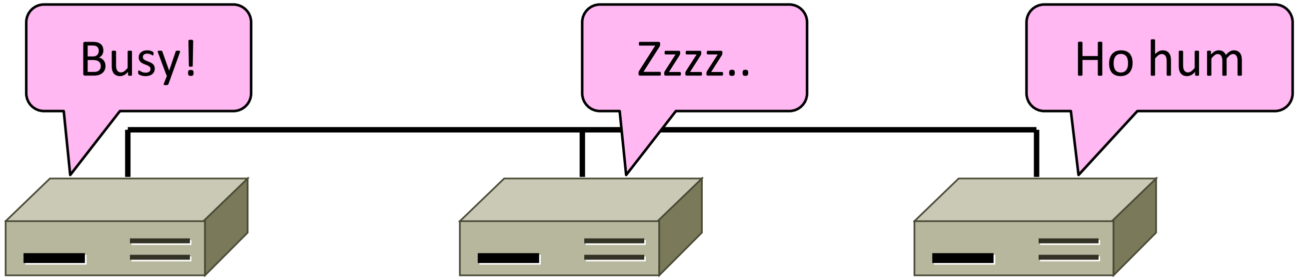
- How do nodes share a single link? Who sends when, e.g., in WiFi?
  - Explore with a simple model



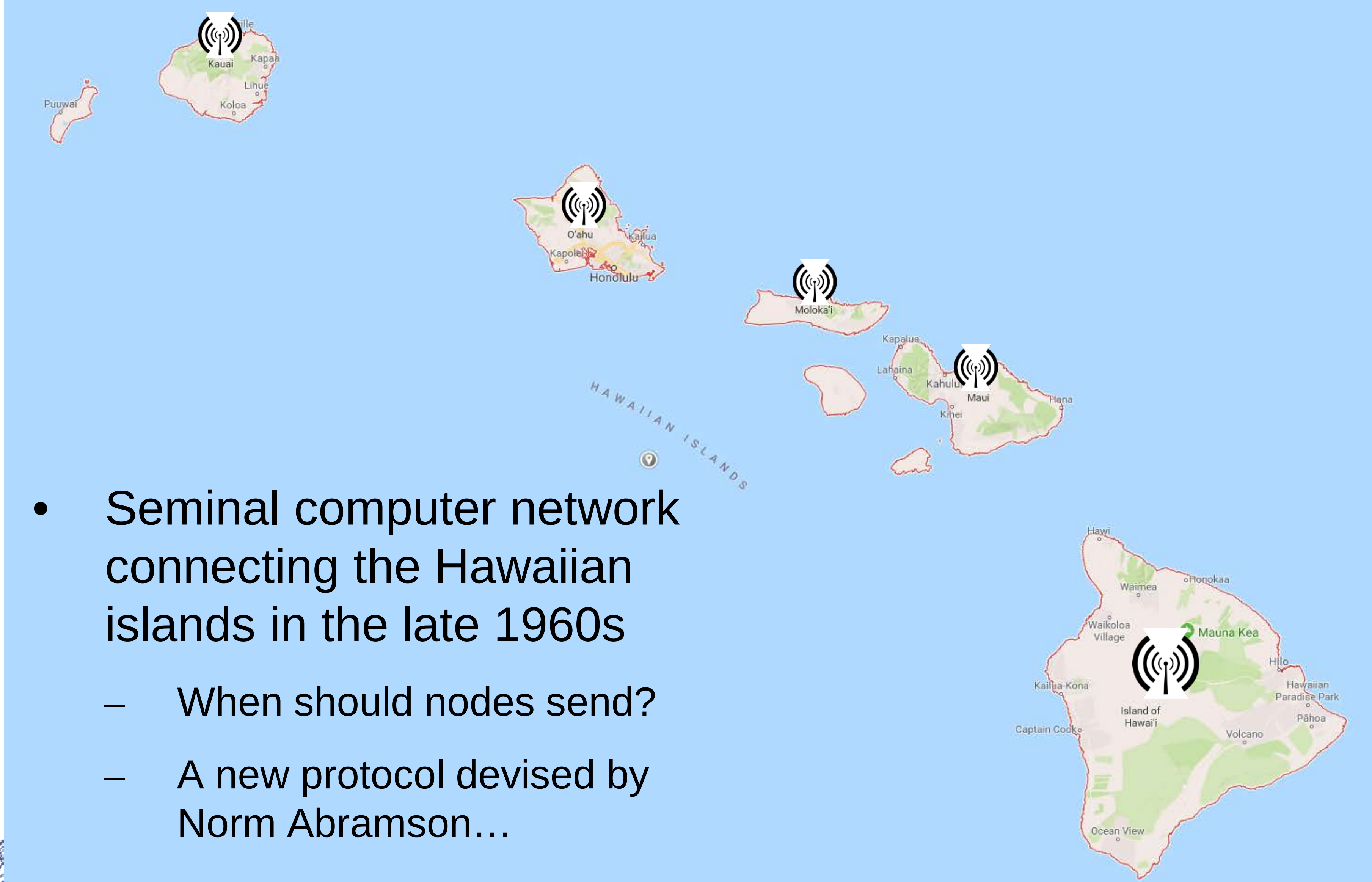
- Assume no-one is in charge; this is a distributed system

Randomized Access (2)

- We will explore random multiple access control (MAC) protocols
  - This is the basis for classic Ethernet
  - Remember: data traffic is bursty



Hawaii Time-Sharing Computer Problem



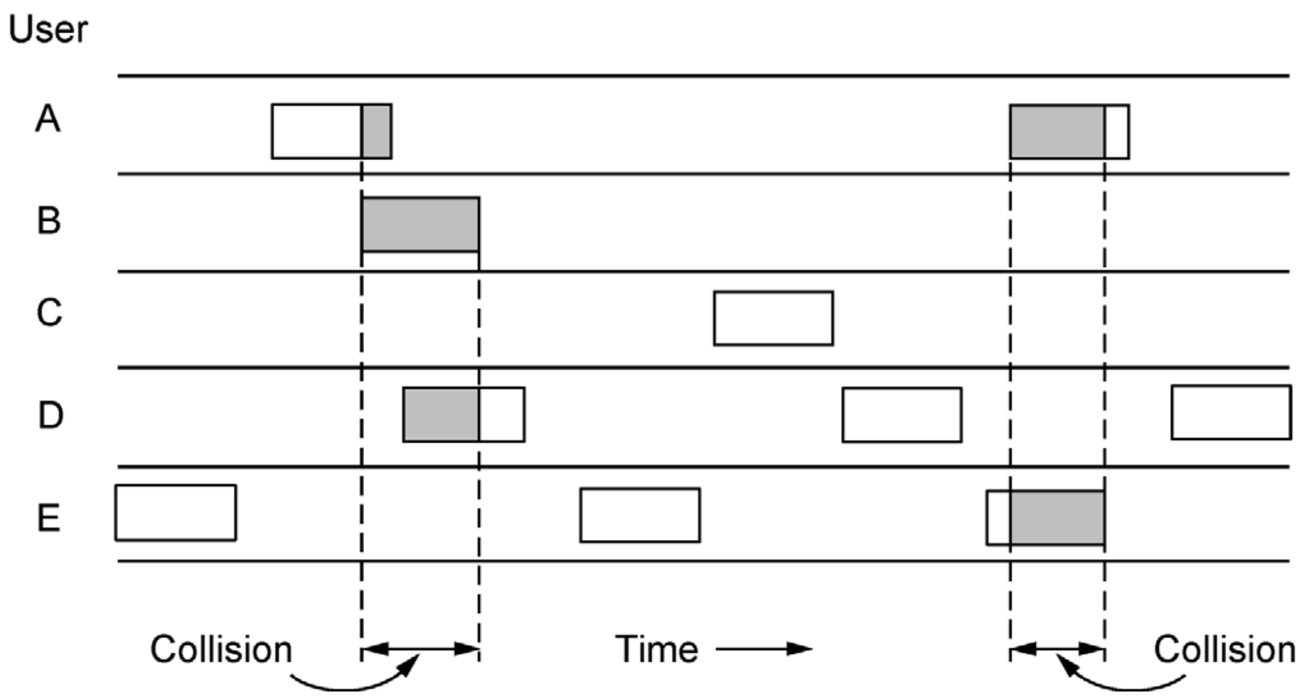
- Seminal computer network connecting the Hawaiian islands in the late 1960s
  - When should nodes send?
  - A new protocol devised by Norm Abramson…

ALOHA

- Wireless links between the Hawaiian islands
- Want distributed allocation
  - no special channels, or single point of failure
- Aloha protocol:
  - Just send when you have data!
  - There will be some collisions of course …
  - If there was a collision (no ACK received), then wait a random time and resend
  - That's it!

ALOHA Protocol

- Some frames will be lost, but many may get through…



- Good idea?

ALOHA Protocol (2)

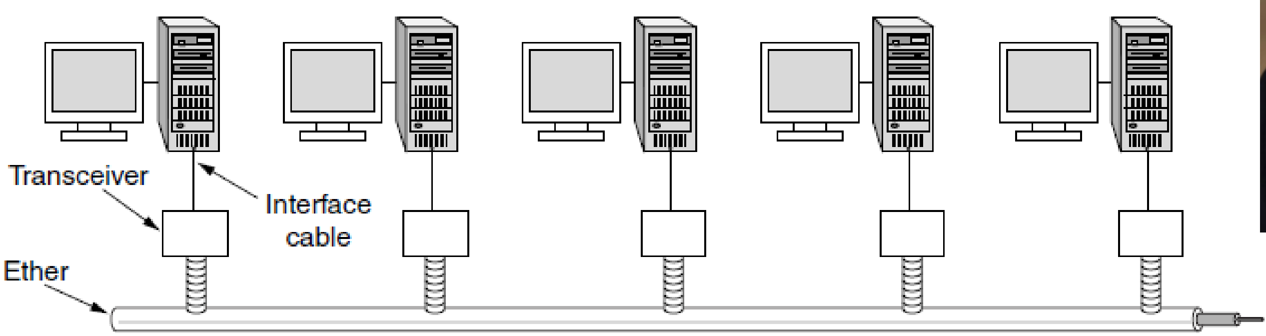
- Simple, decentralized and works well for low load!

- Not efficient under high load
  - Analysis shows at most 18% efficiency
  - Improvement: divide time into slots and efficiency goes up to 36% (called Slotted Aloha)

- We'll look at other improvements

Classic Ethernet

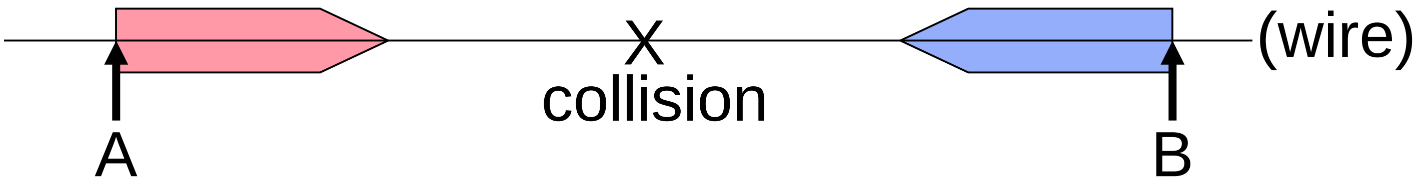
- ALOHA inspired Bob Metcalfe to invent Ethernet for LANs in 1973
  - Nodes share 10 Mbps coaxial cable
  - Hugely popular in the 1980s, 1990s



Source: IEEE © 2019

Carrier Sense Multiple Access (CSMA)

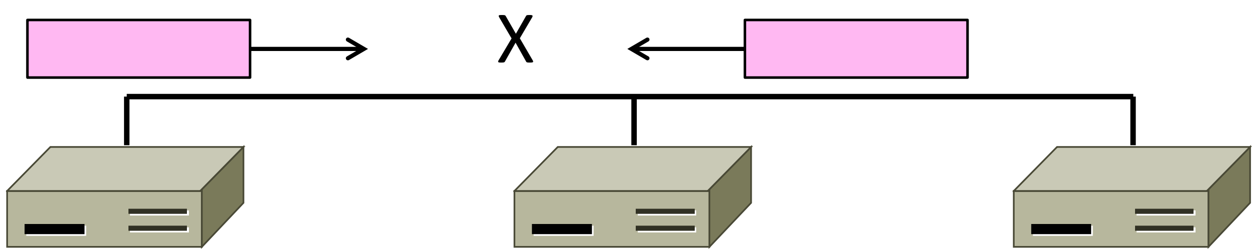
- Improve ALOHA by listening for activity before we send (Doh!) → CSMA
  - Can do easily with wires, not wireless



- Will this eliminate collisions completely?
  - Why or why not?

Carrier Sense Multiple Access (2)

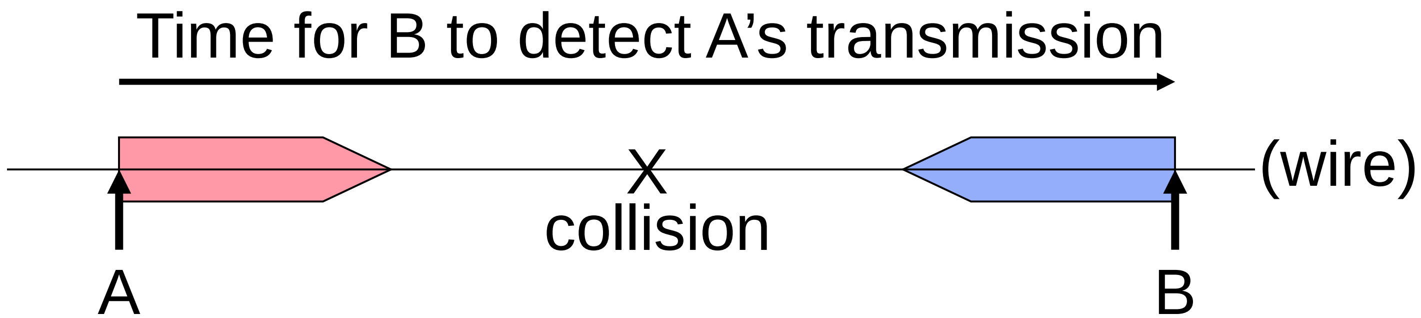
- Still possible to listen and hear nothing when another node is sending because of delay
- CSMA is a good defense against collisions only when BD (Bandwidth-Delay product) is small



- “a” parameter: number of frames that fit on the wire
  - a = bandwidth * delay / frame size
  - Small (<<1) for LANs, large (>>1) for satellites
  - good defense against collisions only if “a” is small (LANs)

CSMA with Collision Detection

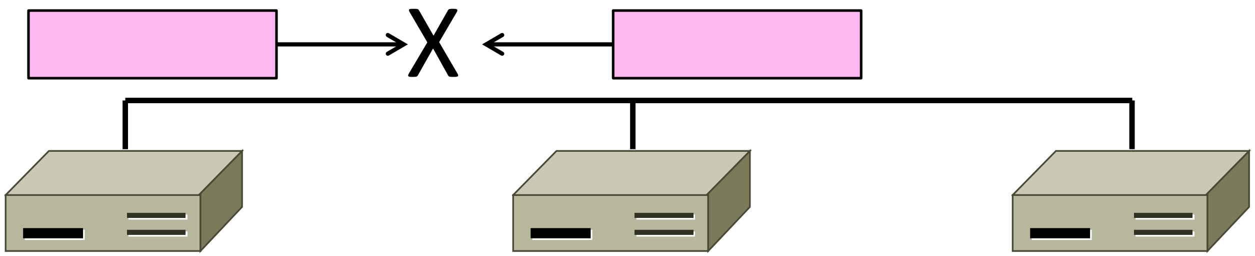
- Even with CSMA there can still be collisions. Why?



- For wired media we can detect all collisions and abort (CSMA/CD):
  - Requires a minimum frame size ("acquiring the medium")
  - B must continue sending ("jam") until A detects collision

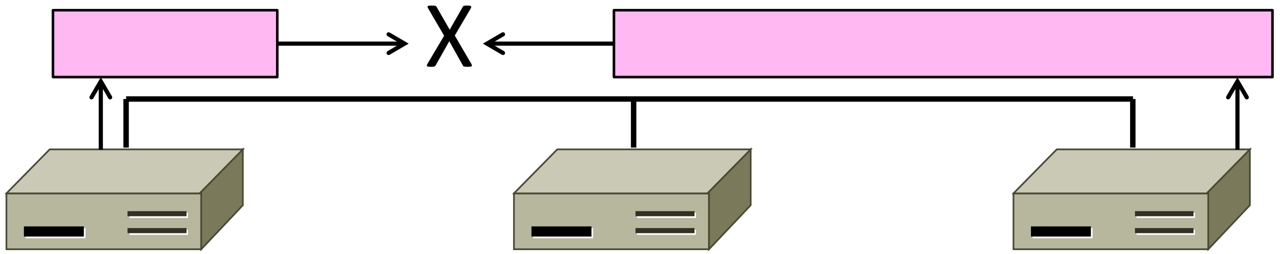
CSMA/CD Complications

- Want everyone who collides to know that it happened
  - Time window in which a node may hear a collision is 2D seconds



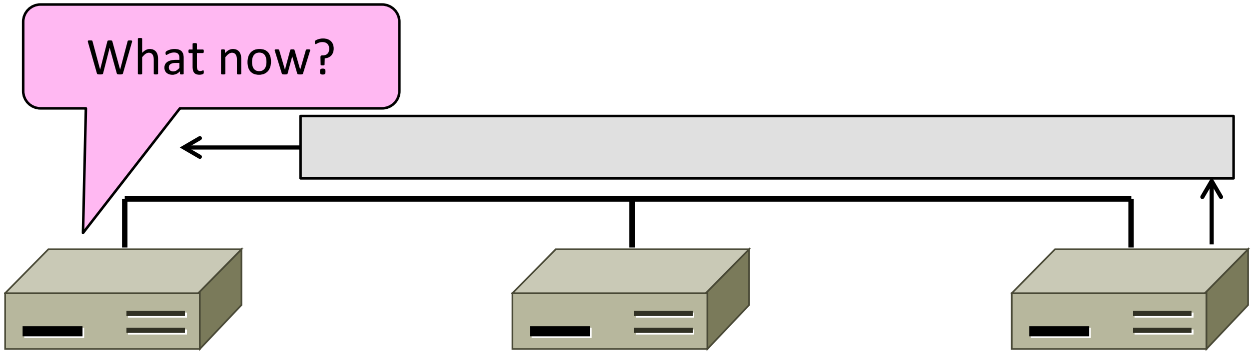
CSMA/CD Complications (2)

- Impose a minimum frame size that lasts for 2D seconds
  - So node can't finish before collision
  - Ethernet minimum frame is 64 bytes



CSMA "Persistence"

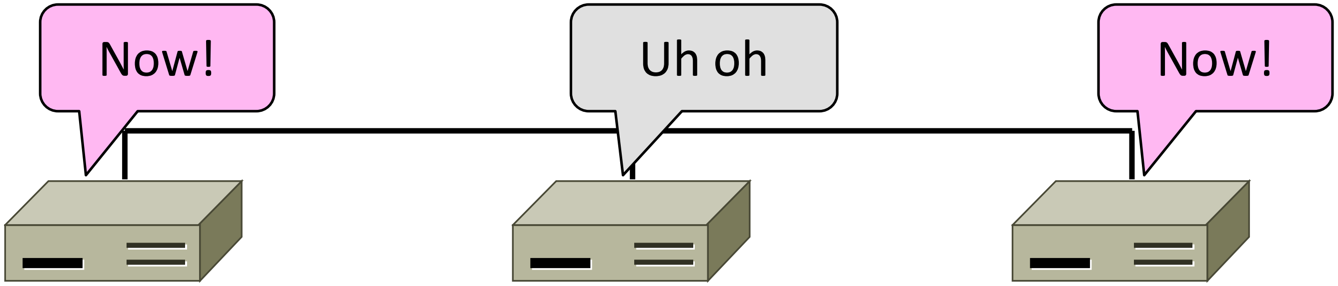
- What should a node do if another node is sending?



- Idea: Wait until it is done, and then send

CSMA "Persistence" (2)

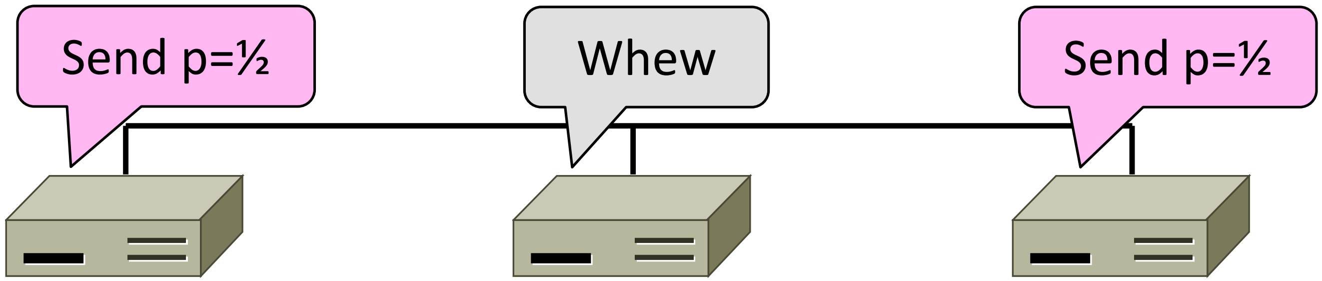
- Problem is that multiple waiting nodes will queue up then collide
  - More load, more of a problem



- Can we do any better?

CSMA "Persistence" (3)

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



  - The problem is that at any given time we don't know what N is!
  - What do we do?

What if the Channel is Busy?

- 1-persistent CSMA
  - Wait until idle then go for it
  - Blocked senders can queue up and collide
- non-persistent CSMA
  - Wait a random time and try again
  - Less greedy when loaded, but larger delay
- p-persistent CSMA
  - If idle send with prob p until done; assumed slotted time
  - Choose p so p * # senders < 1; avoids collisions at cost of delay

What happens with collisions?

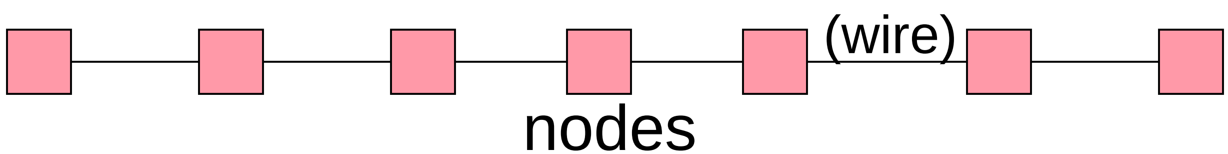
- Binary Exponential Backoff (BEB)
- Build on 1-persistent CSMA/CD
- On collision: jam and exponential backoff
  - Jamming: send 48 bit sequence to ensure collision detection
- Backoff:
  - First collision: wait 0 or 1 frame times at random and retry
  - Second time: wait 0, 1, 2, or 3 frame times
  - Nth time (N<=10): wait 0, 1, …, 2^N-1 times
  - Max wait 1023 frames, give up after 16 attempts
  - Scheme balances average wait with load

Binary Exponential Backoff (BEB)

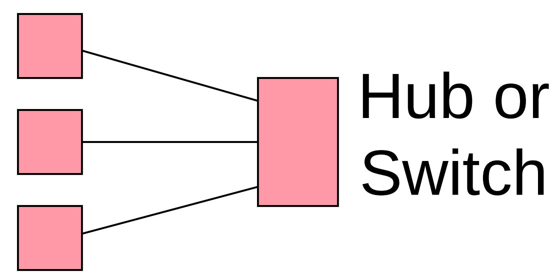
- BEB <u>doubles</u> interval for each successive collision
  - Quickly gets large enough to work
  - Very efficient in practice
  - It is able to adapt over a large operating range
  - Great scalability properties (small and large number of nodes)

3. Classic Ethernet

- IEEE 802.3 standard wired LAN (1-persistent CSMA/CD with BEB)
- Classic Ethernet: 10 Mbps over coaxial cable
  - baseband signals, Manchester encoding, preamble, 32 bit CRC



- Newer versions are much faster
  - Fast (100 Mbps), Gigabit (1 Gbps), 10Gbps to desktop coming…
- Modern equipment isn't one long wire
  - hubs and switches



Ethernet Frame Format

Preamble (8)	Dest (6)	Source (6)	Type (2)	Payload (var)	Pad (var)	CRC (4)

- Min frame 64 bytes, max 1500 bytes
- Max length 2.5km, max between stations 500m (physical repeaters)
- Addresses unique per adaptor; 6 bytes; globally assigned (the famous MAC address!)
- CRC-32 for error detection; no ACKs or retransmission
- Start of frame identified with physical layer preamble
- Broadcast media is readily tapped:
  - Promiscuous mode; multicast addresses

Ethernet Capture

- Randomized access scheme is not fair

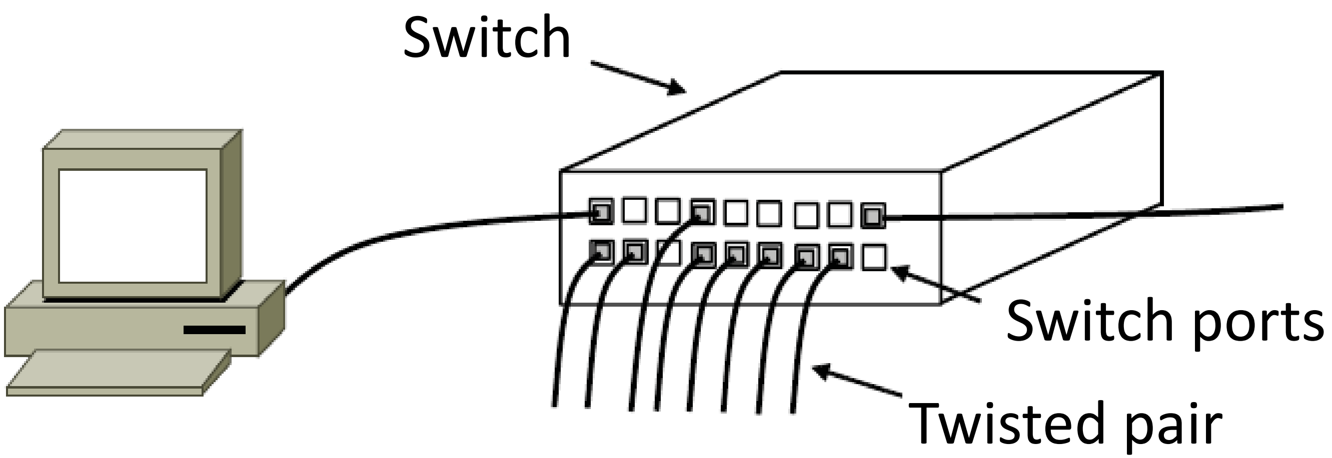
- Stations A and B always have data to send
  - They will collide at some time
  - Suppose A wins and sends, while B backs off
  - Next time they collide and B's chances of winning are halved!

Ethernet Performance

- Much better than Aloha or CSMA!
  - Works very well in practice
- Source of protocol inefficiency: collisions
  - More efficient to send larger frames
    - Acquire the medium and send lots of data
  - Less efficient as the network grows in terms of frames
    - recall “a” = delay * bandwidth / frame size
    - “a” grows as the path gets longer (satellite)
    - “a” grows as the bit rates increase (Fast, Gigabit Ethernet)

Modern Ethernet

- Based on switches, not multiple access, but still called Ethernet
  - We'll get to it later in the course



Ethernet Perspective

- Ethernet is wildly successful!
  - Simple yet effective
- What more could we want?
  - Deterministic service
  - Priorities
  - Scalable

Key Concepts

- TDM/FDM allows multiplexing multiple users in the same channel in a statically allocated way
- Ethernet (CSMA/CD): *randomness* can lead to an effective distributed means of sharing a channel
- Binary Exponential Backoff: elegant *distributed* mechanism to *adaptively* deal with congestion