CISC 7332X T6
Channel Allocation and Multi-Access Protocols

Hui Chen

Department of Computer & Information Science

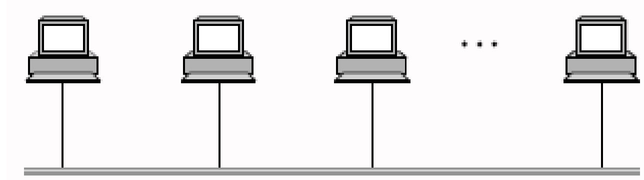
CUNY Brooklyn College

Outline

- Channel allocation problem
- Multiple Access Protocols
    - Collision
        - ALOHA
        - Carrier sense
        - Collision detection
        - CSMA/CD
        - MACA and CSMA/CA
    - Collision free and limited contention

Medium Access Control

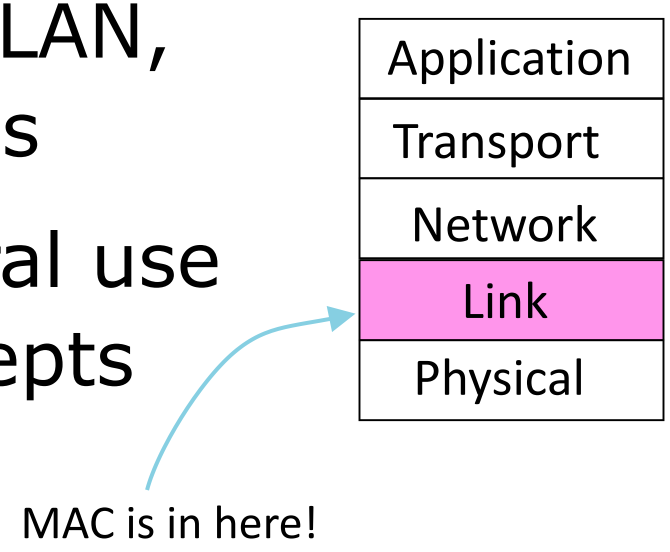
- Two types of network links
  - Point-to-point
  - Multiple access (broadcast)



- Key issue
  - Who gets to use the channel when there is a competition to it?
  - Multiaccess channel/random access channel
  - Medium Access Control (MAC)

The MAC Sublayer

- The protocols used to determine who goes next on a multiaccess channel
- Especially important for LAN, particularly wireless LANs
- In contrast, WANs general use point-to-point links, excepts for satellite networks



Channel Allocation Problem

- The central problem in MAC is about allocating a single broadcast channel among competing users.
- Static channel allocation
- Dynamic channel allocation
- Multiple access protocols

Static Allocation

- For fixed channel and traffic from N users, divide up the bandwidth using multiplexing schemes, such as, FTM, TDM, and CDMA
- A poor fit for computer systems where data traffic extremely bursty
  - e.g., peak traffic to mean traffic ratios: 1000:1
  - Most of channels will be idle most of the time
  - Allocation to a user will sometimes go unused

Dynamic Allocation

- Dynamic allocation gives the channel to a user when they need it.
- Potentially N times as efficient for N users.

Assumptions of Dynamic Allocation

- Schemes vary with assumptions:

Assumption	Implication
Independent traffic	Often not a good model, but permits analysis
Single channel	No external way to coordinate senders
Observable collisions	Needed for reliability; mechanisms vary
Continuous or slotted time	Slotting may improve performance
Carrier sense	Can improve performance if available

Multiple Access Protocols

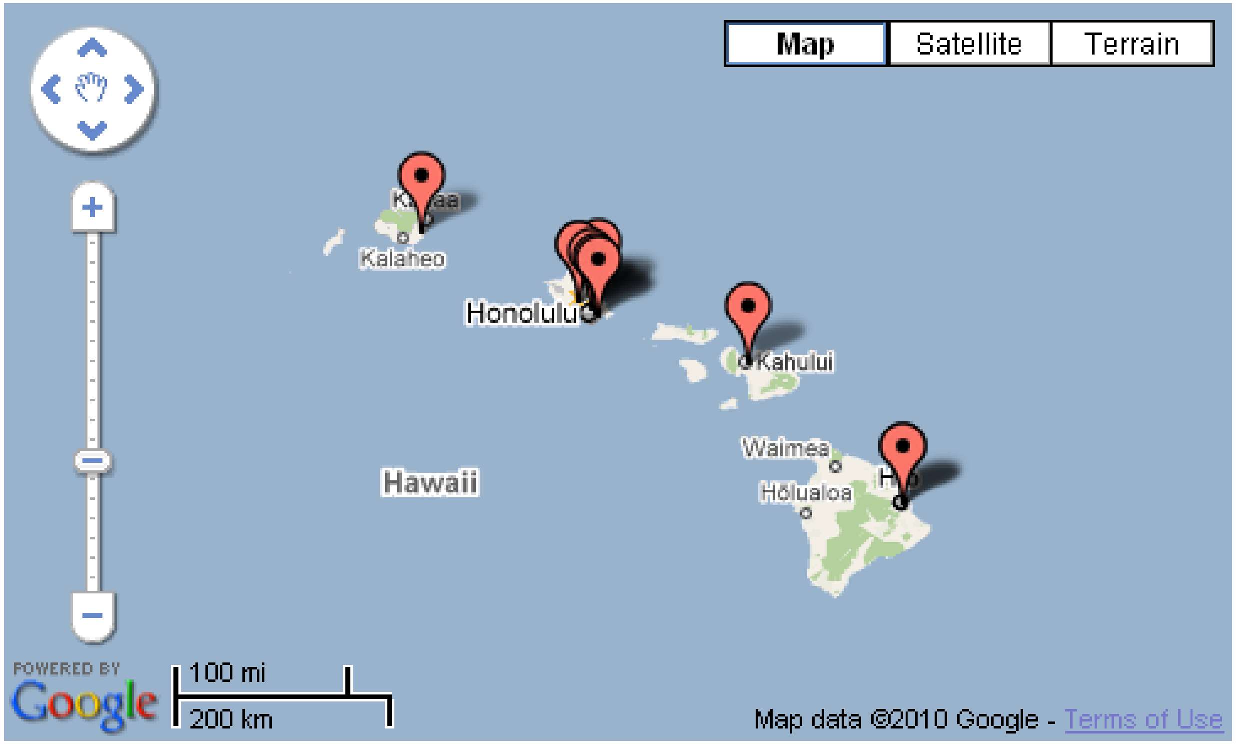
- ALOHA
- CSMA (Carrier Sense Multiple Access)
- Collision-free protocols
- Limited-contention protocols
- Wireless LAN protocols

ALOHA

- Pure ALOHA
- Slotted ALOHA

Pure ALOHA

- Initially developed by Norman Abramson, University of Hawaii in 1970's



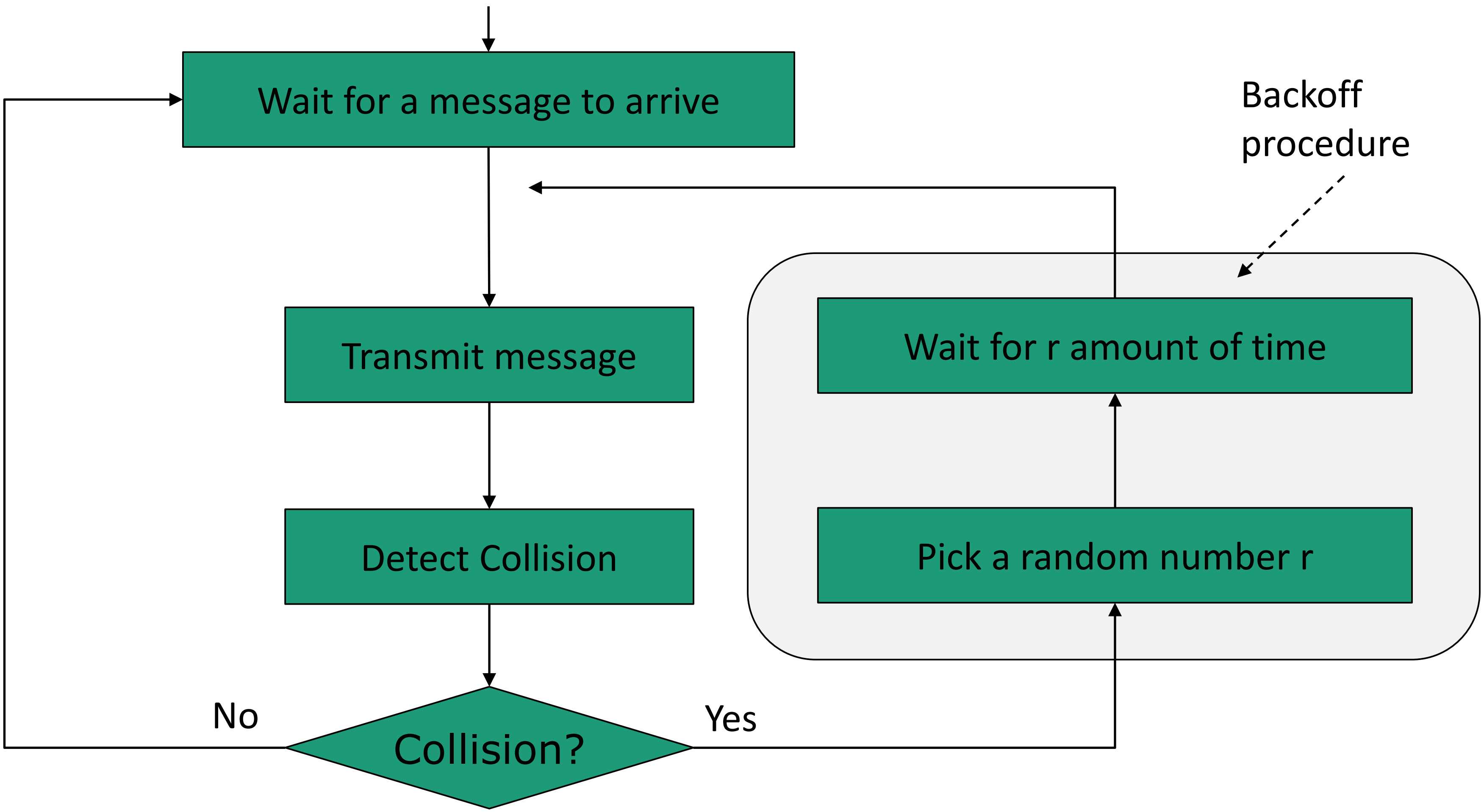
Pure ALOHA

- Served as a basis for many contention resolution protocols
- When to transmit:
  - In pure ALOHA, users transmit frames whenever they have data
- What if collision
  - Users retry after a random time for collisions

Pure ALOHA: Protocol

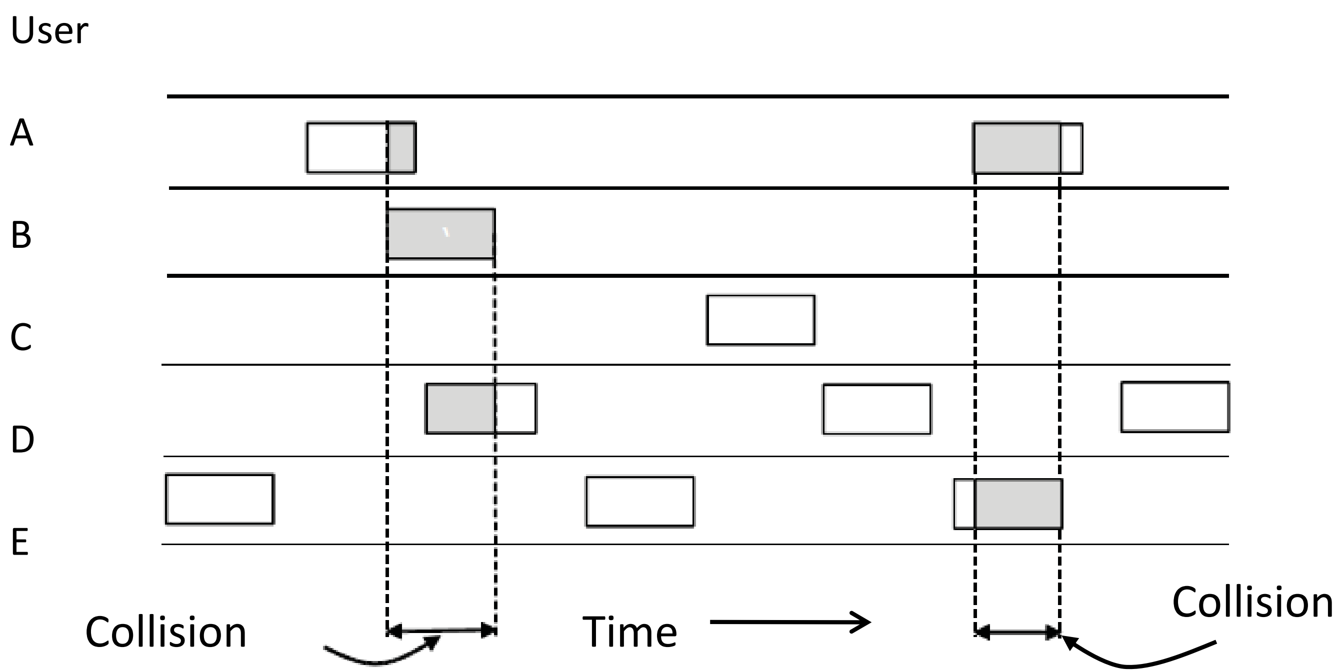
- Transmit message : A node transmits whenever it has data to send
- Detect collision: The sender waits to see if a collision occurred after the complete frame is sent
  - Note: a collision may occur if multiple nodes transmit at the same time
- Random backoff: If collision occurs, all the stations involved in collision wait a random amount of time, then try again
- Questions
  - Is it a good protocol? (how much can the throughput and latency be?)
  - How do we choose the random amount of waiting time?

Pure ALOHA: Protocol



Pure ALOHA: Throughput Analysis

- Frames are transmitted and retransmitted at completely arbitrary



Pure ALOHA: Throughput Analysis: Flow Balanced

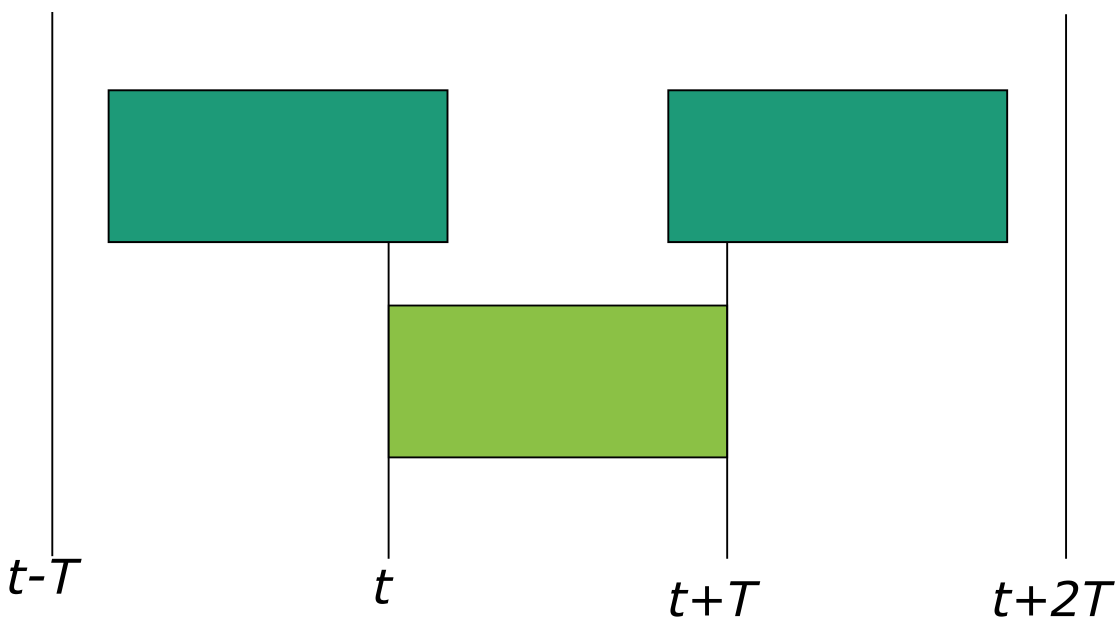
- The successful transmitted frames equals to the arrived frames

Pure ALOHA: Throughput Analysis: More Details

- Assume
  - Infinite number of nodes
  - Fixed length frames. Denote length as T
  - Overall arrival of frames is a Poisson process with rate λ frames/second
- Then, denote S as the number of frames arriving in T seconds
  - $S = \lambda T$
- In case of a collision, retransmission happens
  - New transmission and retransmission combined (all transmissions) is a Poisson process
  - Let the rate be G attempts per T seconds
- Note that
  - $S \leq G$, equality only if there are no collisions.
- Assume the system is in a stable state and denote the probability of a successful transmission by P_0
  - $S = GP_0$

Vulnerable Period/Contention Window

- A frame is successfully transmitted, if there are no frames transmitted in the contention window of 2T seconds



Frames Generated in Vulnerable Period

- Vulnerable Period: 2T seconds
- The rate of all transmissions in 2T seconds: 2G
- The probability that k frames are generated during 2T seconds is given by a Poisson distribution

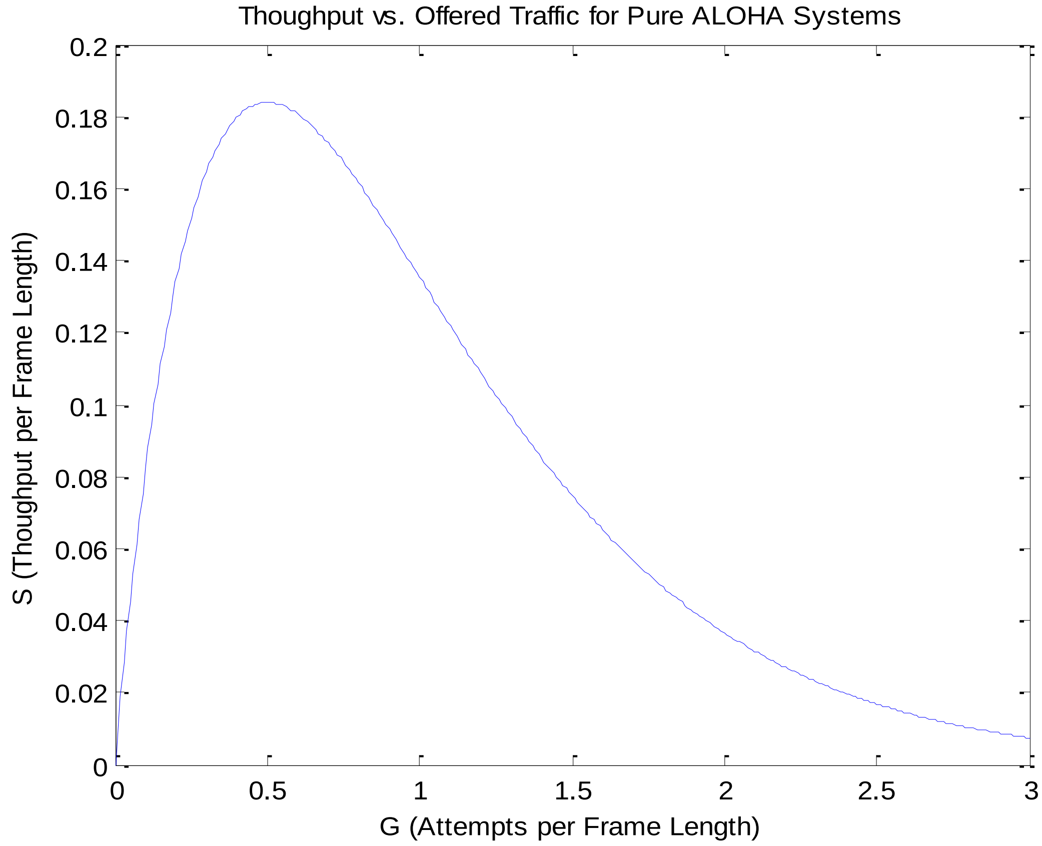
$$\Pr[k] = \frac{(2G)^k e^{-2G}}{k!}$$

- The probability of no other frames (0 frames) being generated (new transmission and retransmission) during the entire vulnerable period is

$$S = GP_0 = G\frac{(2G)^0 e^{-2G}}{0!} = Ge^{-2G}$$

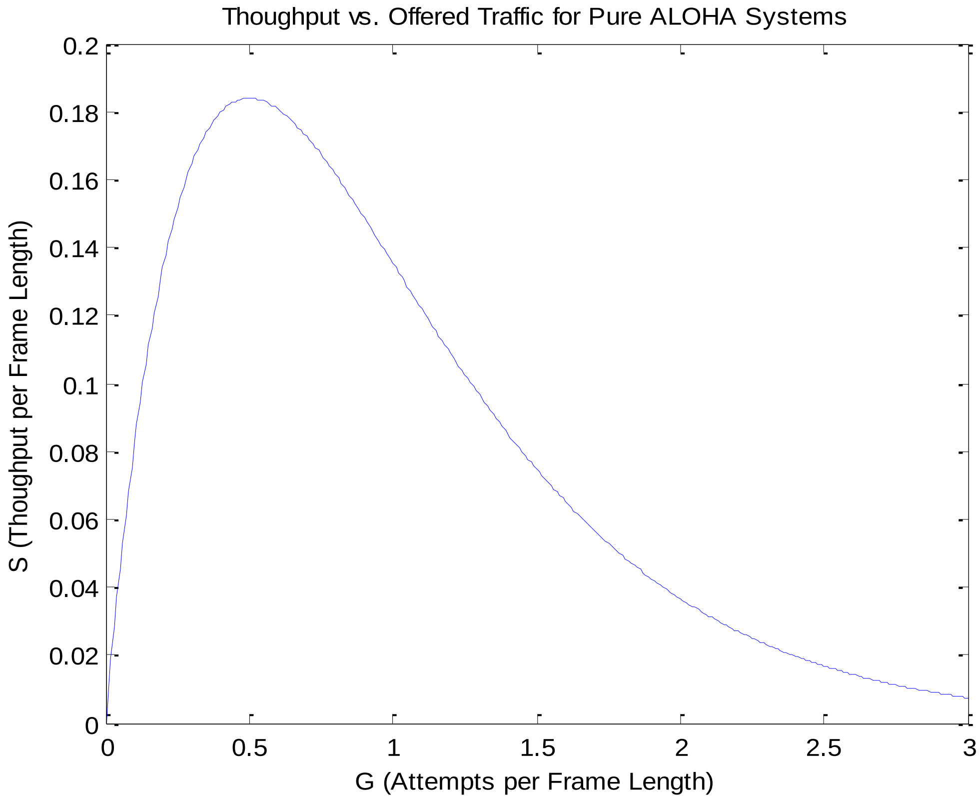
Throughput of Pure ALOHA

- Let us graph it $S = Ge^{-2G}$

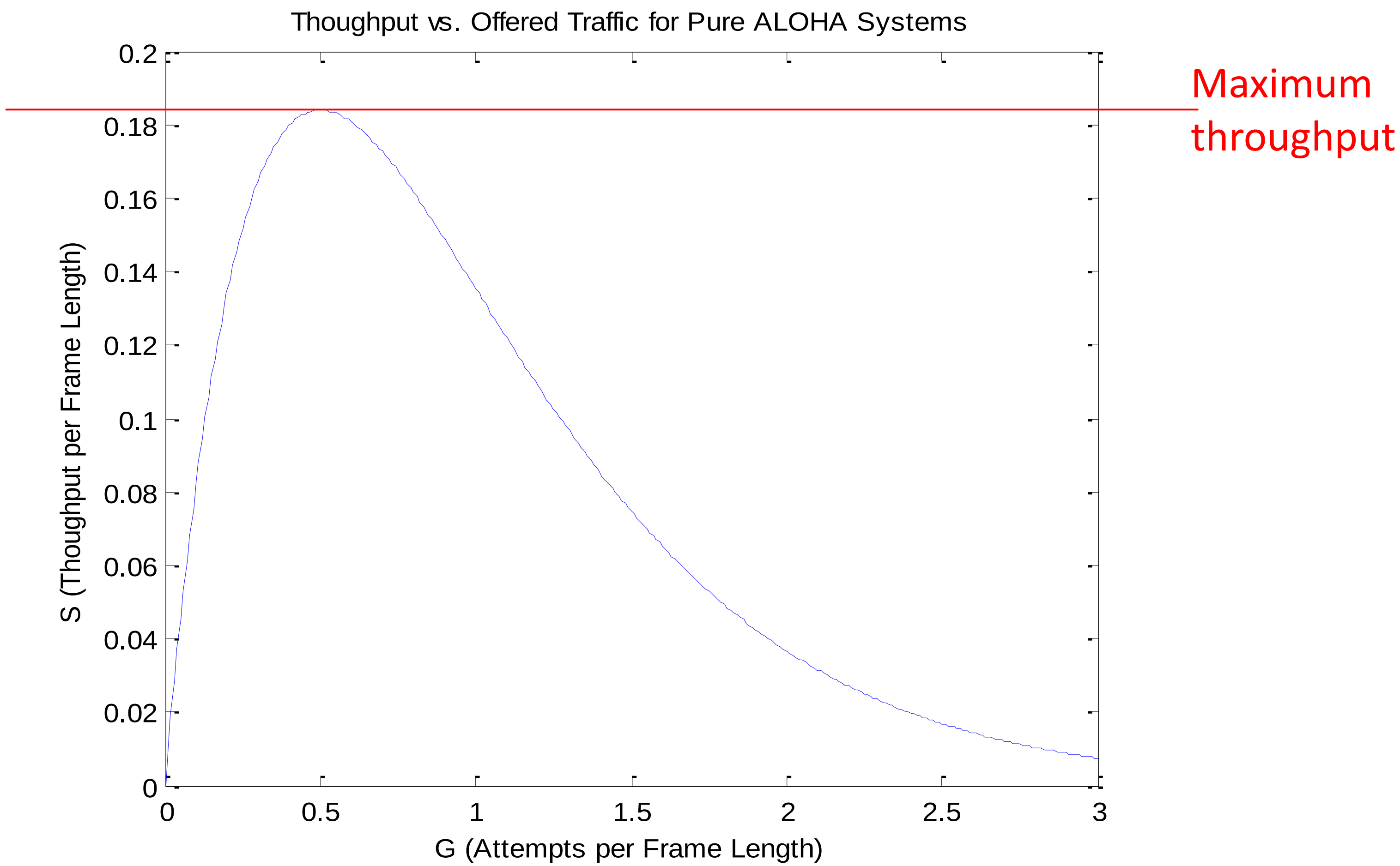


Throughput of Pure ALOHA

- What is the implication?



Maximum Throughput of Pure ALOHA



Maximum Throughput of Pure ALOHA

- The derivative is 0

$$S = Ge^{-2G}$$

$$\frac{dS}{dG} = \frac{dGe^{-2G}}{dG}$$

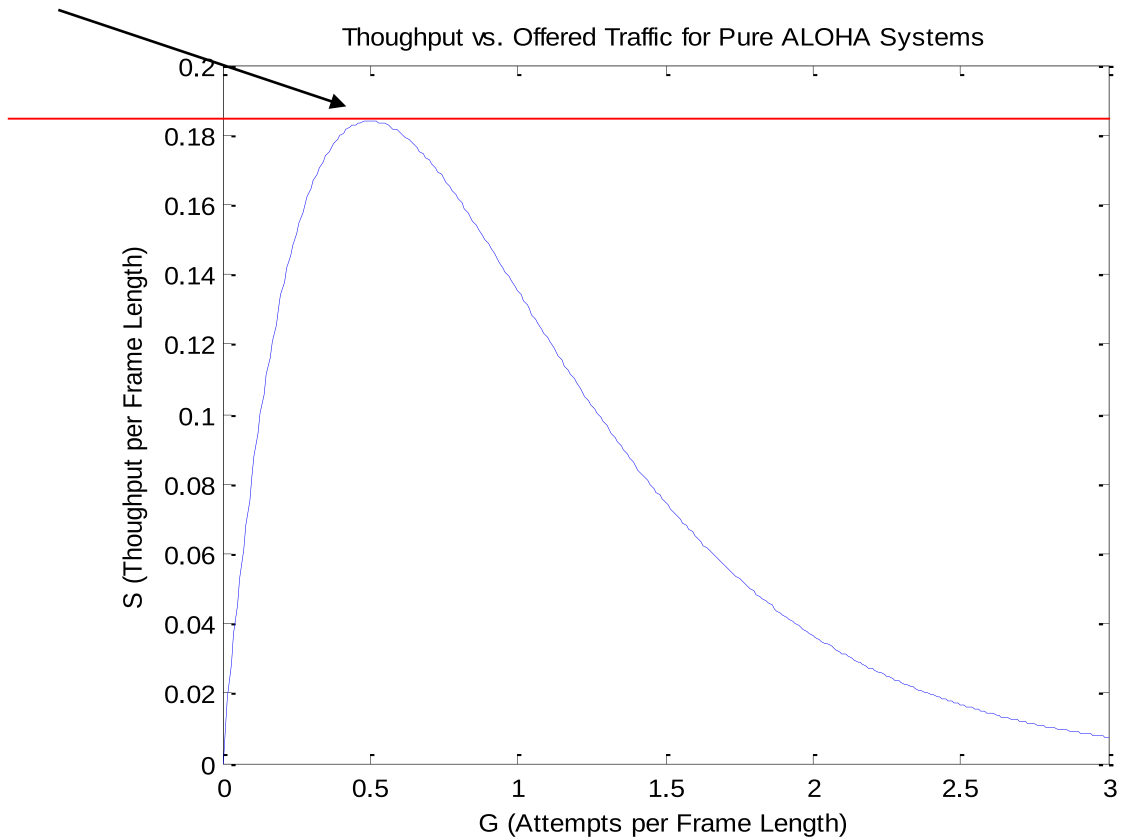
$$= e^{-2G} - 2Ge^{-2G}$$

$$\frac{dS}{dG} = e^{-2G} - 2Ge^{-2G} = 0$$

$$G^* = \frac{1}{2}$$

$$S = G^* e^{-2G^*}$$

$$= \frac{1}{2} e^{-2\frac{1}{2}} \approx 0.1839$$



Pure ALOHA: Remark

- Considered a simplified analysis of a pure Aloha
  - Found that the maximum throughput is limited to be at most 1/(2*e*).
  - Not taken into account
    - How the offered load changes with time
    - How the retransmission time may be adjusted.
- Channel utilization of a busy Pure ALOHA system is 18%
- What improvement can we make?

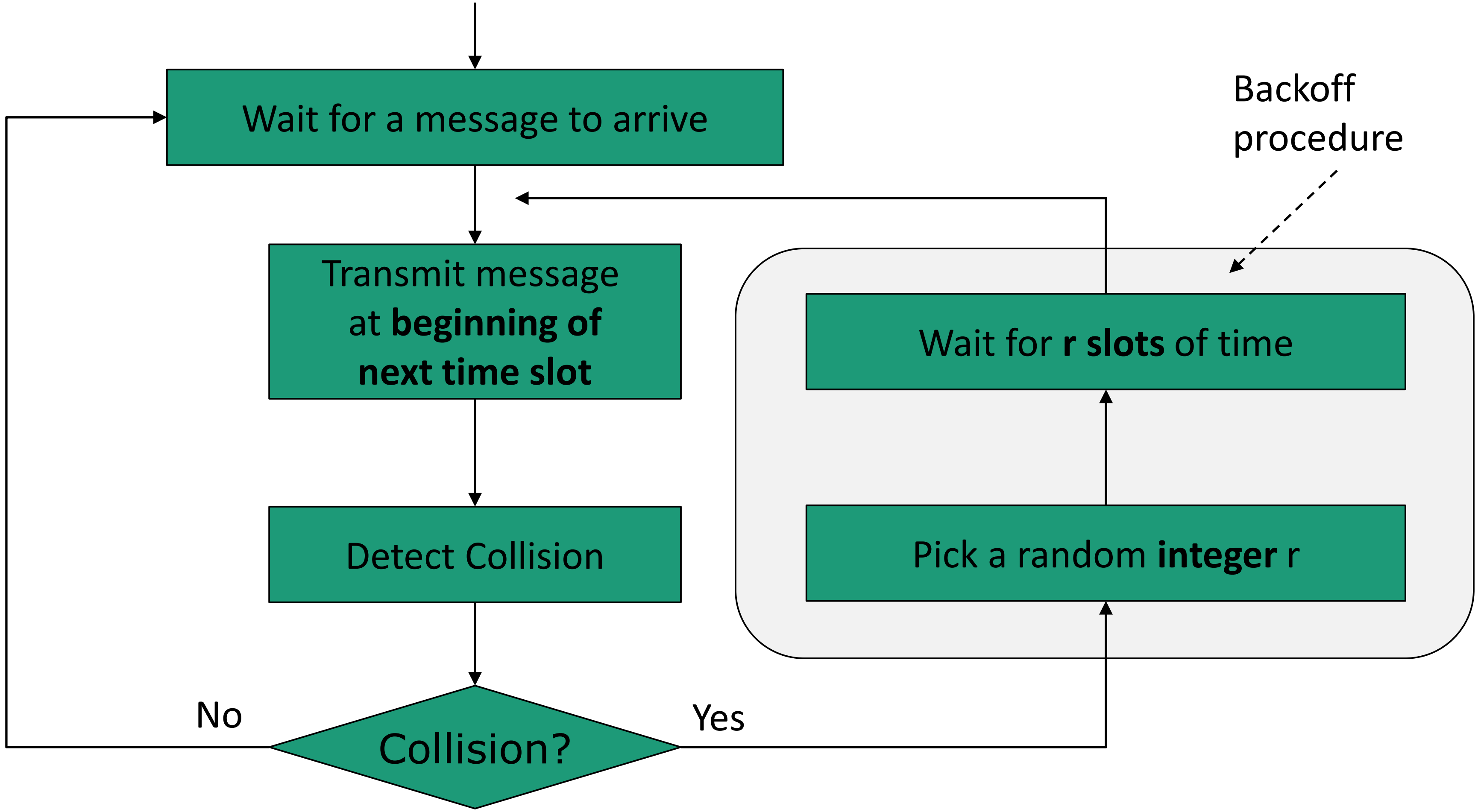
Pure ALOHA: Remark

- What improvement can we make?
  - Collision causes retransmission and reduces throughput
- Can we reduce chance of collisions?
  - Collisions happen within the Vulnerable Period/Contention Window.
  - Can we shorten the Vulnerable Period/Contention Window?
- Slotted ALOHA

Slotted ALOHA

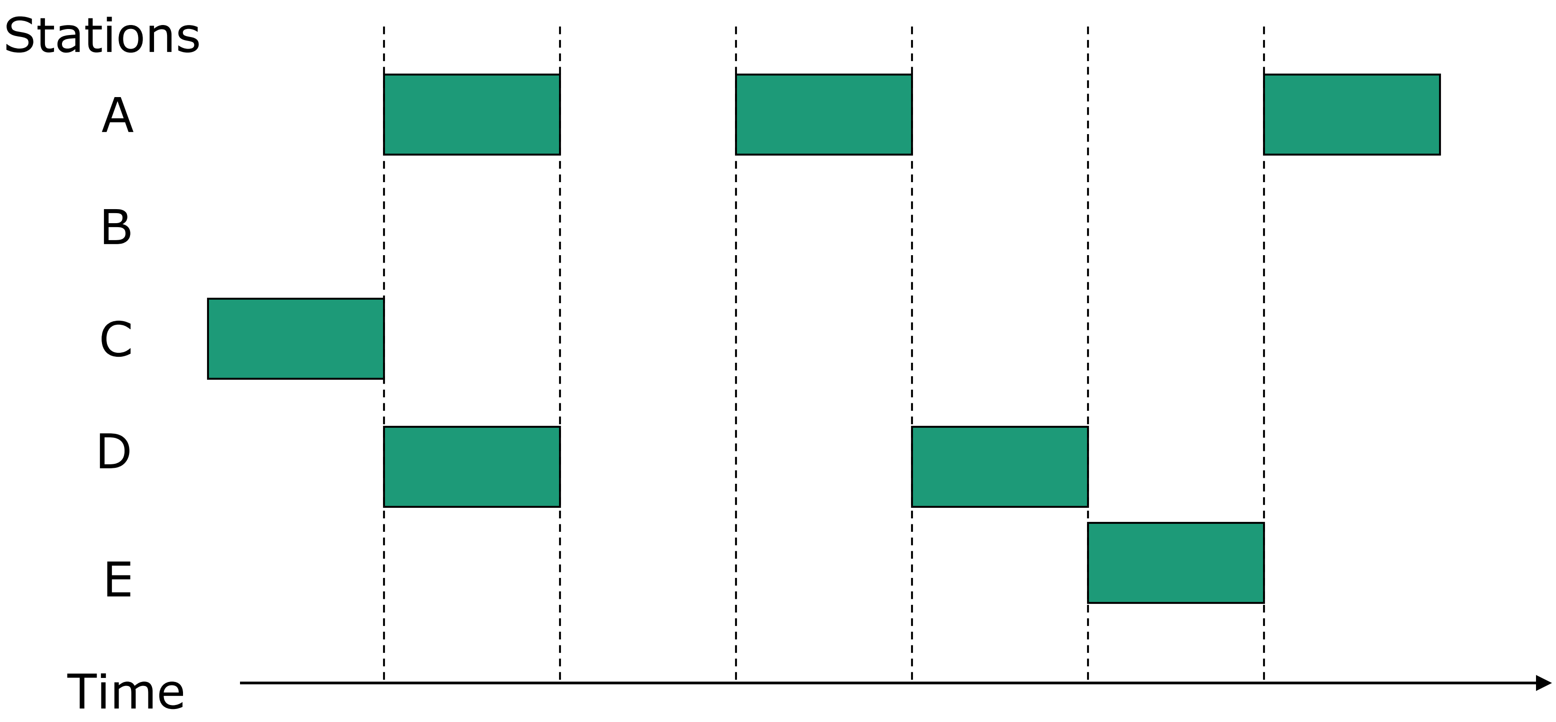
- Improvement to Pure ALOHA
  - Divided time into discrete intervals
  - Each interval corresponds to a frame
  - Require stations agree on slot boundaries

Slotted ALOHA: Protocol



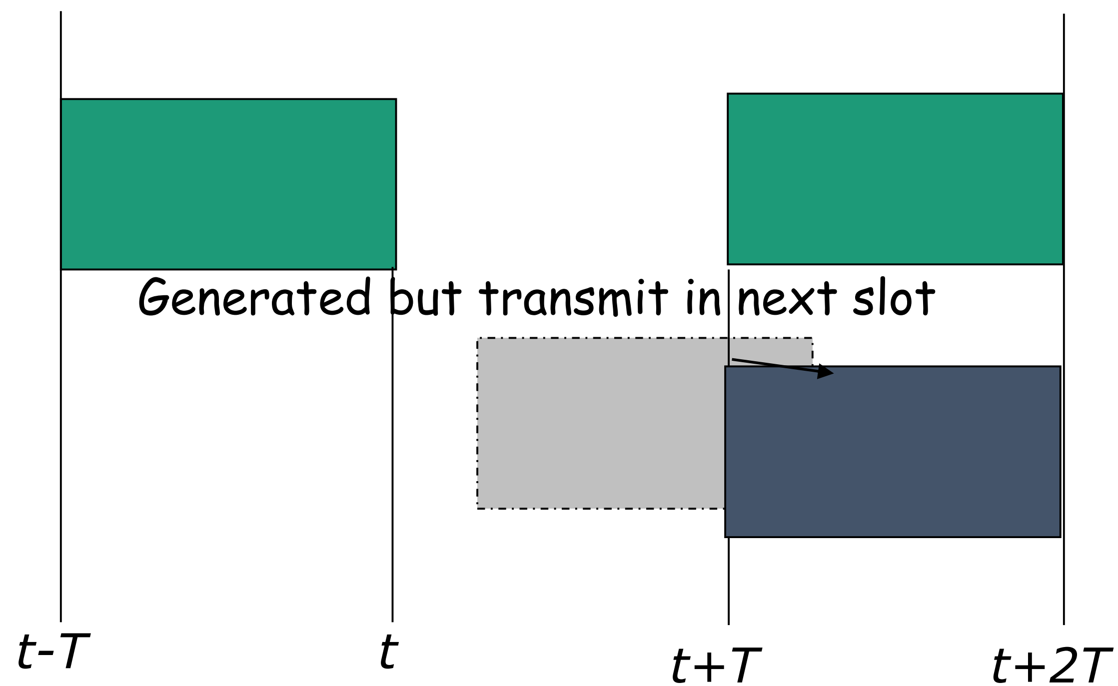
Slotted ALOHA: Throughput Analysis

- Time is slotted



Vulnerable Period/Contention Window

- A frame is successfully transmitted, if there are no frames transmitted in the contention window of T seconds



Frames Generated in Vulnerable Period

- Vulnerable Period: T seconds
- The rate of all transmissions in T seconds: G
- The probability that k frames are generated during T seconds is given by a Poisson distribution

$$\Pr[k] = \frac{G^k e^{-G}}{k!}$$

- The probability of no other frames being initiated (new transmission and retransmission) during the entire vulnerable period is

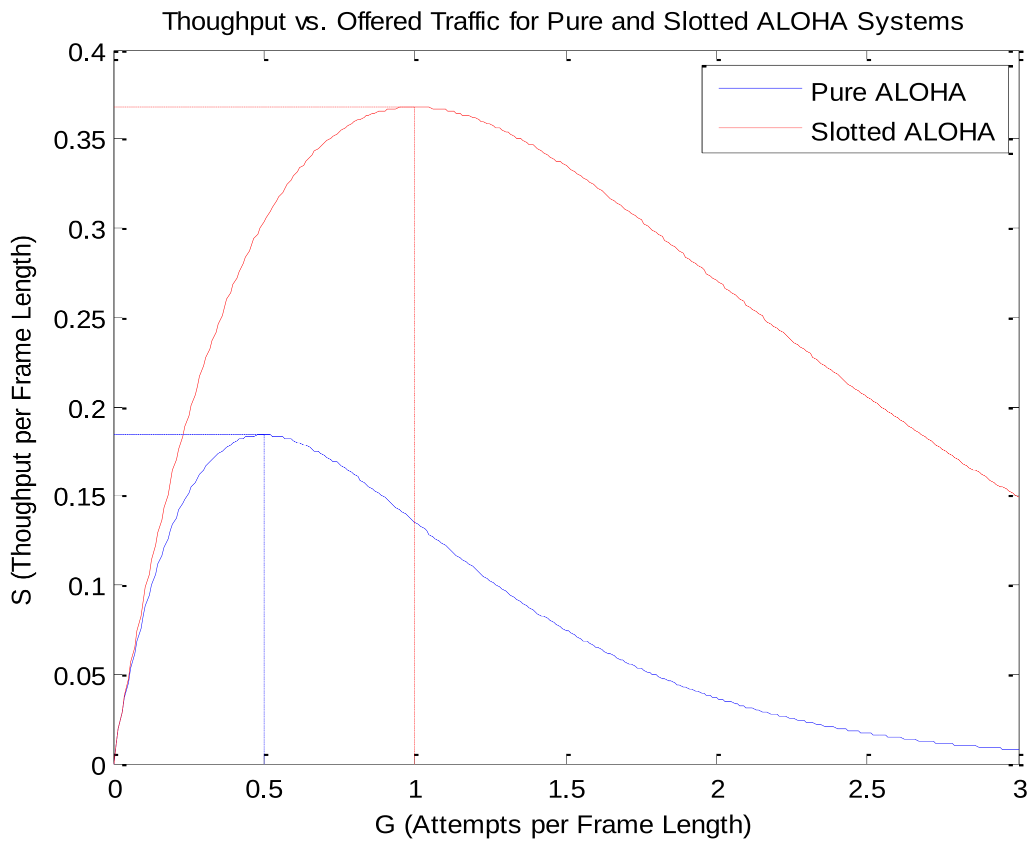
$$S = GP_0 = G\frac{G^0 e^{-G}}{0!} = Ge^{-G}$$

Throughput of Slotted ALOHA

- $S = Ge^{-2G}$

vs

- $S = Ge^{-G}$



Exercise 1

- Derive the maximum throughput of the Slotted ALOHA protocol
- How much is the maximum throughput?
- Note

$$S = Ge^{-G}$$

Exercise 2

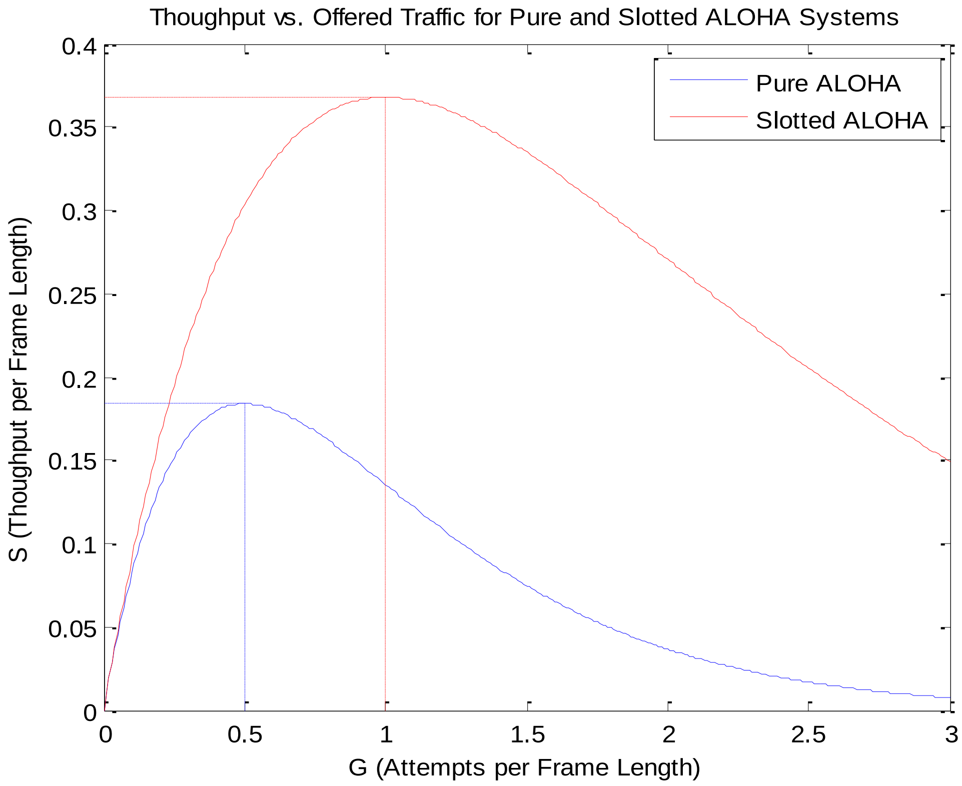
- In original ALOHA system, packets are of fixed size of 34 ms. Assume each active user sending a message packet at an average rate of once every 60 seconds. Estimate maximum number of users does the system can concurrently support?
- Answer:
  - Maximum throughput = maximum channel utilization = 1/(2e) → channel can only be *1/(2e)* full.
  - packet rate: $\lambda = 1/60$
  - Packet length: $\tau = 34$ ms
  - Maximum # of concurrent users: k_{max}
  - $k_{max}\lambda\tau = 1/(2e)$
  - $k = 1/(2e\lambda\tau) \approx 1/(2\times 2.7183\times 1/60\times 0.034) \approx 324$

Exercise 3

- In an ALOHA system, packets are 816 bits and link bandwidth is 24 kbps. Assume each active user sending a message packet at an average rate of once every 60 seconds. Estimate maximum number of users does the system can concurrently support?
- Answer:
  - Maximum throughput = maximum channel utilization = 1/(2e) → channel can only be *1/(2e)* full.
  - packet rate: $\lambda = 1/60$
  - Packet length: $\tau = 816/24\ kbps = 816/24000 = 0.034\ sec = 34\ ms$
  - Maximum # of concurrent users: k_{max}
  - $k_{max}\lambda\tau = 1/(2e)$
  - $k = 1/(2e\lambda\tau) \approx 1/(2\times2.7183\times1/60\times0.034) \approx 324$

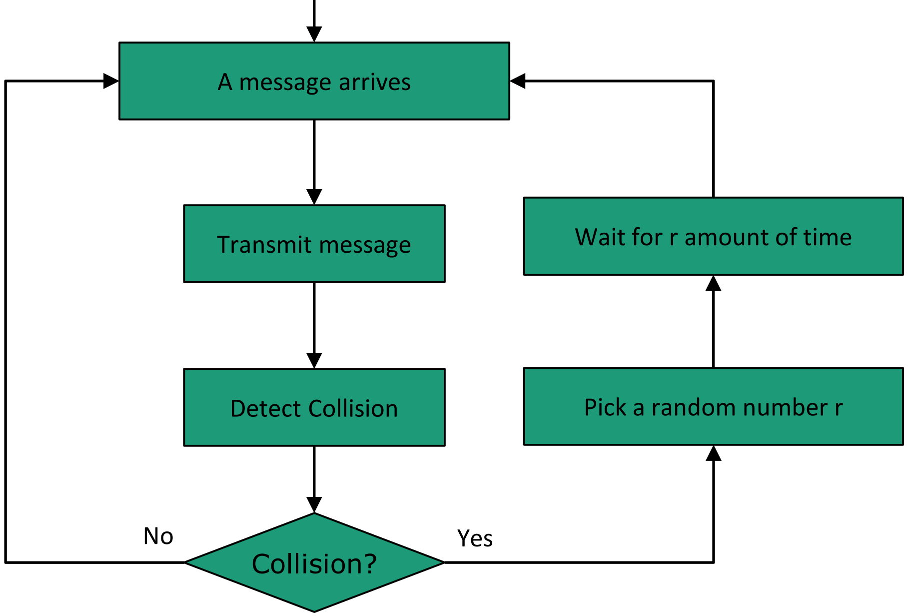
Making Further Improvements?

- Maximum throughputs are small

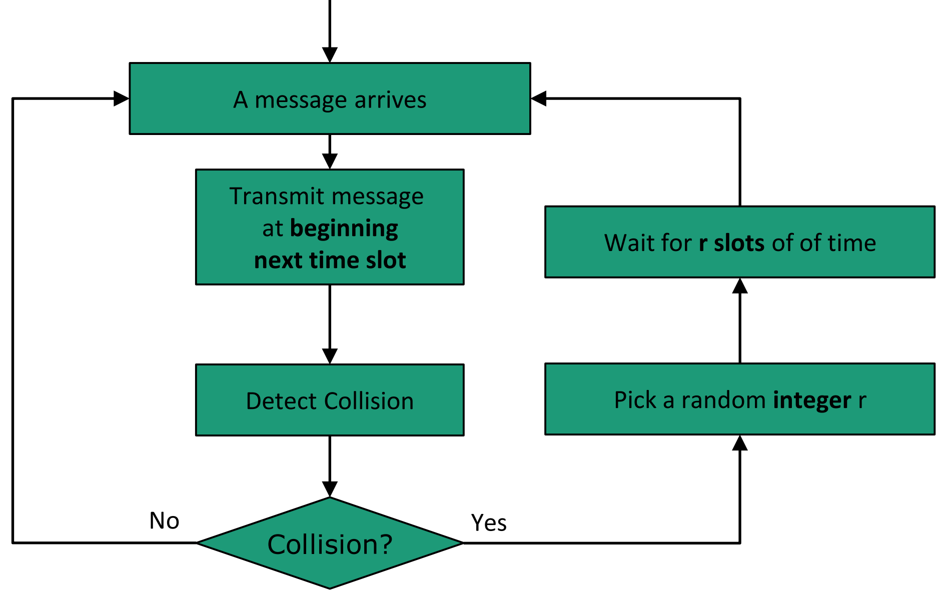


Making Further Improvements?

Pure ALOHA

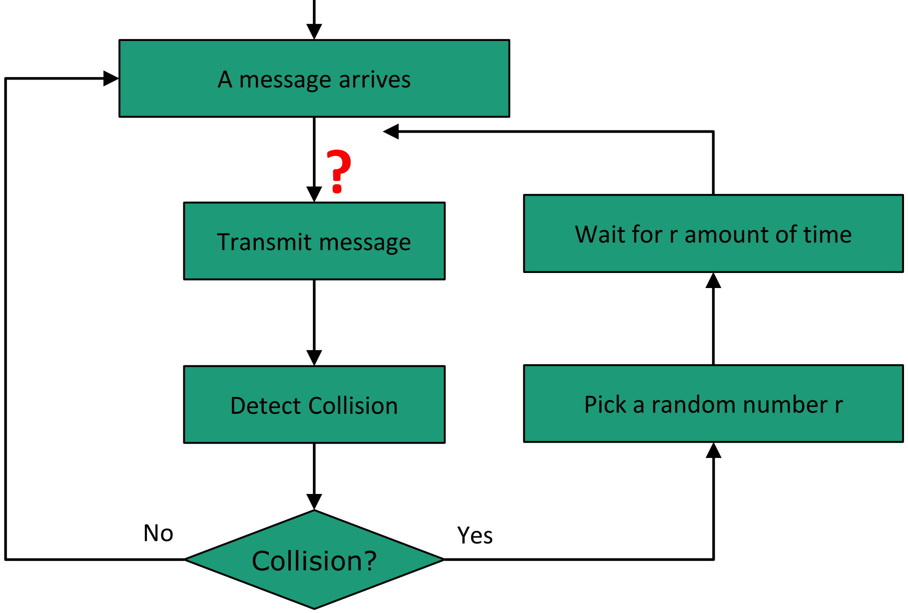


Slotted ALOHA

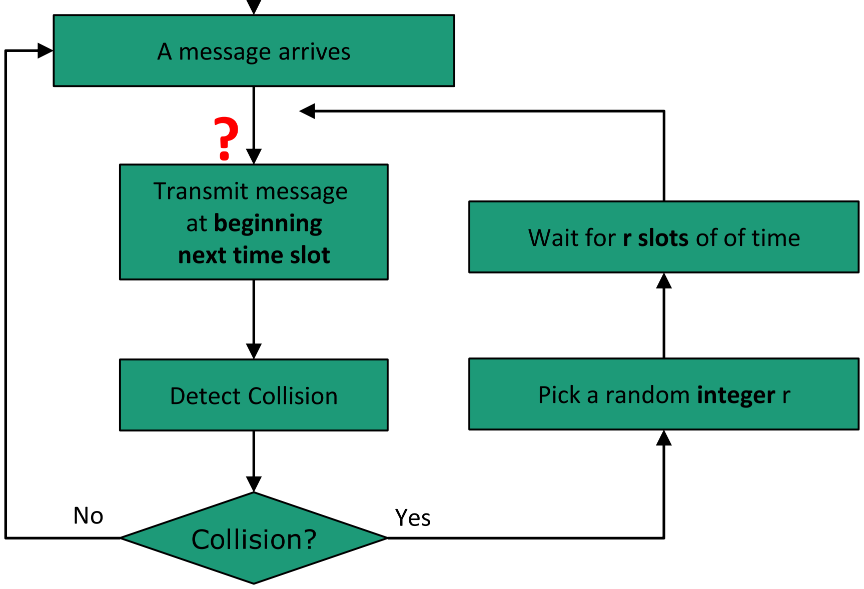


Making Further Improvements?

Pure ALOHA



Slotted ALOHA



- *ALOHA transmits even if another node is transmitting → collision*

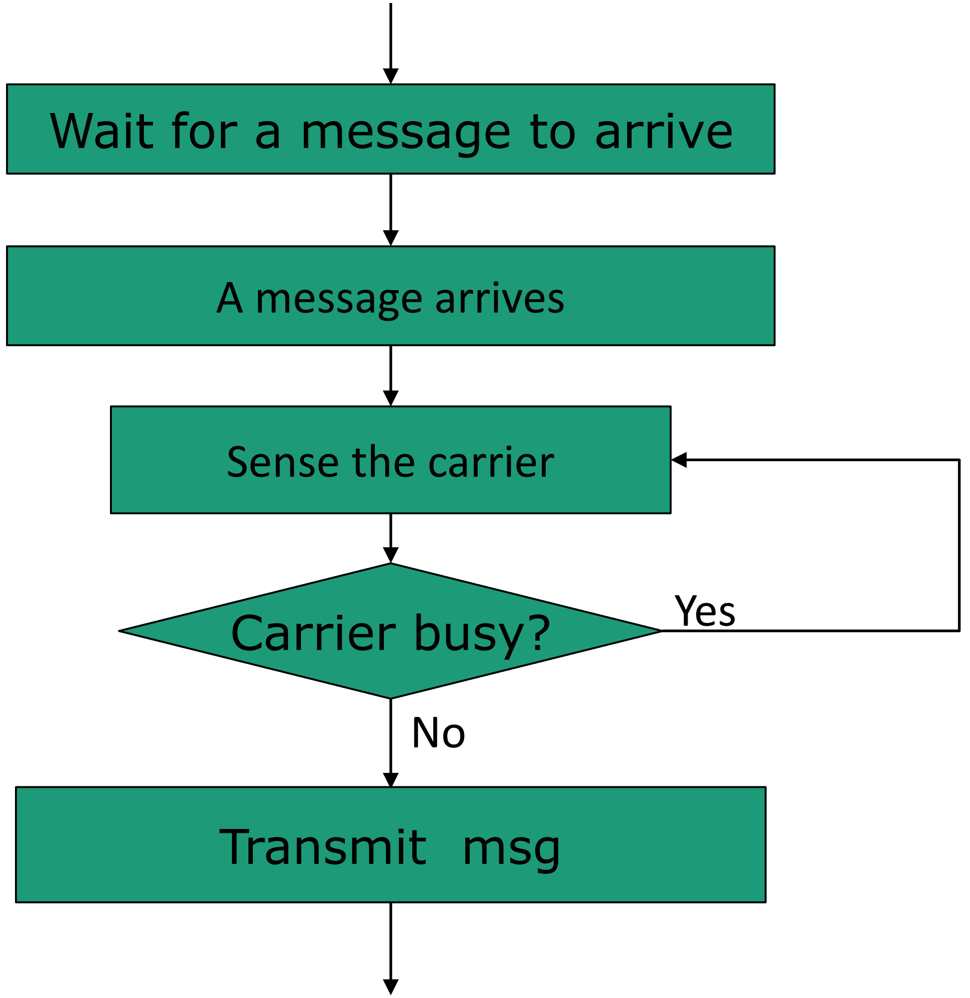
Carrier Sense

- If another transmits, don’t transmit
- i.e., Listen first, transmit when the channel is idle → reduce chance of collision

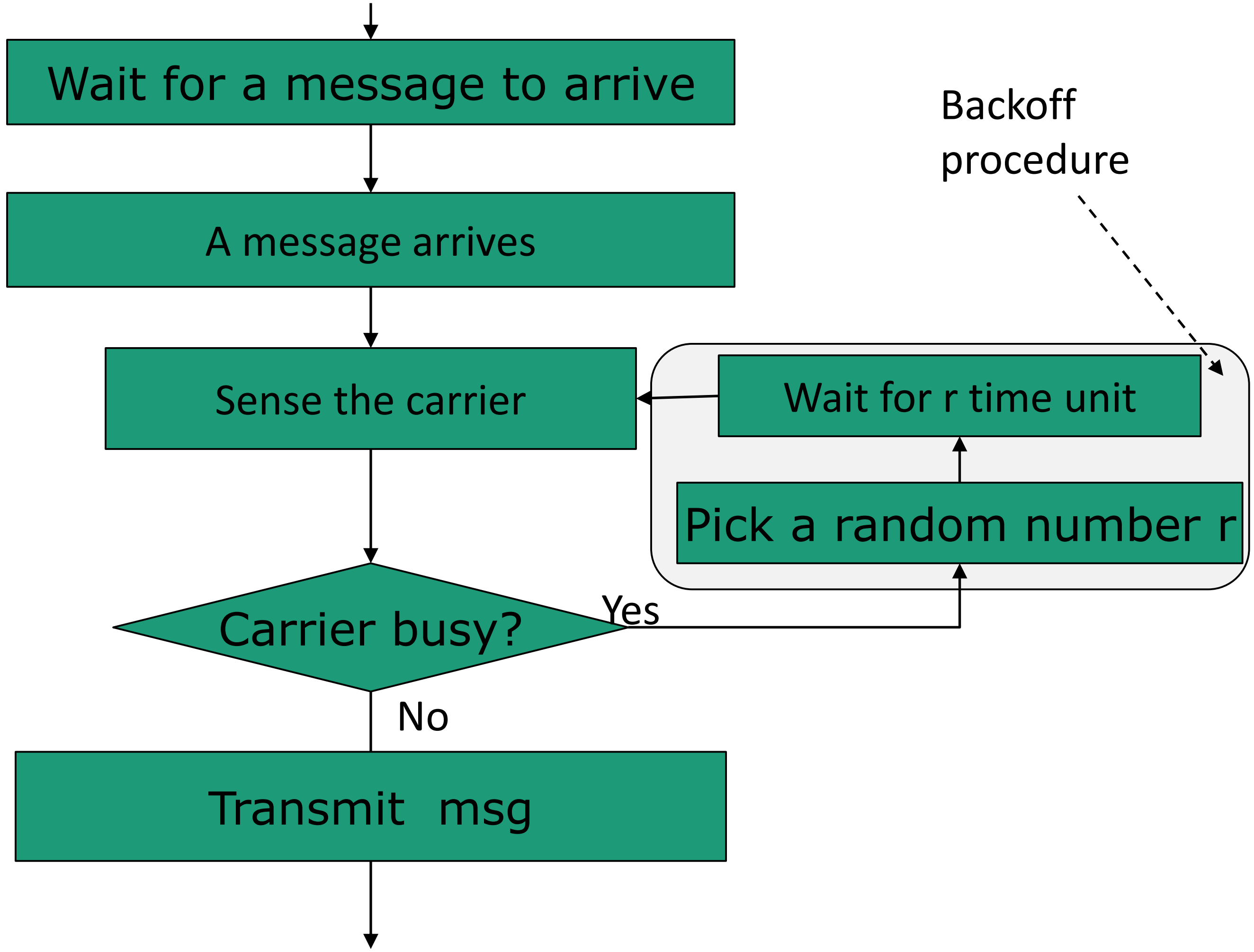
Carrier Sense (without Collision Detection)

- Non-persistent CSMA
  - Transmit after a random amount of waiting time regardless if channel is idle (from carrier sense)
  - Large delay when channel is idle
- 1-persistent CSMA
  - Transmit as soon as the channel becomes idle
  - Collision happens when two or more nodes all want to transmit
- p-persistent CSMA
  - If idle, transmit the frame with a probability p

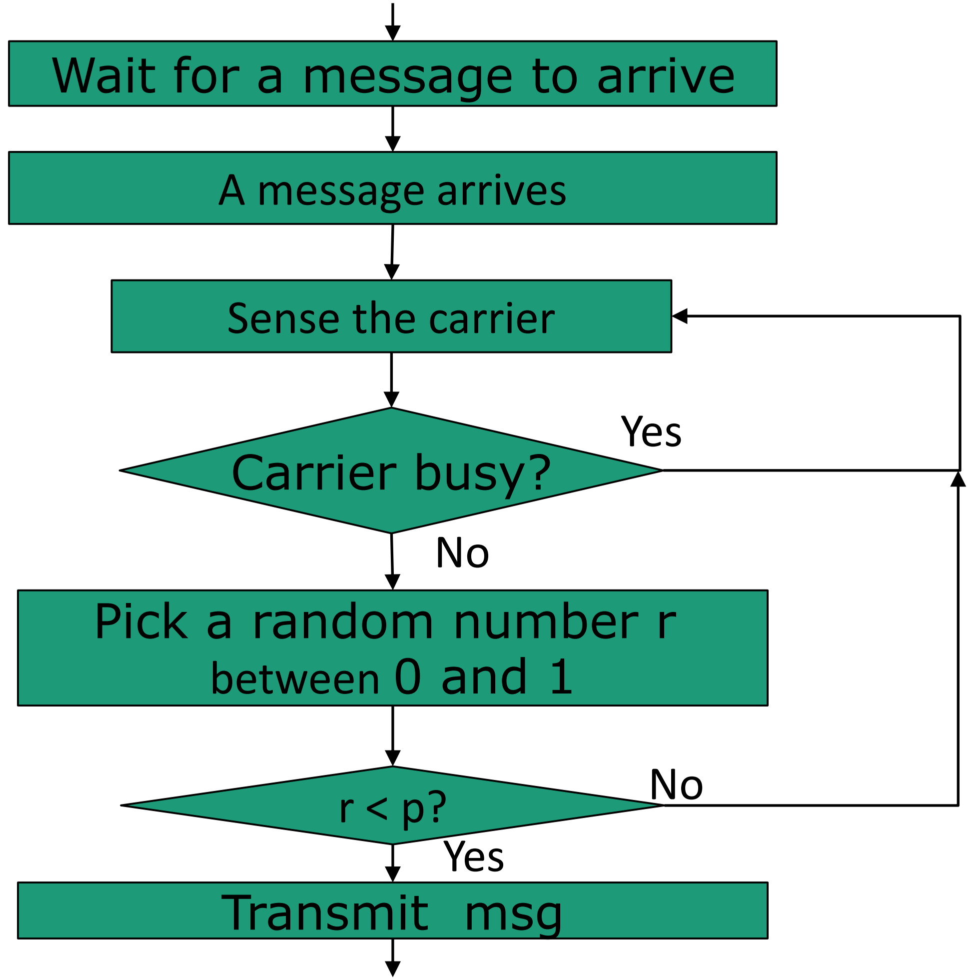
1-persistent CSMA



Non-persistent CSMA



p-persistent CSMA



Comparison of Throughput

- Pure ALOHA
- Slotted ALOHA
- Nonpersistent CSMA
- 1-persistent CSMA
  - Unslotted
  - Slotted
- p-persistent CSMA
  - skipped

$$S = Ge^{-2G}$$

$$S = Ge^{-G}$$

$$S = \frac{Ge^{-aG}}{G(1+2a)+e^{-aG}}$$

$$S = \frac{G\left[1+G+aG\left(1+G+aG/2\right)\right]e^{-G(1+2a)}}{G\left(1+2a\right)-\left(1-e^{-aG}\right)+\left(1+aG\right)e^{-G(1+a)}}$$

$$S = \frac{Ge^{-G(1+a)}\left[1+a-e^{-aG}\right]}{\left(1+a\right)\left(1-e^{-aG}\right)+ae^{-G(1+a)}}$$

Comparison of Throughput

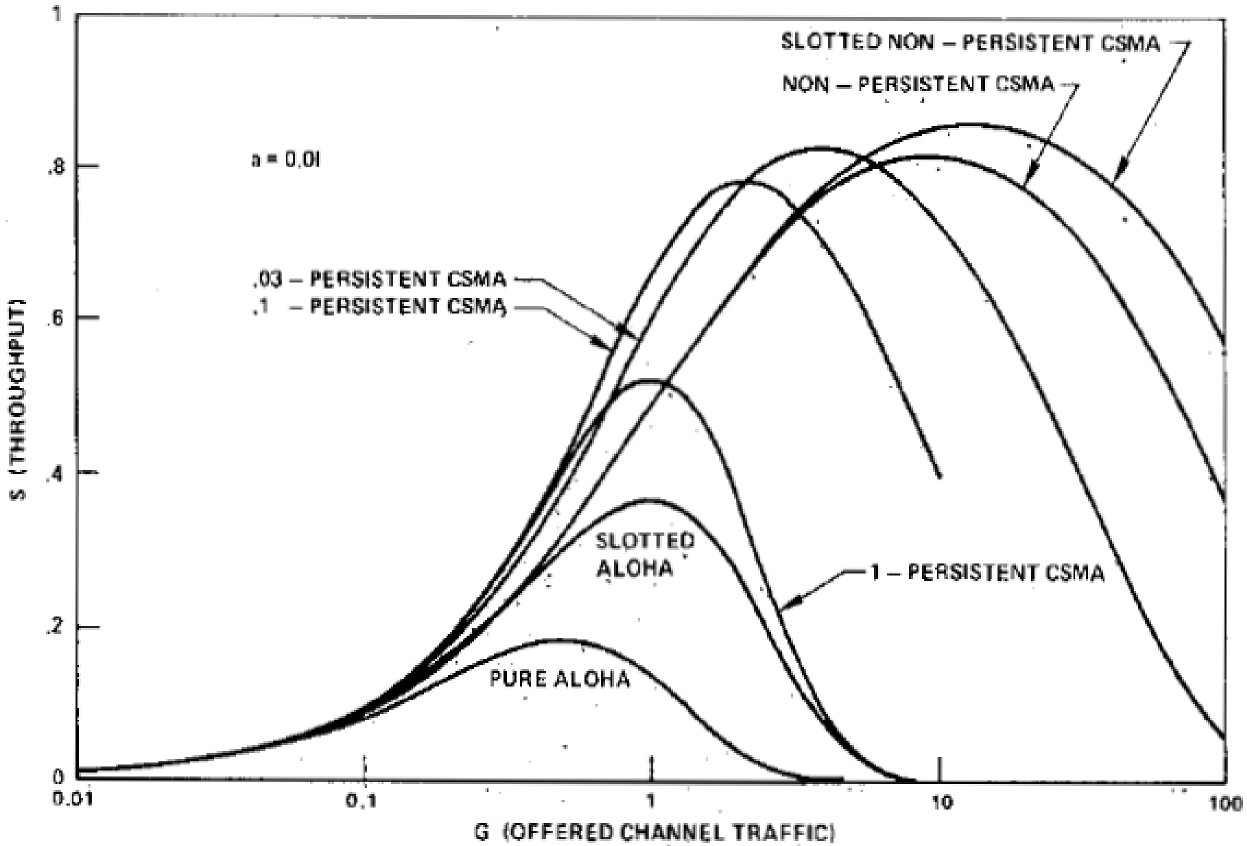


Fig. 9. Throughput for the various access modes ($a = 0.01$).

From LEONARD KLEINROCK, 1975

Carrier Sense

- Listen first, transmit when the channel is idle → reduce chance of collision
- Can collisions be **completely** mitigated?

Carrier Sense

- Listen first, transmit when the channel is idle → reduce chance of collision
- Can collisions be **completely** mitigated?
- Q: Under what condition can Carrier Sense be more beneficial to throughput?

Examining Two Cases

- Case 1: a land-based wireless network
  - 1000-bit frame sent over a 100 kbps link
  - Sender and receiver are 10 km apart
  - Q: calculate transmission time and propagation delay
- Case 2: a satellite wireless network
  - Geostationary satellite orbits are ~36,000 km above sea level
  - Q: calculate transmission time and propagation delay between the satellite and a ground station provided the frame size is the same

Examining Two Cases

Case 1

$$t_{TX1} = \frac{1000}{100 \times 1000} = \frac{1}{100}\sec = 10\,ms$$

$$t_{p1} = \frac{10 \times 10^3}{3 \times 10^8} = \frac{1}{3} \times 10^{-4} \approx 0.000033\sec = 0.033\,ms$$

$$t_{TX1} >> t_{p1}$$

Case 2

$$t_{TX2} = \frac{1000}{100 \times 1000} = \frac{1}{100}\sec = 10\,ms$$

$$t_{p2} = \frac{36000 \times 10^3}{3 \times 10^8} = 0.12\sec = 120\,ms$$

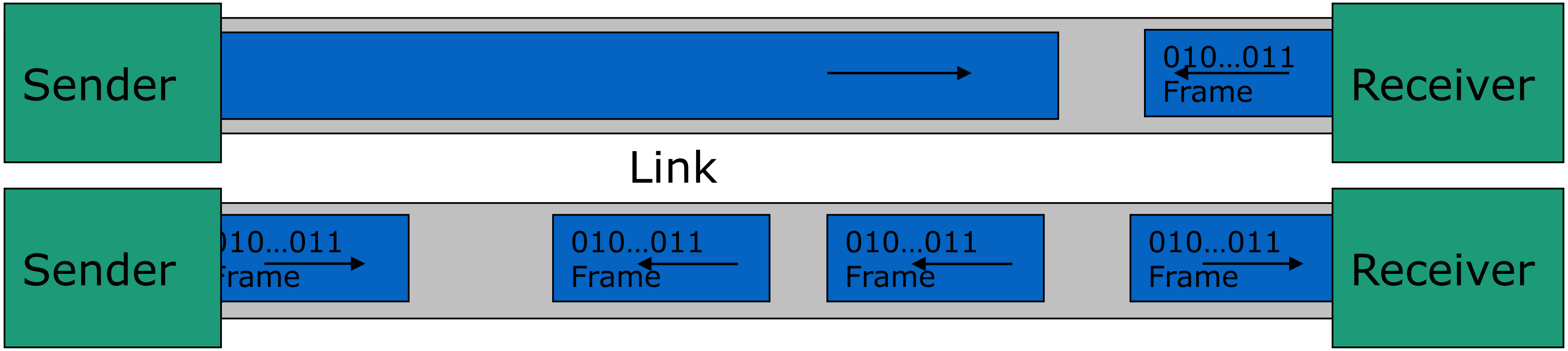
$$t_{TX2} << t_{p2}$$

- Q: which case can be benefited more from “carrier sense”?

Propagation Delay vs. Transmit Time

- Two stations: A and B
  - A begins sending frame 1.
  - Before frame 1 arrives at B, B becomes ready and sense the channel
  - Channel is clear, B sends frame 2
  - Will Frames 1 and 2 collide?
  - Consider a special case: what if propagation delay is 0?
- The longer the propagation delay (versus frame size) is , the more carrier sense helps
- Image there are three or more stations
  - Collision can happen even if propagation delay is 0 when carrier sense is employed
  - Why?

Propagation Delay vs. Transmit Time



Carrier Sense and Collision

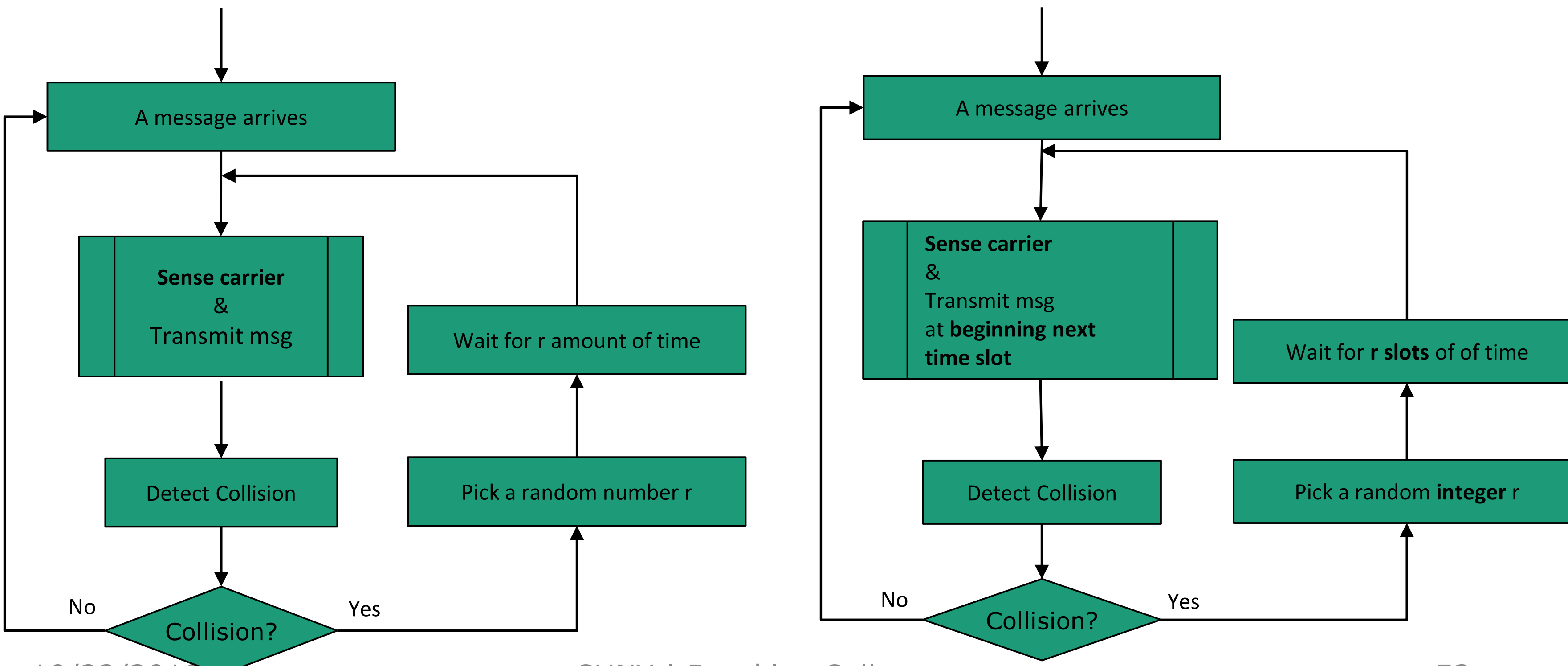
- Even with CSMA there can still be collisions.
- What do Pure ALOHA and Slotted ALOHA do?

Collision Detection

- If nodes detect collisions, abort transmissions!
  - Requires a minimum frame size (“acquiring the medium”)
  - Continues to transmit a jamming signal (called runt) until other nodes detects it
  - Requires a full duplex channel

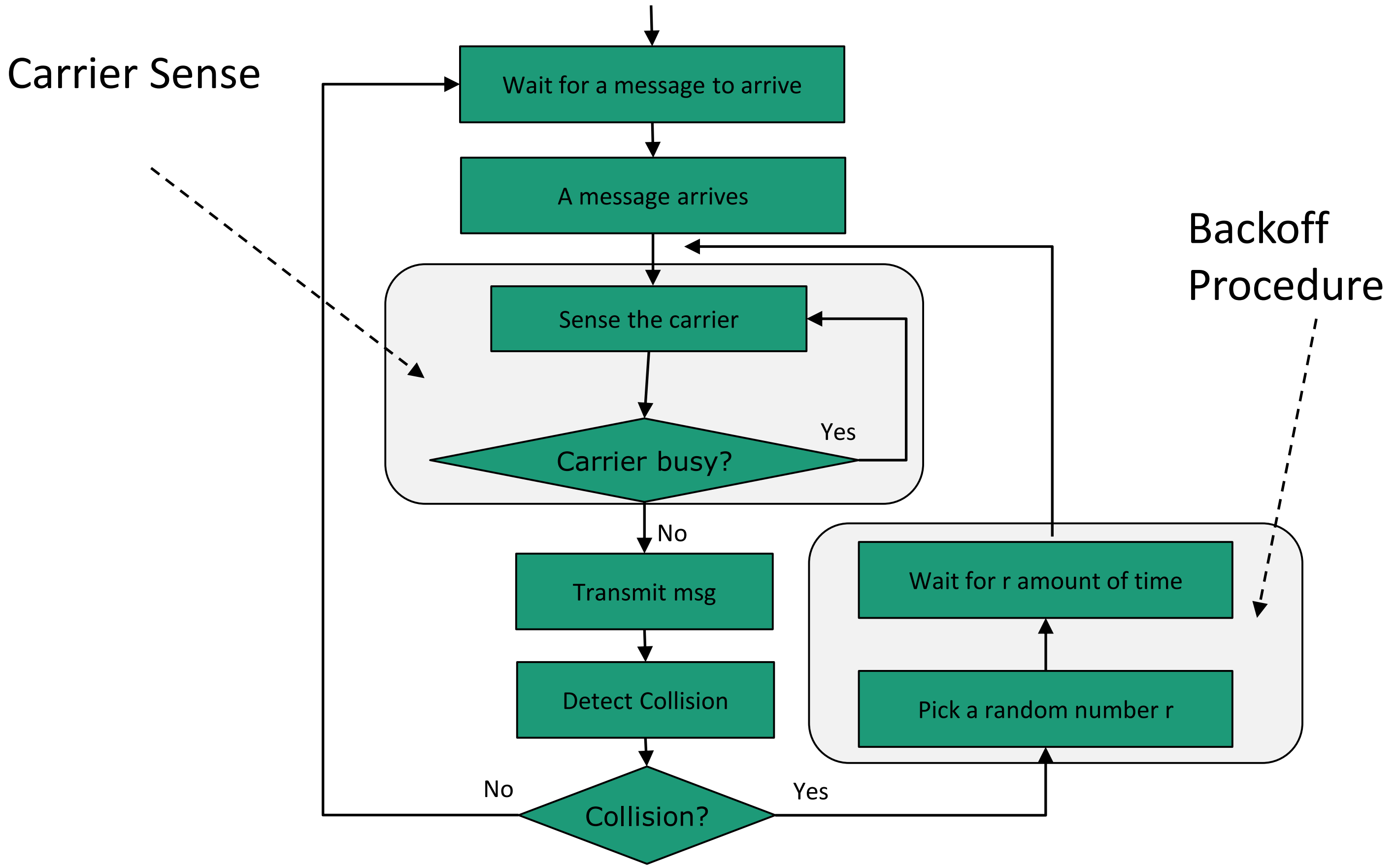
Complete the Picture

- Carrier Sense Multiple Access and Collision Detection



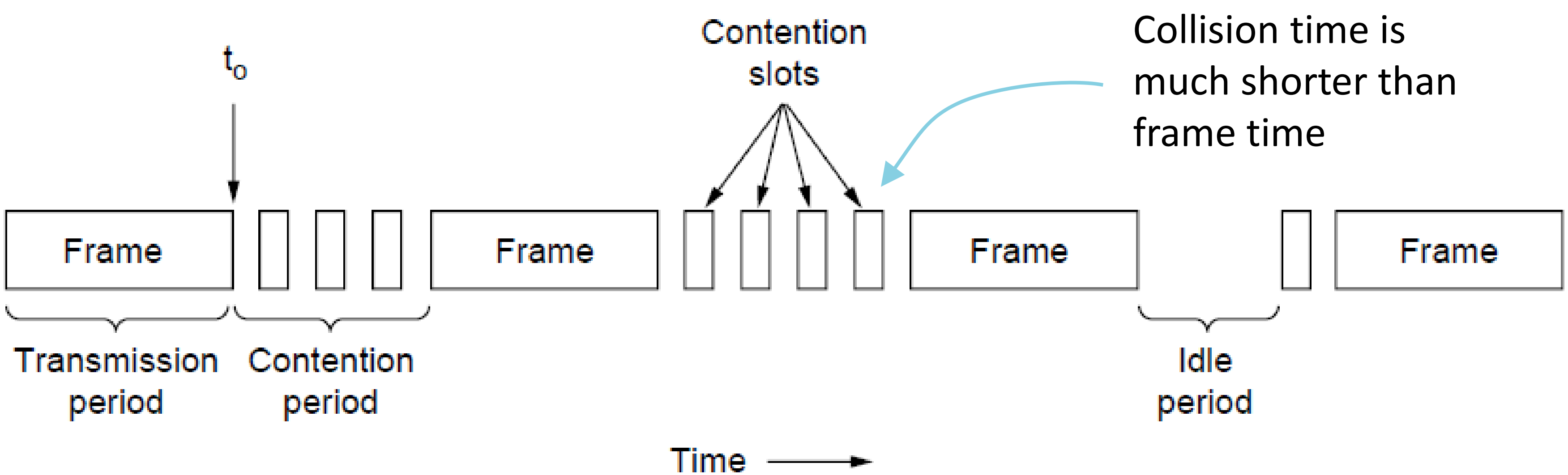
CSMA/CD

- 1-Persistent CSMA and CD



Collision Detection

- CSMA/CD improvement is to detect/abort collisions
  - Reduced contention times improve performance



Questions?

- ALOHA
- Carrier sense
- Collision detection
- CSMA/CD