This lecture is being recorded

18-452/18-750
Wireless Networks and Applications
Lecture 7: LAN MAC Protocols
Wireless versus Wired

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http://www.cs.cmu.edu/~prs/wirelessS22/

Outline

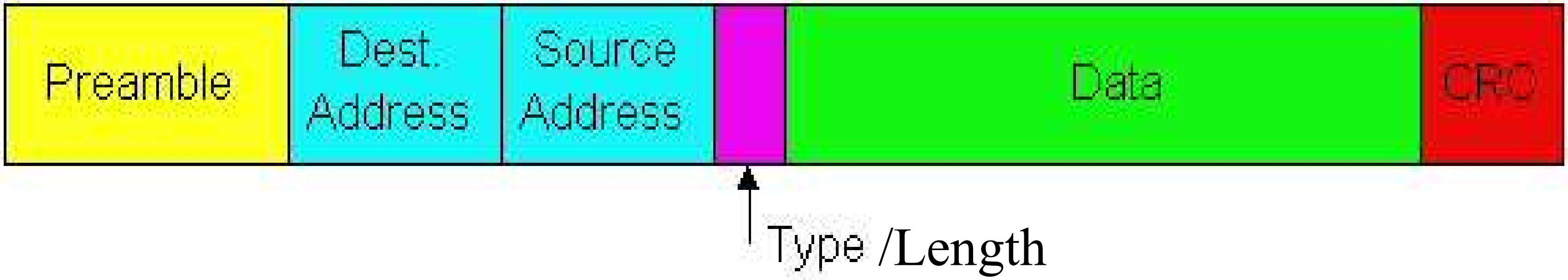
- Data link fundamentals
  - And what changes in wireless
- Aloha
- Ethernet
- Wireless-specific challenges
- 802.11 and 802.15 wireless standards

Datalink Functions

- Framing: encapsulating a packet into a bit stream.
  - Add header, mark and detect frame boundaries, …
- Logical link control: managing the transfer between the sender and receiver, e.g.
  - Error detection and correction to deal with bit errors
  - Flow control: avoid that the sender outruns the receiver
- Media access: controlling which device gets to send a frame next over a link
  - Easy for point-to-point links; half versus full duplex
  - Harder for multi-access links: who gets to send?

Framing

- Typical structure of a “wired” packet:
  - » Preamble: synchronize clocks sender and receiver
  - » Header: addresses, type field, length, etc.
  - » The data to be send, e.g., an IP packet
  - » Trailer: padding, CRC, ..



- How does wireless differ?
  - » Different transmit rates for different parts of packet
  - » Explicit multi-hop support
  - » Control information for physical layer
  - » Ensure robustness of the header

Error Control: Error Detection and Error Recovery

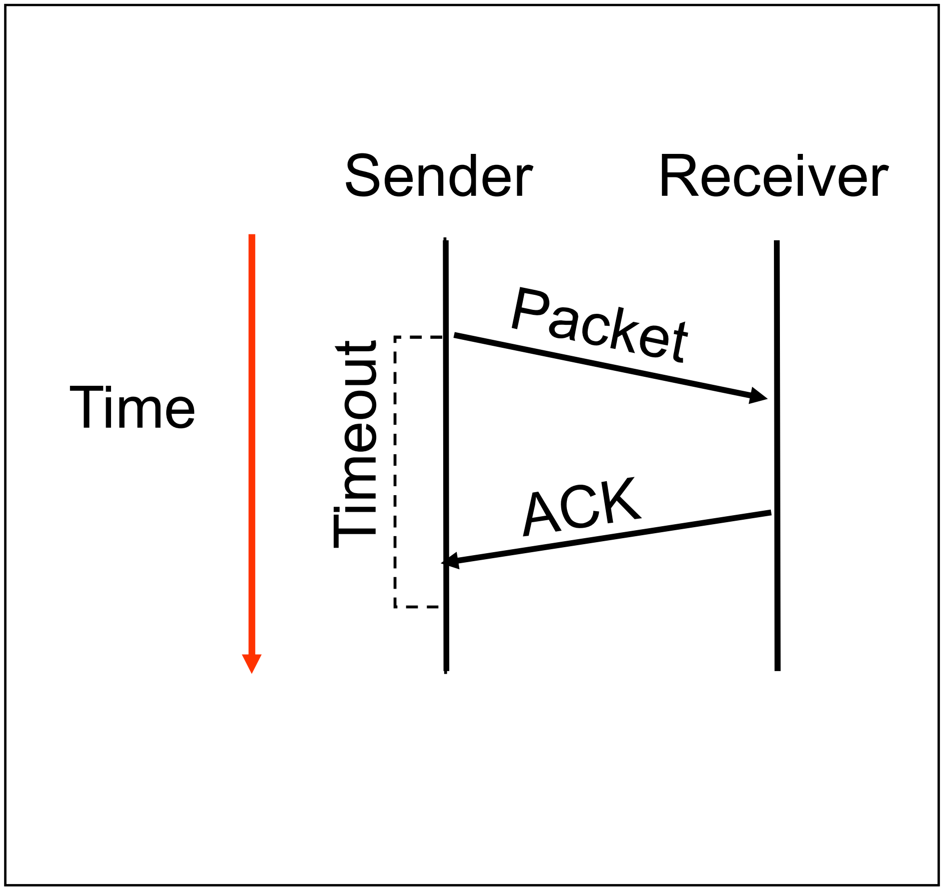
- Detection: only detect errors
  - Make sure corrupted packets get thrown away, e.g. Ethernet
  - Use of error detection codes, e.g. CRC
- Recovery: also try to recover from lost or corrupted packets
  - Option 1: forward error correction (redundancy)
  - Option 2: retransmissions
- How does wireless differ?
  - Uses CRC to detect errors, similar to wired
  - Error recovery is much more important because errors are more common and error behavior is very dynamic
  - What approach is used?

Error Recovery in Wireless

- Use of redundancy:
  - Very common at physical layer – see PHY lectures
- Use of Automatic Repeat Request (ARQ)
  - Use time outs to detect loss and retransmit
- Many variants:
  - Stop and wait: one packet at a time
    - The most common at the datalink
  - Sliding window: receiver tells sender how much to send
    - Many retransmission strategies: go-back-N, selective repeat, …
- When should what variant be used?
  - Noise versus bursty (strong) interference

Stop and Wait

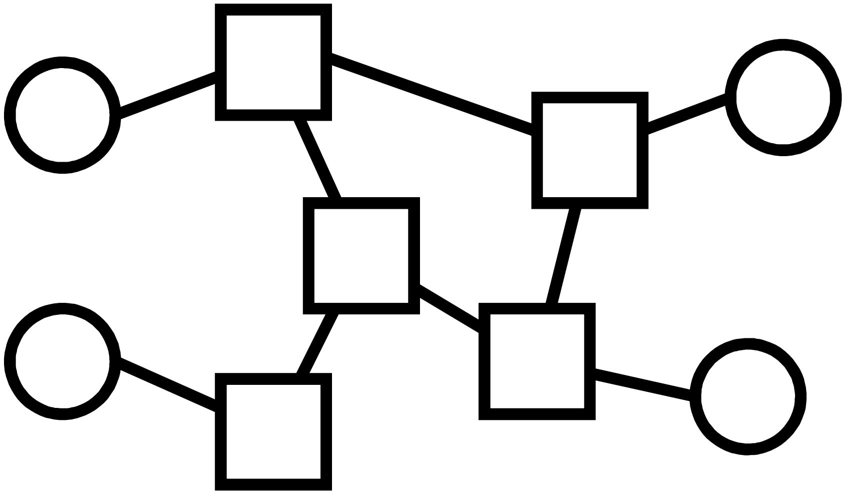
- **Simplest ARQ protocol**
- **Send a packet, stop and wait until acknowledgement arrives**
- **Will examine ARQ issues later in semester**
- **Limitations?**
- **What popular for the datalink?**

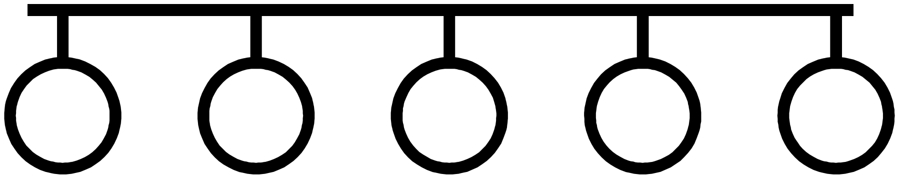


Media Access Control

- How do we transfer packets between two hosts connected to the same network?
- Using point-to-point “links” with “switches” -- store-and-forward
  - Very common in wired networks, at multiple layers
- Multiple access networks
  - Multiple hosts are sharing the same transmission medium
  - Need to control access to the medium
  - Taking turn versus contention based protocols
- What is different in wireless?
  - Is store and forward used?
  - Is multiple access used?

Datalink Architectures





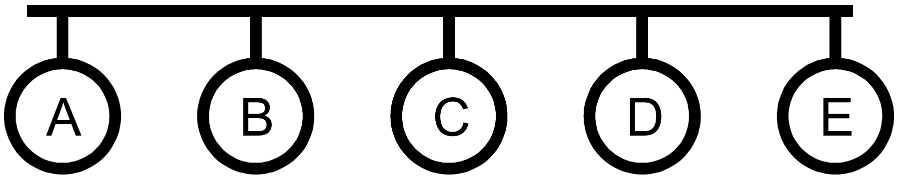
- **Routing and packet forwarding.**
- **Point-to-Point error and flow control.**

Switched ethernet, mesh and ad hoc networks

- **Media access control.**
- **Scalability.**

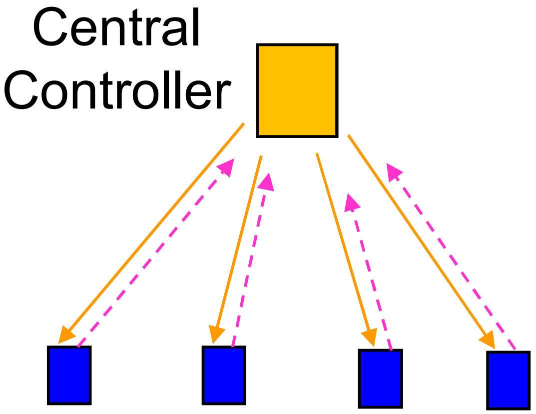
Traditional ethernet, Wifi, Aloha, …

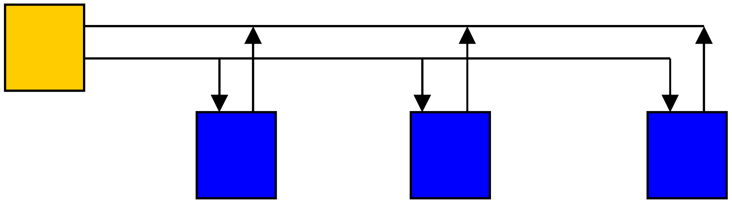
Multiple Access Networks

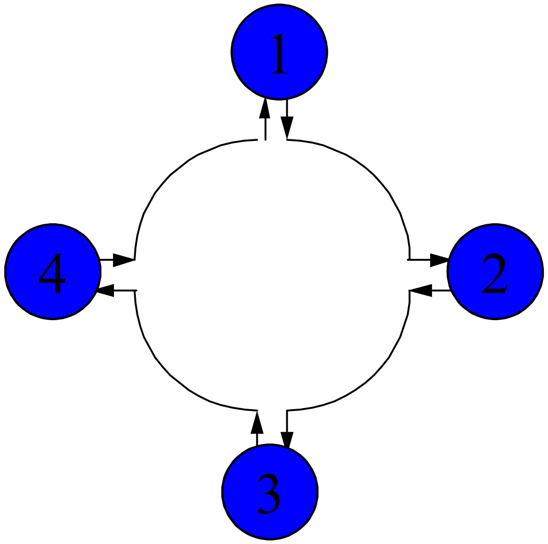


- Who gets to send a packet next?
- Scheduled access: explicit coordination ensures that only one node transmits
  - Looks cleaner, more organized, but …
  - Coordination introduces overhead – requires communication (oops)
- Random access: no explicit coordination
  - Potentially more efficient, but …
  - How does a node decide whether it can transmit?
  - Collisions are unavoidable – also results in overhead
  - How do you even detect a collision?

Scheduled Access MACs







- **Polling: controller polls each nodes**
- **Reservation systems**
  - » **Central controller**
  - » **Distributed algorithm, e.g. using reservation bits in frame**
- **Token ring: token travels around ring and allows nodes to send one packet**
  - » **Distributer version of polling**
  - » **FDDI, …**

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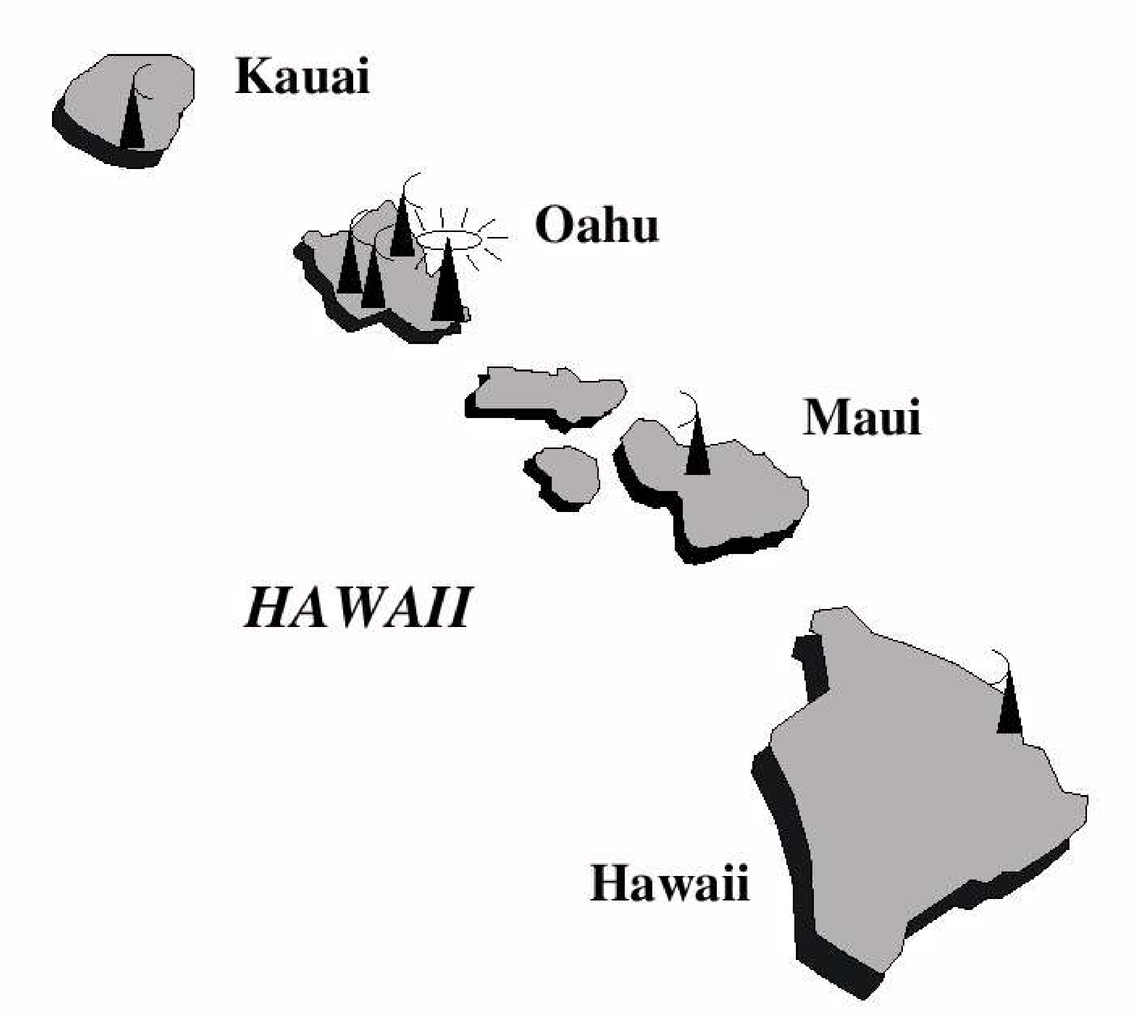
Why ALOHA



Pure ALOHA

- Developed in University of Hawaii in early 1970’s.
- It does not get much simpler:
  1. A user transmits at will
  2. If two or more messages overlap in time, there is a collision – receiver cannot decode packets
  3. Receive waits for roundtrip time plus a fixed increment – lack of ACK = collision
  4. After a collision, colliding stations retransmit the packet, but they stagger their attempts randomly to reduce the chance of repeat collisions
  5. After several attempts, senders give up
- Although very simple, it is wasteful of bandwidth, attaining an efficiency of at most 1/(2e) = 0.18

Informal: memory less

Poisson Process

- A Poisson process of “rate” $\lambda > 0$ is a counting process a(t) which satisfies the following conditions:

1. The process has independent increments in disjoint intervals
   - i.e., $a(t_1+\Delta t)-a(t_1)$ is independent of $a(t_2+\delta t)-a(t_2)$ if $[t_1, t_1+\Delta t]$ and $[t_2, t_2+\delta t]$ are disjoint intervals
2. The increments of the process are stationary.
   - i.e., $a(t_1+\Delta t)-a(t_1)$ does not depend on t_1
3. The probability of exactly one event occurring in an infinitesimal interval Δt is $P[a(\Delta t)=1] \cong \lambda\Delta t$
4. The probability that more than one event occurs in any infinitesimal interval Δt is $P[a(\Delta t)>1] \cong 0$
5. The probability of zero events occurring in Δt is $P[a(\Delta t)=0] \cong 1-\lambda\Delta t$

Poisson Distribution

- Above definitions lead to: Probability P(k) that there are exactly k events in interval of length T is,

$$P(k) = \frac{(\lambda T)^k e^{-\lambda T}}{k!}$$

- We call the above probability the “Poisson distribution” for arrival rate λ
- Its mean and variance are:

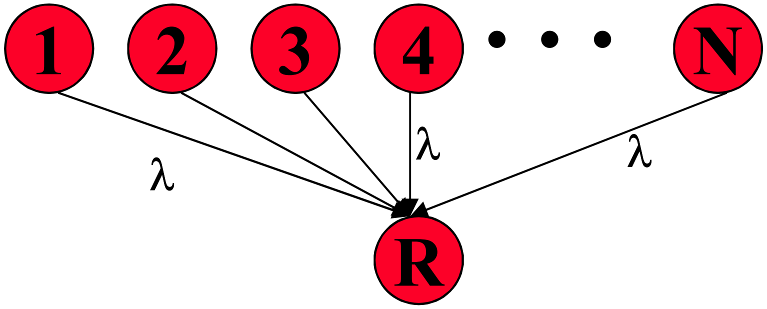
$$E(k) = \lambda T$$

$$\sigma_k^2 = E(k^2) - E^2(k) = \lambda T$$

- Many nice properties, e.g. sum of a N independent Poisson processes is a Poisson process

Pure ALOHA: Model

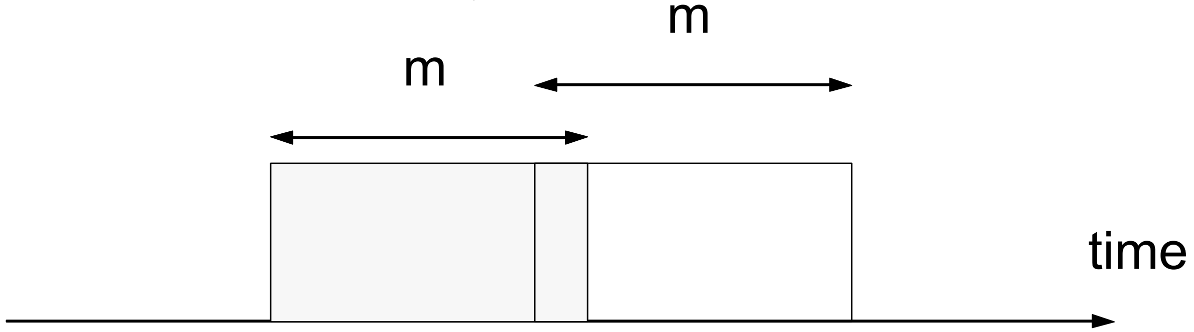
- Let there be N stations contending for use of the channel.
- Each station transmits λ packets/sec on average based on a Poisson arrival process
- All messages transmitted are of the same fixed length, m, in units of time
- Let new traffic intensity be S ≡ Nλm
- Since all new packets eventually get through, ‘S’ is also the network throughput



Pure Aloha: Vulnerability

- **Simplification: assume the retransmitted messages are independent Poisson process as well**
- **The total rate of packets attempting transmission = newly generated packets + retransmitted ones =** $\lambda' > \lambda$
- **The total traffic intensity (including retransmissions) is ,**

$$G = N\lambda' m$$



Collision between two messages

- **The "vulnerable period" in which a collision can occur for a given packet is 2 x m sec**

Pure Aloha: Analysis

Calculate the "Probability of no collision" two ways:

1. Probability that there is no arrival in interval 2 x m:

   P(no arrival in 2 x m sec) = $e^{-2N\lambda' m} = e^{-2G}$

2. Since all new arrivals eventually get through, we have

   λ/λ' = S/G = Fraction of transmissions that are successful

   - S = rate of successful transmissions
   - G = network load – successful transmissions and retransmissions

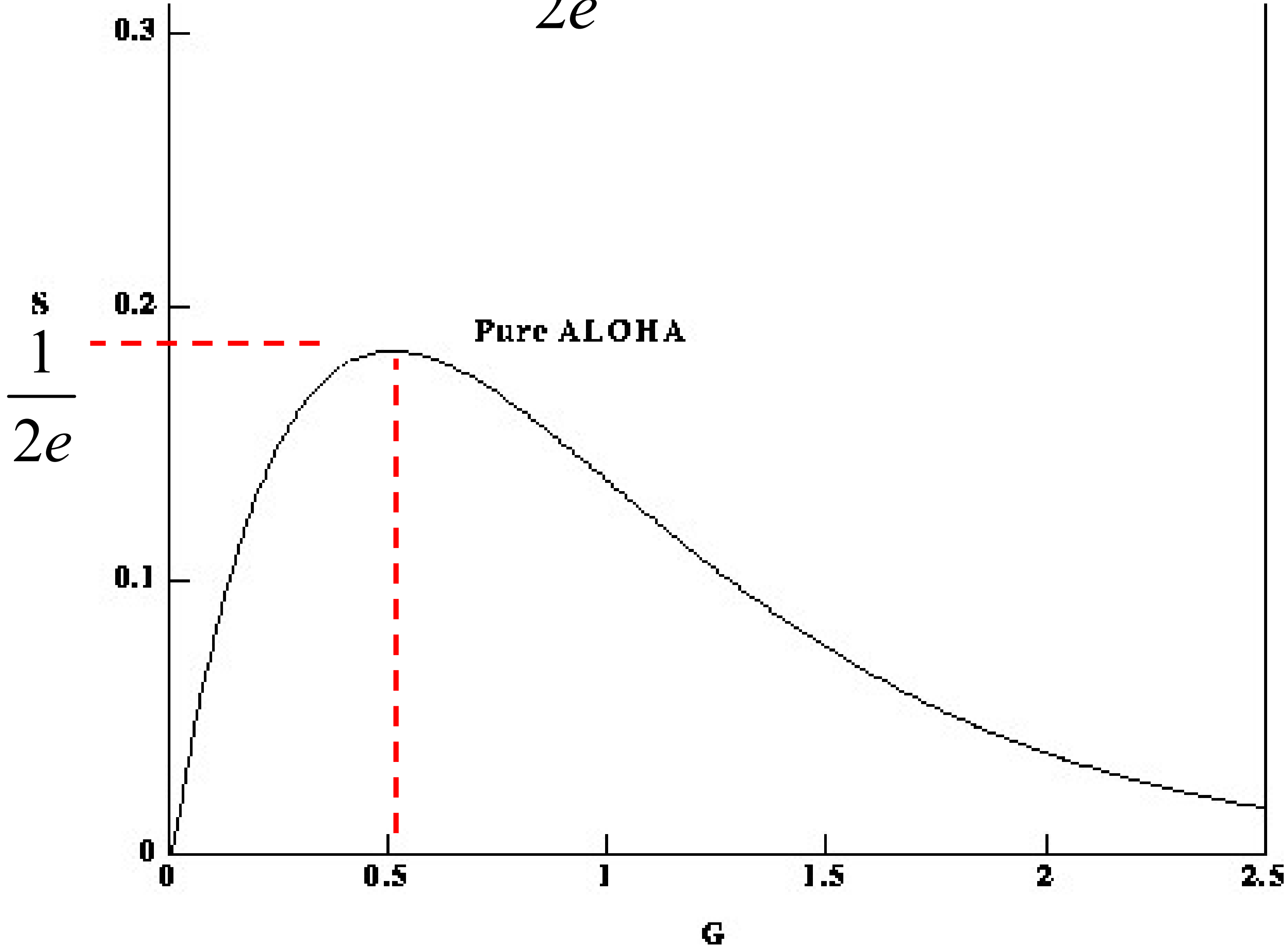
- So, S/G = Probability of no collision
  = P(no arrival in 2m sec)
- Thus,

$$S/G = e^{-2G}$$
$$S = Ge^{-2G} \longrightarrow$$

Maximum Throughput of Pure Aloha

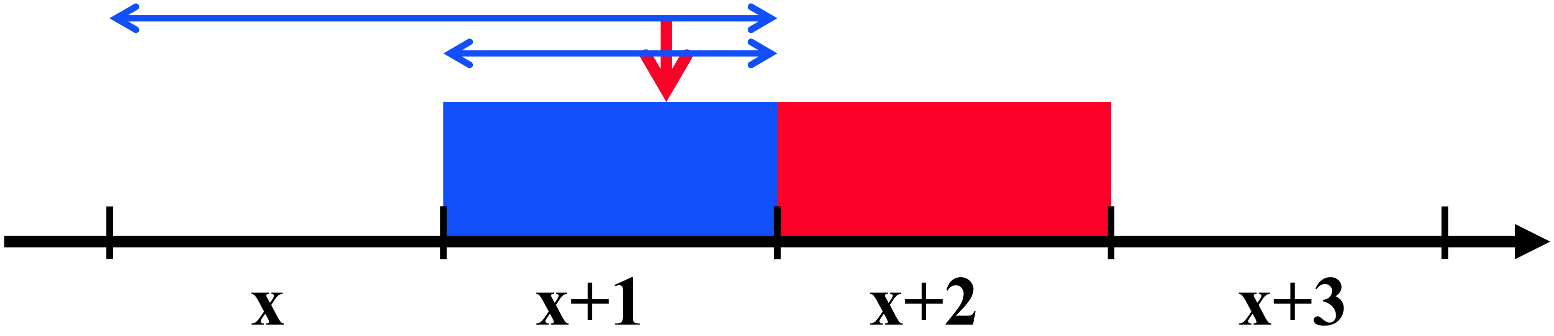
Analysis Conclusion

- **S is maximum at** $S = \frac{1}{2e}$ at $G = 0.5$



Slotted ALOHA

- Transmission can only start at the beginning of each slot of length T
- Vulnerable period is reduced to T
  - Instead of 2xT in Aloha
- Doubles maximum throughput.



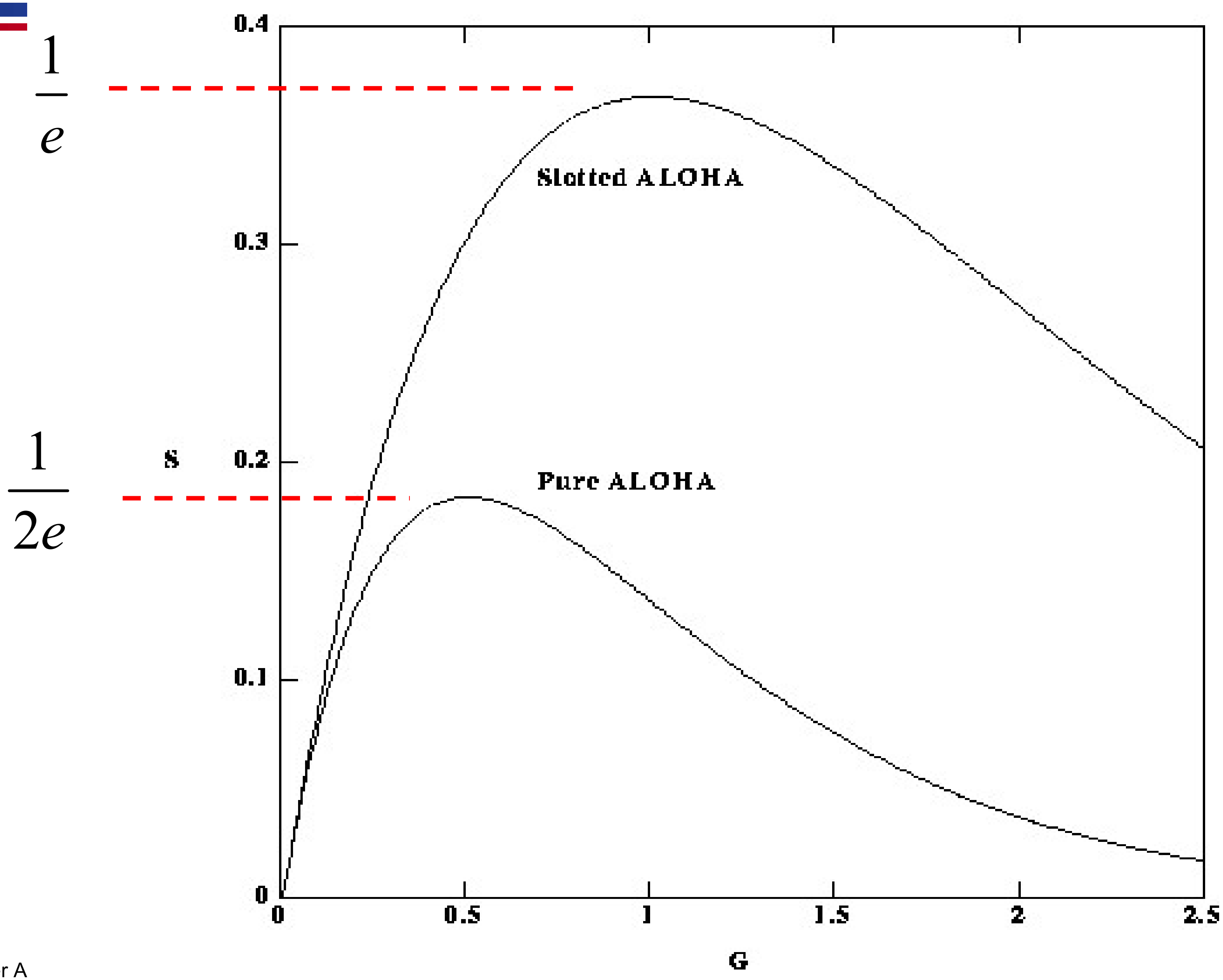
Slotted ALOHA Analysis

- Key point: The ”vulnerable period” of the packet of size *m* has been reduced from 2*m* to only *m* !
- Since Poisson arrivals,

  P(successful transmission) = e^{-G} ← Note: Not 2G
- The throughput is then,

  $S = Ge^{-G}$
- The throughput S has maximum value of 1/e = 0.368 at G = 1.

Analysis Results Slotted ALOHA



Discussion of ALOHA

- Maximum throughput of ALOHA is very low 1/(2e) = 18%, but
  - Has very low latency under light load
- Slotted Alohas has twice the performance of basic Aloha, but performance is still poor
  - Slightly longer delay than pure Aloha
  - Inefficient for variable sized packets!
  - Must synchronize nodes
- Still, not bad for an absolutely minimal protocol!
  - Good solution if load is low – used in some sensor networking technologies (cheap, simple)

- How do we go faster?

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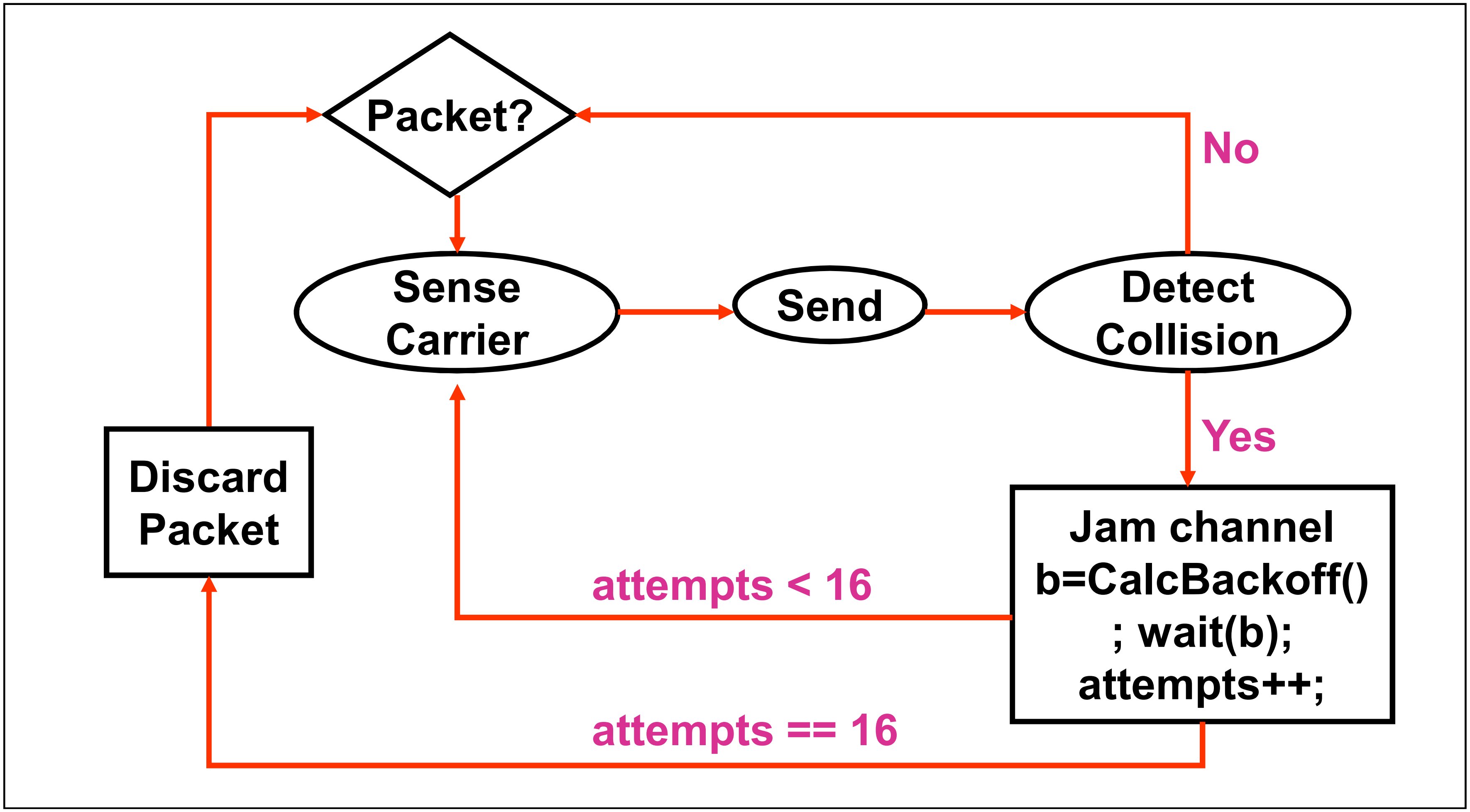
"Regular" Ethernet
CSMA/CD

- Multiple Access: multiple hosts are competing for access to the channel
- Carrier-Sense: make sure the channel is idle before sending – "listen before you send"
- Collision Detection: collisions are detected by listening on the medium and comparing the received and transmitted signals
- Collisions results in 1) aborting the colliding transmissions and 2) retransmission of the packets
- Exponential backoff is used to reduce the chance of repeat collisions
  - » Also effectively reduces congestion

Carrier Sense Multiple Access/ Collision Detection (CSMA/CD)



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Ethernet Backoff Calculation

- Challenge: how do we avoid that two nodes retransmit at the same time collision
- Exponentially increasing random delay
  - » Infer "number" senders from # of collisions
  - » More senders → increase wait time
- First collision: choose K from {0,1}; delay is K x 512 bit transmission times
- After second collision: choose K from {0,1,2,3}
- After ten or more collisions, choose K from {0,1,2,3,4,…,1023}

How to Handle Transmission When Line is Sensed Busy

- ***p-persistent scheme*:**
  - **Transmit with probability p once the channel goes idle**
  - **Delay the transmission by t_{prop} with the probability (1-p)**
- ***1-persistent scheme*: p = 1**
  - **E.g. Ethernet**
- ***nonpersistent scheme*:**
  - **Reschedule transmission for a later time based on a retransmission delay distribution (e.g. exp backoff)**
  - **Senses the channel at that time**
  - **Repeat the process**
- **When is each solution most appropriate?**

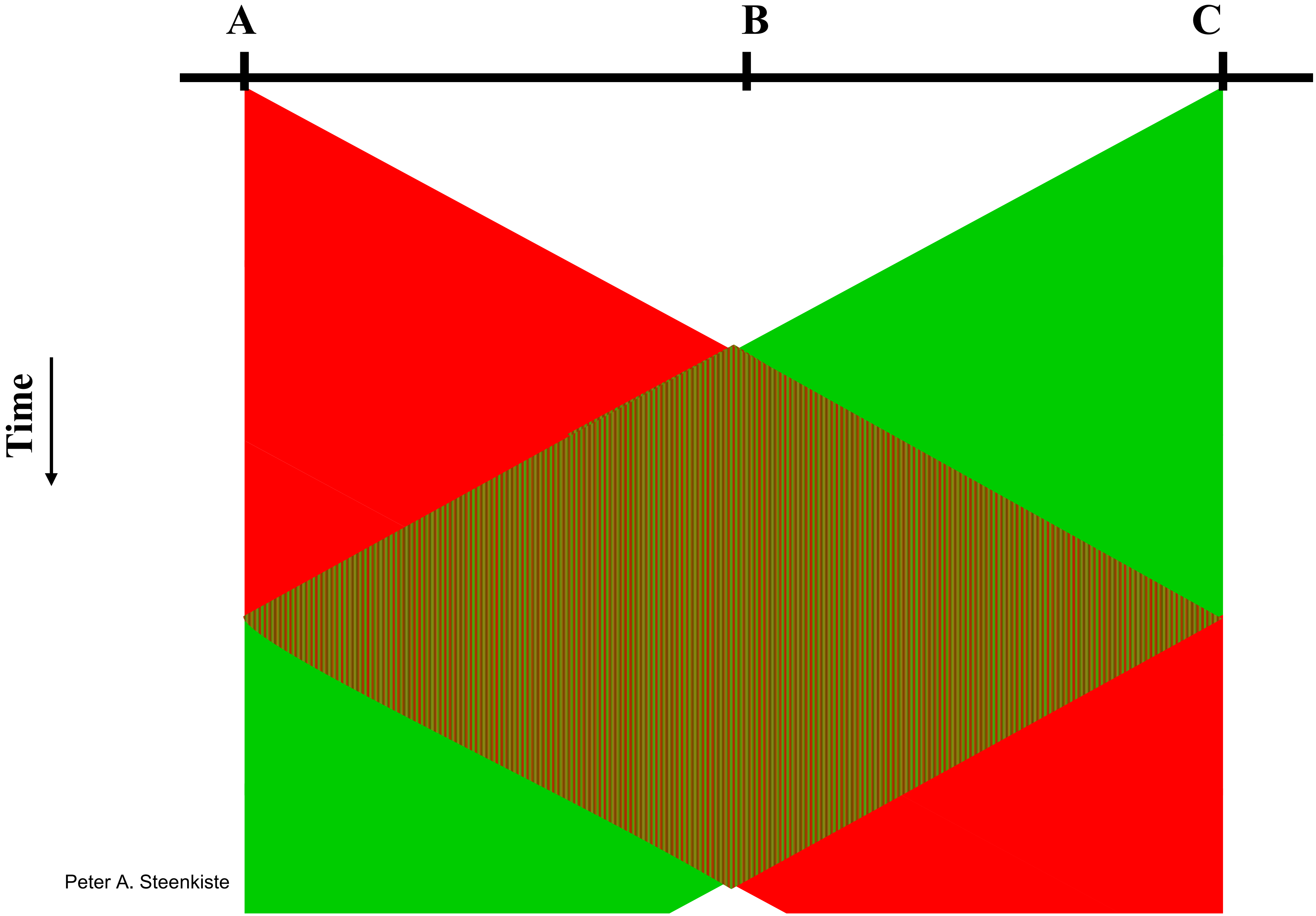
Dealing with Collisions

- Collisions will happen: nodes can start to transmit “simultaneously”
  - » Vulnerability window depends on length of wire
- Recovery requires that both transmitters can detect the collision reliably
  - » Clearly a problem as shown on previous slide
- How can we guarantee detection?

1. Make sure the wire is not too long, and
2. Packets are long enough

- These requirements are enforced in the Ethernet standard

Detect Collisions: Example



Ethernet Discussion

- Ethernet does not acknowledge packets
  - Packet loss due to bit errors is rare
  - Collision detection is very reliable
  - ACKs introduced unnecessary overhead
  - Ethernet relies on higher level protocols for recovery
- As bit rates increase, collision detection requires larger minimum sized packets and/or shorter wires
  - This made the technology unattractive
- Today we exclusively use switched ethernet
  - Same name, same network properties, same packet format
  - Completely different technology

So What about Wireless?

- Depends on many factors, but high level:
- Random access solutions are a good fit for data in the unlicensed spectrum
    - Lower control complexity, especially for contention-based protocols (e.g., Ethernet)
    - There may not always be a centralized controller
    - Potentially very efficient because no or limited coordination overhead
    - Our focus in the next few lectures
- Cellular uses scheduled access
    - Need to be able to guarantee performance
    - Have control over spectrum – simplifies scheduled access
    - More on this later in the course

Summary

- Wireless uses the same types of protocols as wired networks
  - But it is inherently a multiple access technology
- Some fundamental differences between wired and wireless may result in different design choices
  - Higher error rates
  - Must support variable bit rate communication
  - Signal propagation and radios are very different