Link Layer

(continued)

Topics

1. Framing
    - Delimiting start/end of frames
2. Error detection and correction
    - Handling errors
3. Retransmissions
    - Handling loss
4. Multiple Access
    - 802.11, classic Ethernet
5. Switching
    - Modern Ethernet

Retransmissions

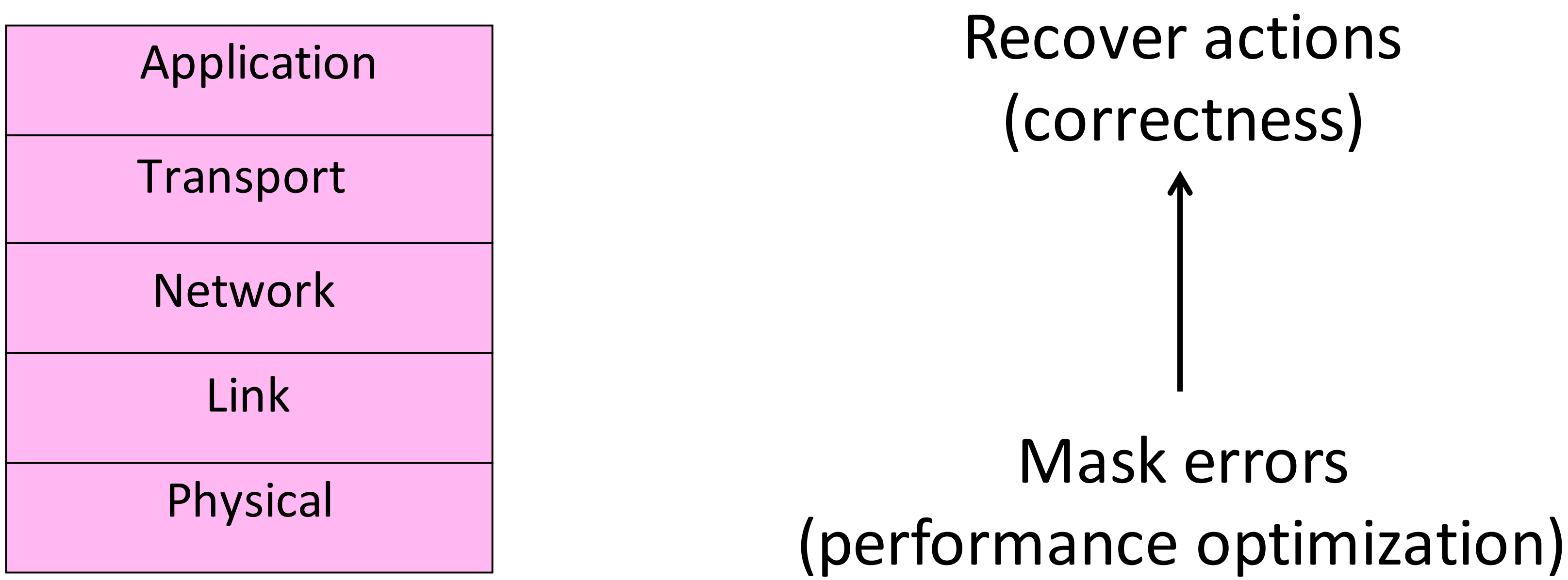
Context on Reliability

- Where in the stack should we place reliability functions?

Application
Transport
Network
Link
Physical

Context on Reliability

- Everywhere? It is a key issue
  - Different layers contribute differently



ARQ (Automatic Repeat reQuest)

- ARQ often used when errors are common or must be corrected
  - E.g., WiFi, and TCP
- Rules at sender and receiver:
  - Receiver automatically acknowledges correct frames with an ACK
  - Sender automatically resends after a timeout, until an ACK is received

So What's Tricky About ARQ?

- Two non-trivial issues:
  - How long to set the timeout?
  - How to avoid accepting duplicate frames as new frames
- Want performance in the common case and correctness always

Timeouts

- Timeout should be:
  - Not too big (link goes idle)
  - Not too small (spurious resend)
- Fairly easy on a LAN
  - Clear worst case, little variation
- Fairly difficult over the Internet
  - Much variation, no obvious bound
  - We'll revisit this with TCP (later)

Detecting Duplicates

- Frames and ACKs must both carry UIDs for correctness
- Sequence numbers are a handy form of UID that also allow receiver to detect missing frames
  - Useful for sliding window
- Do we need sliding window on a LAN?

Link Layer Retransmission Summary

- Should retranmissions occur at link layer
  - Depends on expected error rate
  - Think of them as a performance optimization (relative to just leaving it to TCP) when they're implemented
- Because latencies are typically small(ish) and tightly bounded on a single link
  - Timeout estimation is simpler
  - Less motivation to use sliding window, rather than stop-and-wait

Multiple Access

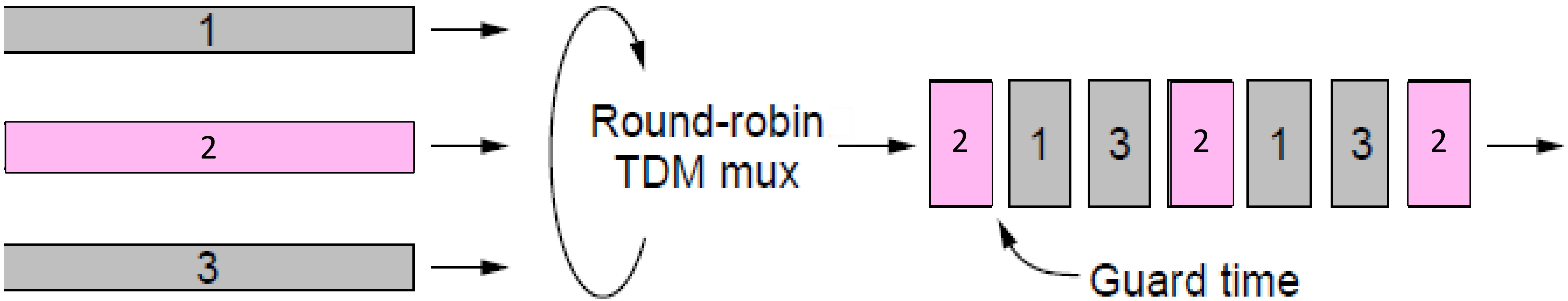
Topic

- 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)

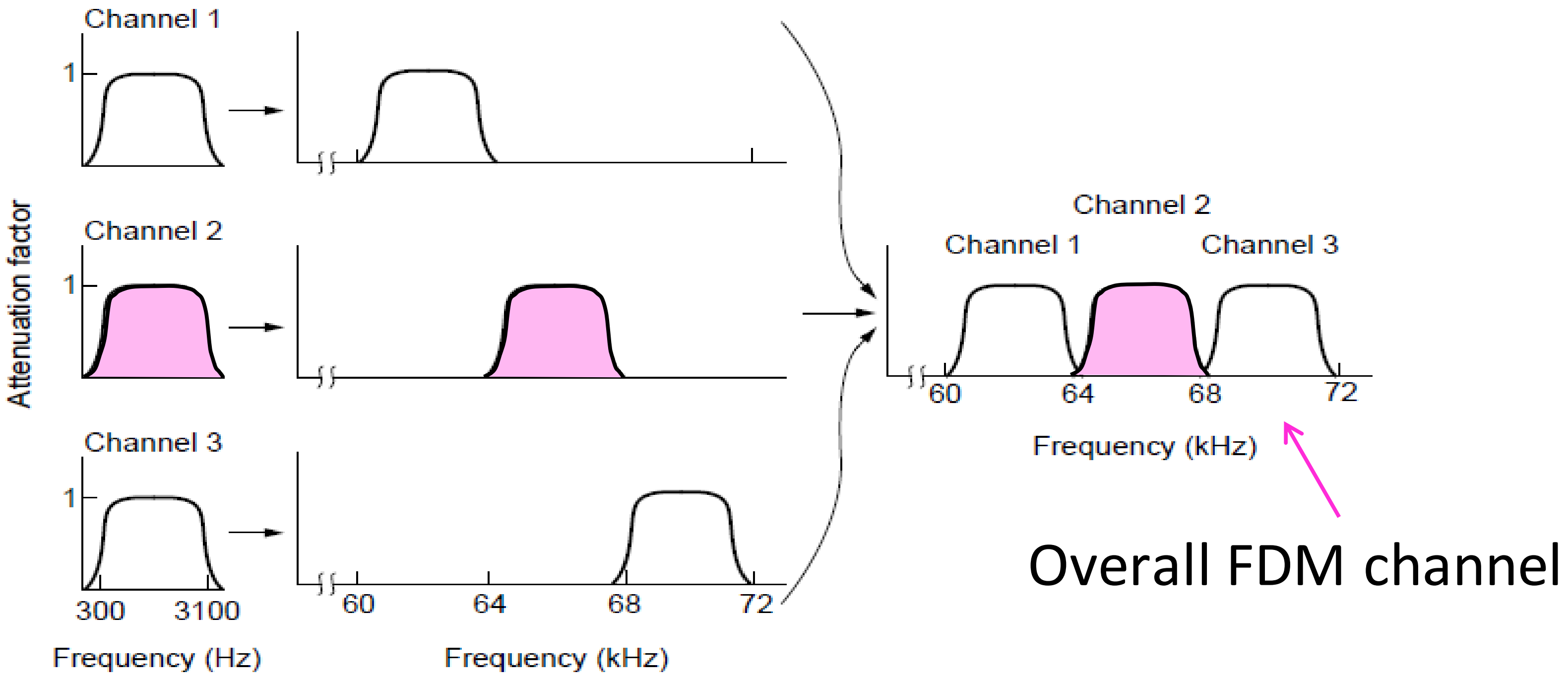
Time Division Multiplexing (TDM)

- Users take turns on a fixed schedule



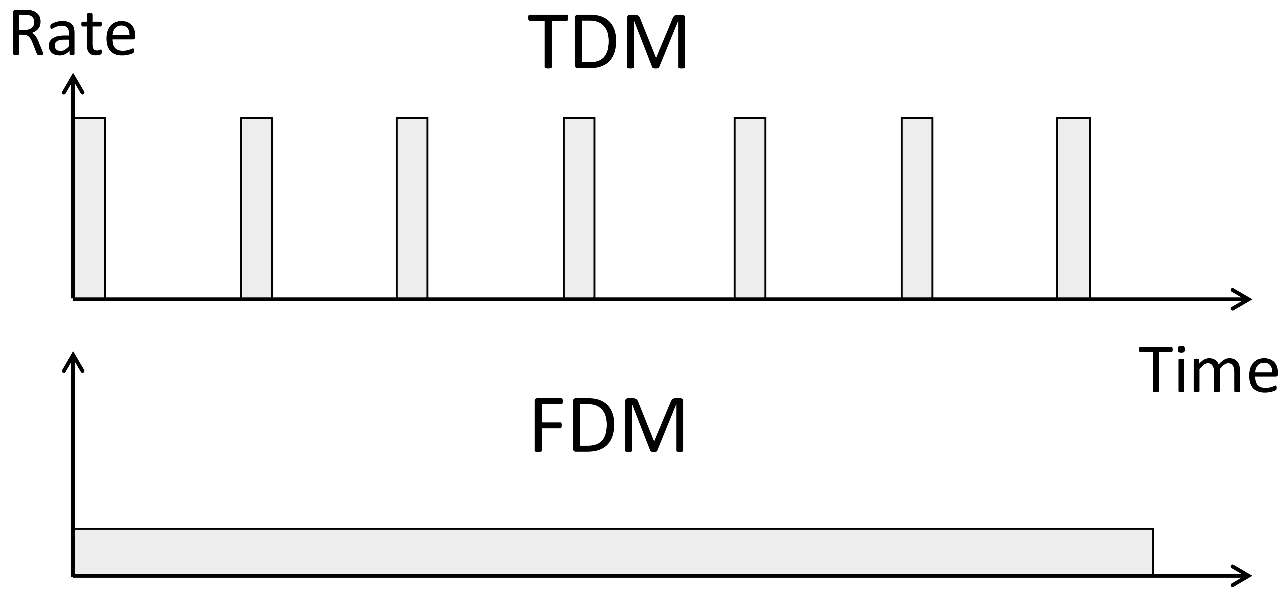
Frequency Division Multiplexing (FDM)

- Put different users on different frequency bands



TDM versus FDM (2)

- 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

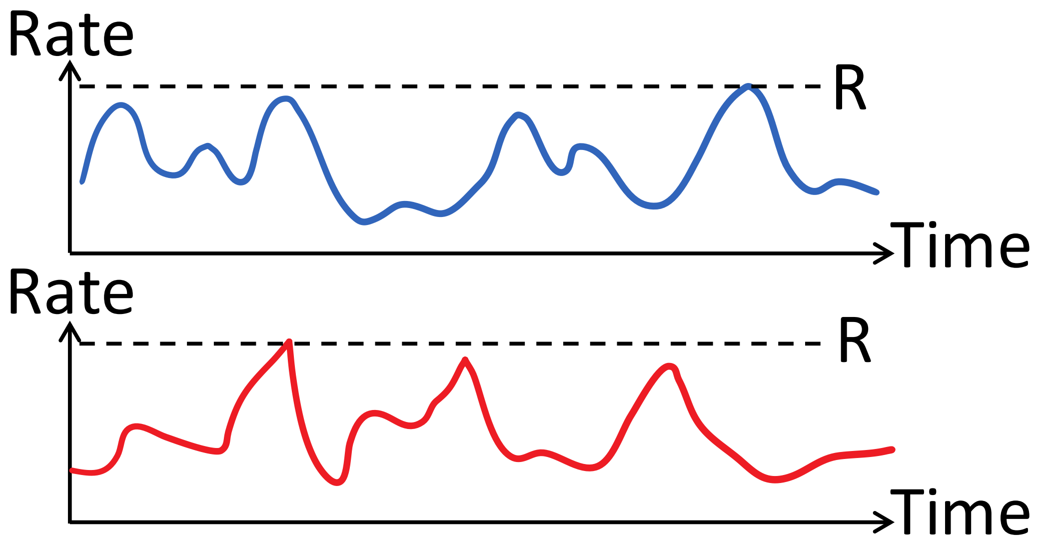


TDM/FDM Usage

- Statically divide a resource
  - Suited for continuous traffic, fixed number of users
- Widely used in telecommunications
  - TV and radio stations (FDM)
  - GSM (2G cellular) allocates calls using TDM within FDM

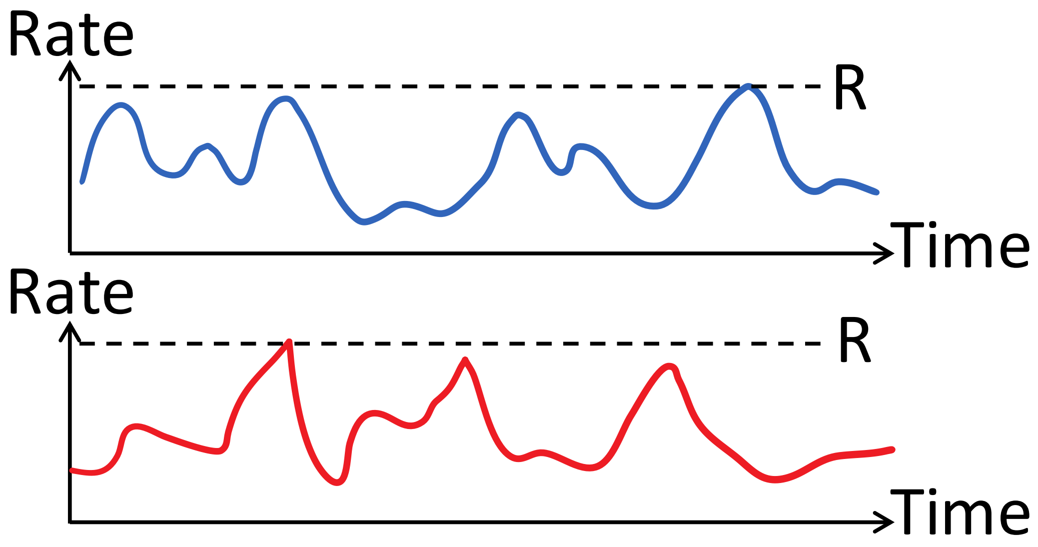
Multiplexing Network Traffic

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



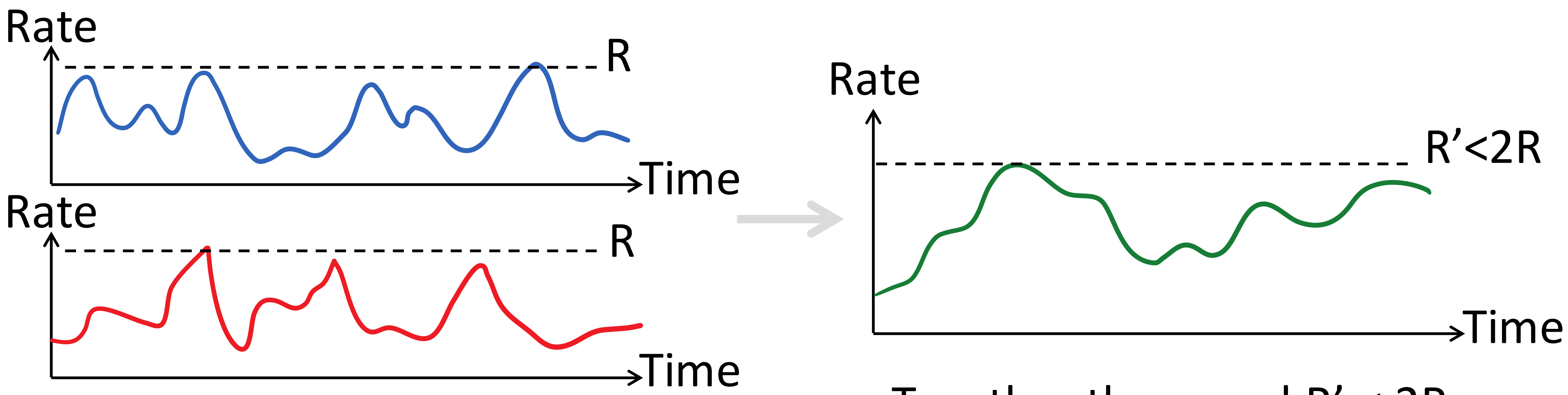
Multiplexing Network Traffic (2)

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



Multiplexing Network Traffic (3)

- Multiple access schemes multiplex users according to demands – for gains of statistical multiplexing

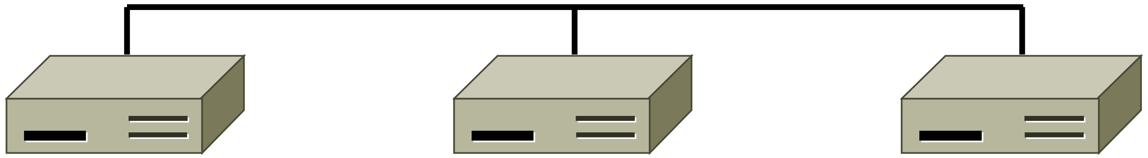


Two users, each need R

Together they need R’ < 2R

Random Access

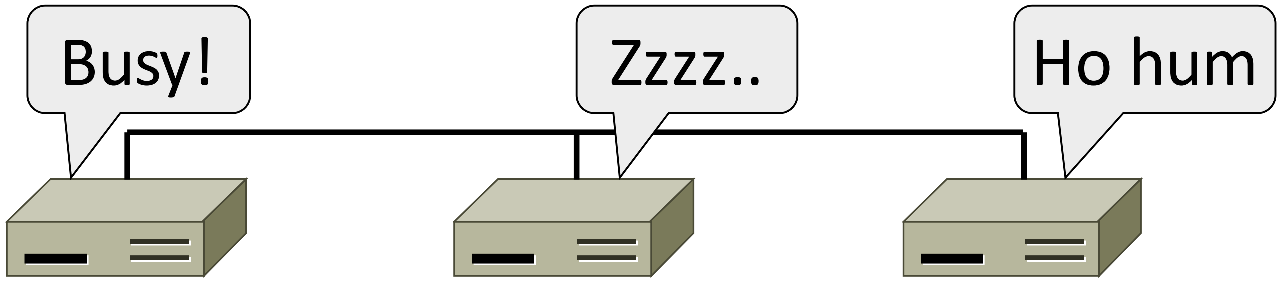
- How do nodes share a single link? Who sends when, e.g., in WiFI?
  - Explore with a simple model



- Assume no-one is in charge
  - Distributed system

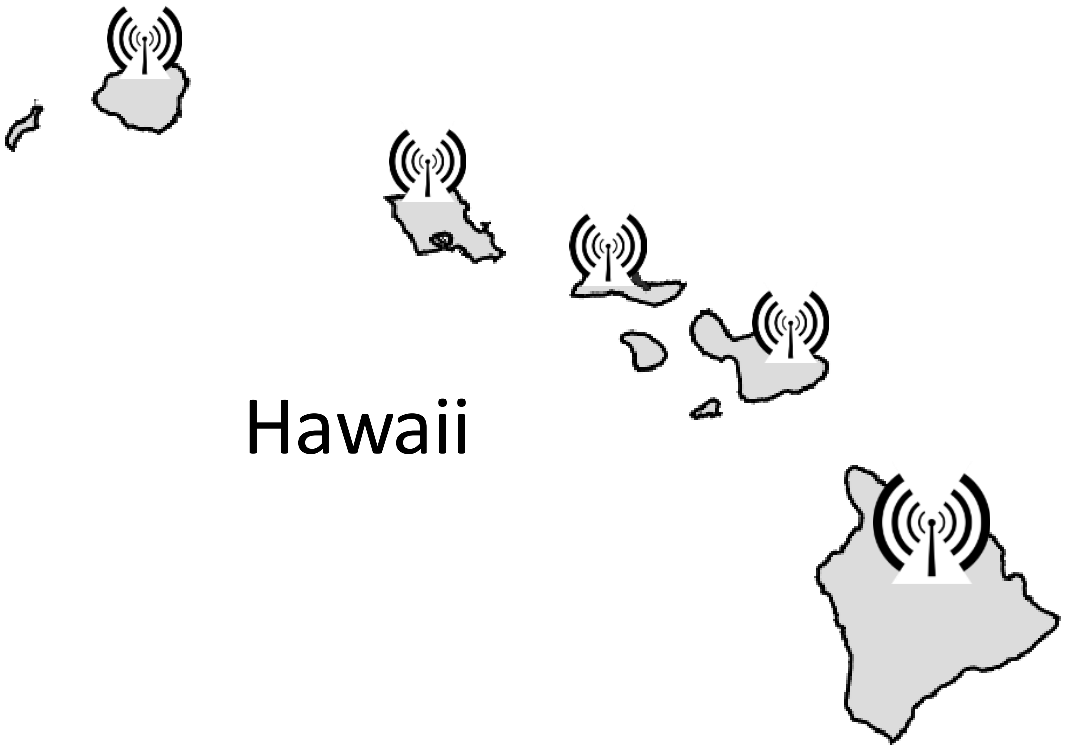
Random Access

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



ALOHA Network

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



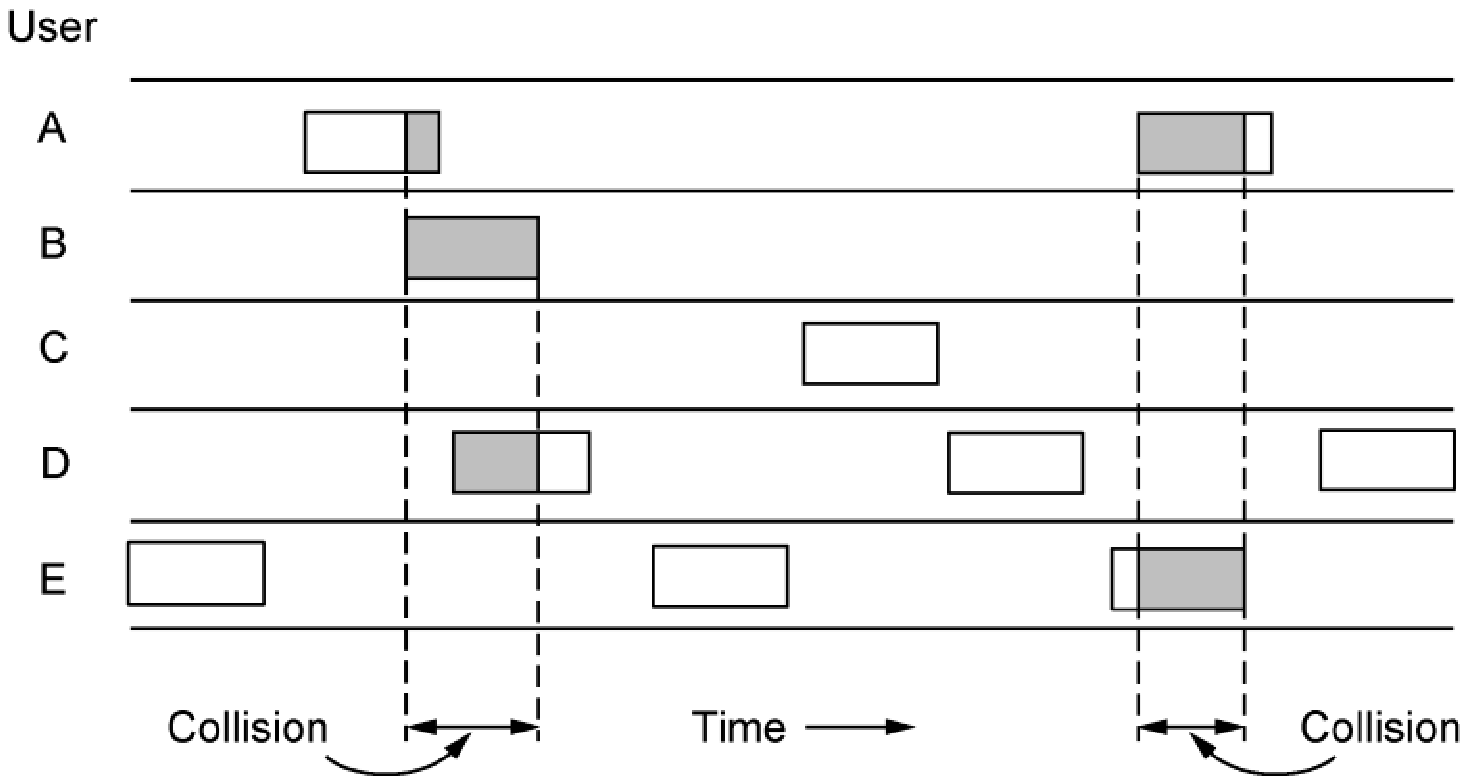
ALOHA Protocol

- Simple idea:
  - Node just sends when it has traffic.
  - 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?

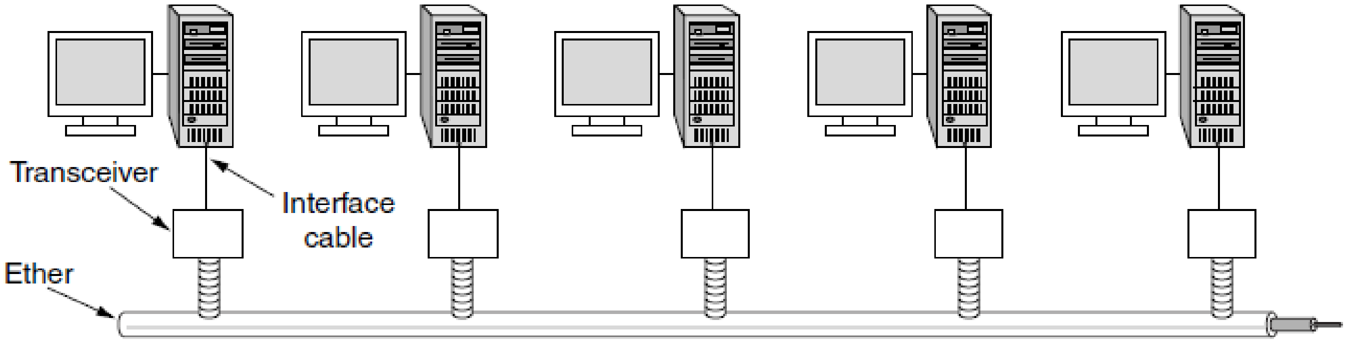


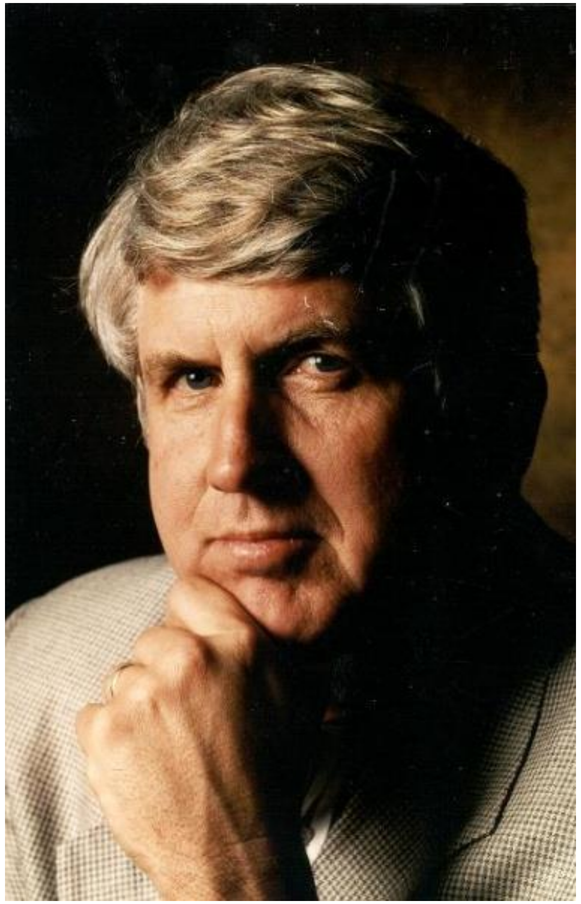
ALOHA Protocol

- Simple, decentralized protocol that works well under low load!
- Not efficient under high load
  - Analysis shows at most 18% efficiency
  - Improvement: divide time into slots and efficiency goes up to 36%
- 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 1980s, 1990s



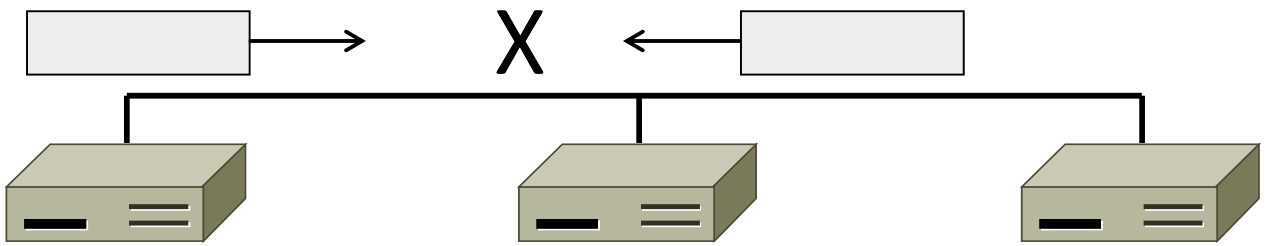


CSMA (Carrier Sense Multiple Access)

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

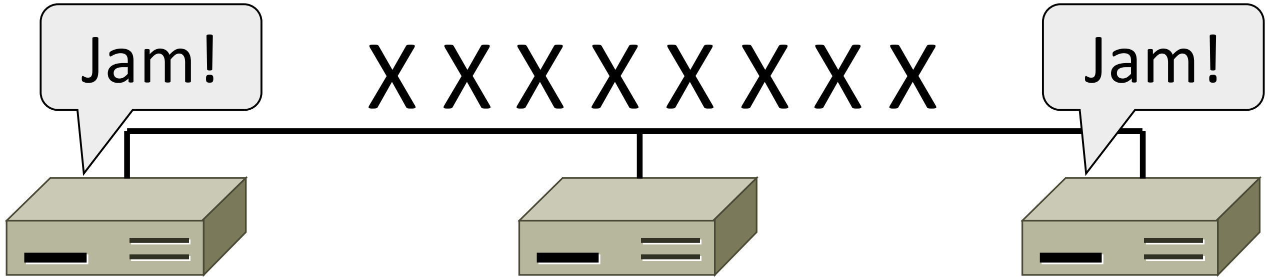
CSMA

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



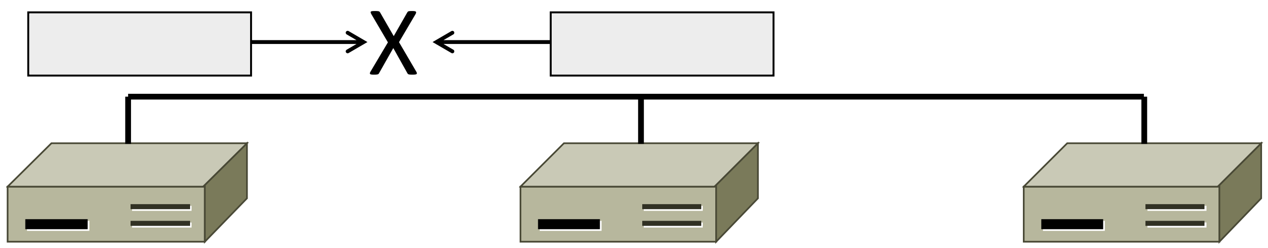
CSMA/CD (with Collision Detection)

- Can reduce the cost of collisions by detecting them and aborting (Jam) the rest of the frame time
  - Again, we can do this with wires



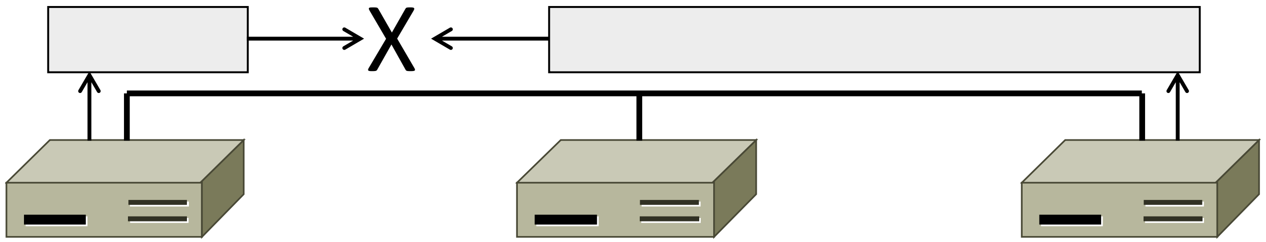
CSMA/CD Complications

- Everyone who collides needs to know it happened
  - Time window in which a node may hear of a collision is 2D seconds



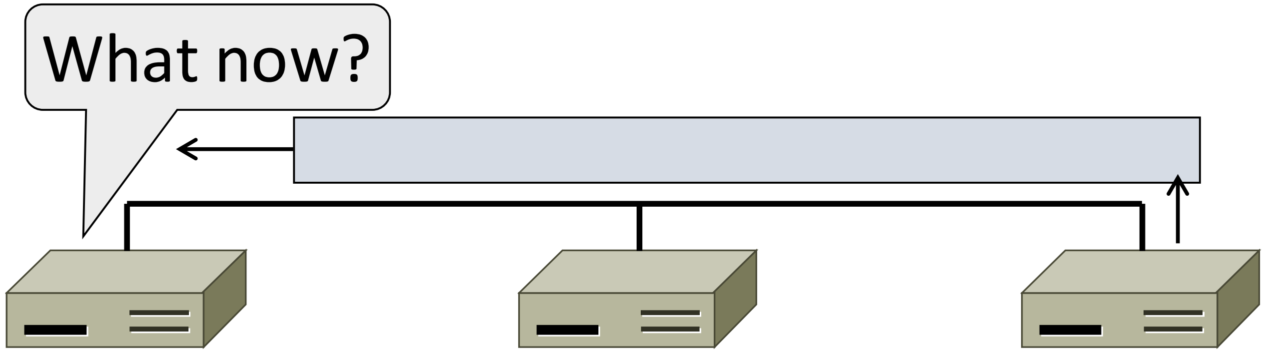
CSMA/CD Complications

- Impose a minimum frame length of 2D seconds
  - So node can't finish before collision
  - Ethernet minimum frame is 64 bytes



CSMA "Persistence"

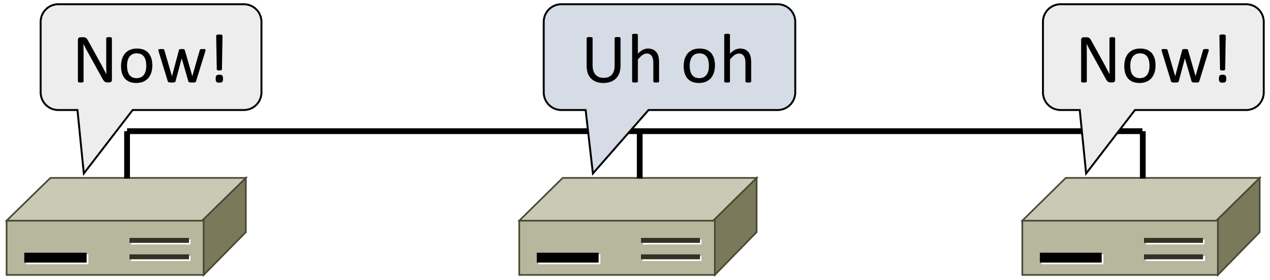
- What should a node do if another node is sending?



- Idea: Wait until it is done, and send

CSMA "Persistence" (2)

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



CSMA "Persistence"

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