L6: Building Direct Link Networks IV

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# Acknowledgements

- Some pictures used in this presentation were obtained from the Internet

- The instructor used the following references
  - Larry L. Peterson and Bruce S. Davie, Computer Networks: A Systems Approach, 5th Edition, Elsevier, 2011
  - Andrew S. Tanenbaum, Computer Networks, 5th Edition, Prentice-Hall, 2010
  - James F. Kurose and Keith W. Ross, Computer Networking: A Top-Down Approach, 5th Ed., Addison Wesley, 2009
  - Larry L. Peterson's (http://www.cs.princeton.edu/~llp/) Computer Networks class web site
  - Shun Y. Cheung, Introduction to Computer Networks (http://www.mathcs.emory.edu/~cheung/Courses/455/index.html)

Direct Link Networks

- Types of Networks
  - Point-to-point
  - Multiple access
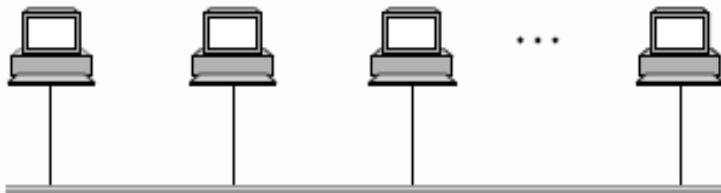
- Encoding
  - Encoding bits onto transmission medium
- Framing
  - Delineating sequence of bits into messages
- Error detection
  - Detecting errors and acting on them
- Reliable delivery
  - Making links appear reliable despite errors
- **Media access control**
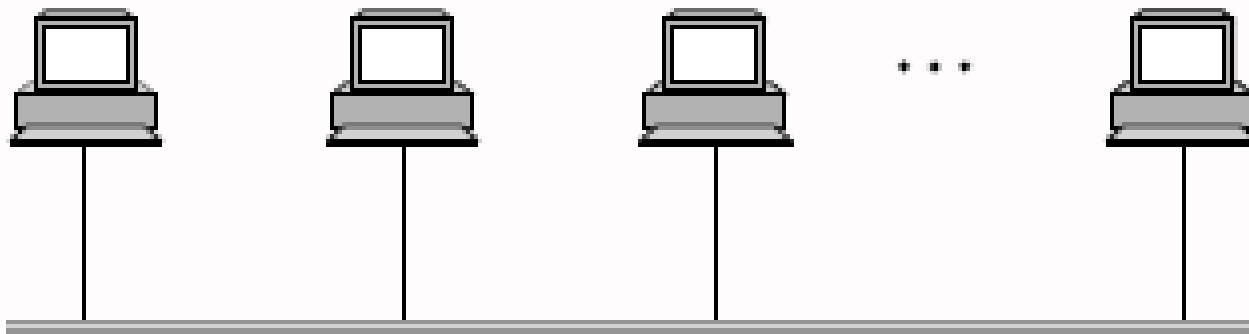 - **Mediating access to shared link**

Outlines

- ☐ Media Access Control
- ☐ Contention Resolution Approaches
  - ■ Performance analysis
- ☐ Ethernet

Multiple Access Network

- More than two nodes share a single physical link
  - Bus (Ethernet/802.3)
  - Ring (Token-ring/802.5)
  - Wireless (Wireless LAN/802.11)

Multiple Access Networks

- ☐ Characteristics
  - ■ A transmitter can be heard by multiple receivers
  - ■ A receiver can hear multiple transmitters
- ☐ Problems
  - ■ How to identify nodes?
    - ☐ Cannot identify node by stating "the sender" and "the receiver"
    - ☐ Addressing
  - ■ How to mediate nodes' access to the link?
    - ☐ Interference and collision of transmission
    - ☐ Media access control

Media Access Control

❑ How to allocate a multi-access channel among multiple competing users

   ▪ Rules that each node must follow to communicate and avoid interference and collision

Media Access Control Approaches

- Can be classified into two categories
  - Static
    - Channel's capacity is divided into fixed portions
    - Each node is allocated a portion for all time
    - Better suited when traffic is predictable
    - Examples: TDMA, FDMA, and CDMA
  - Dynamic
    - Allocate channel capacity based on the traffic generated by the users
    - Try to obtain better channel utilization and delay when traffic is unpredictable
    - Examples: ALOHA, Slotted ALOHA, and MACA

Dynamic Channel Allocation

☐ Perfectly scheduled approaches

☐ Contention resolution approaches

☐ Approaches that combined both scheduling and contention resolution

Perfectly Scheduled Approaches

- ☐ A schedule is dynamically formed based on which users have data to send
- ☐ Users transmit contention free according to the schedule
- ☐ Schedule can be formed by polling, reservation, etc.

Contention Resolution Approaches

- Contention
  - A node transmits a packet when it has data to send
  - A collision occurs if multiple nodes transmit at the same time
  - Packets/Frames must be retransmitted based on some rule
- Examples
  - Pure ALOHA, Slotted ALOHA
  - MACA, MACAW
  - CSMA, CSMA/CD and CSMA/CA
  - D-MAC

Performance Metrics

- Latency (delay)
  - In particular, when traffic load is low
- Throughput (channel efficiency)
  - In particular, when traffic load is high
- Jitter

Performance Analysis

- Multiple-access model
- Pure ALOHA
- Slotted ALOHA
- CSMA

Performance Analysis

◻ References and Further Readings

▪ Kleinrock, L.; Tobagi, F.A, "Packet Switching in Radio Channels: Part I--Carrier Sense Multiple-Access Modes and Their Throughput-Delay Characteristics," Communications, IEEE Transactions on , vol.23, no.12, pp.1400,1416, Dec 1975. doi: 10.1109/TCOM.1975.1092768.

▪ Abramson, Norman, "Development of the ALOHANET," Information Theory, IEEE Transactions on , vol.31, no.2, pp.119,123, Mar 1985. doi: 10.1109/TIT.1985.1057021.

Multiple-Access Model

- ❑ User Model
  - ■ N users (nodes, or stations).
  - ■ At each station, frames to be transmitted randomly arrive
  - ■ The arrivals are independent of each other
- ❑ Channel model
  - ■ All communications of the N users rely on one single shared channel
- ❑ Transmission model
  - ■ Frames are garbled and cannot be received, whenever the frames overlap in time (called a *collision*)
  - ■ Only errors allowed are introduced by collisions. If no collisions, a frame is successfully received
- ❑ Feedback model
  - ■ All stations are able to detect if a frame is collided with another or successfully sent after a complete frame is sent

Approaches in Feedback Model

- Listen while transmitting
  - Typically, collisions can be detected in a delay of ~RTT
    - Ethernet (link length, 4 segments, 2500 meter): 51.2 µs
    - Satellite: it may take as much as 270 ms delay
- If not possible, acknowledgements are used
  - *Not* until recently is it considered *possible to listen while transmitting* on wireless networks
  - Dinesh Bharadia, Emily McMilin, and Sachin Katti. 2013. Full duplex radios. In *Proceedings of the ACM SIGCOMM 2013 conference on SIGCOMM* (SIGCOMM '13). ACM, New York, NY, USA, 375-386. DOI=10.1145/2486001.2486033. http://doi.acm.org/10.1145/2486001.2486033

Pure ALOHA

- Initially developed by Norman Abramson, University of Hawaii in 1970's
- Served as a basis for many contention resolution protocols
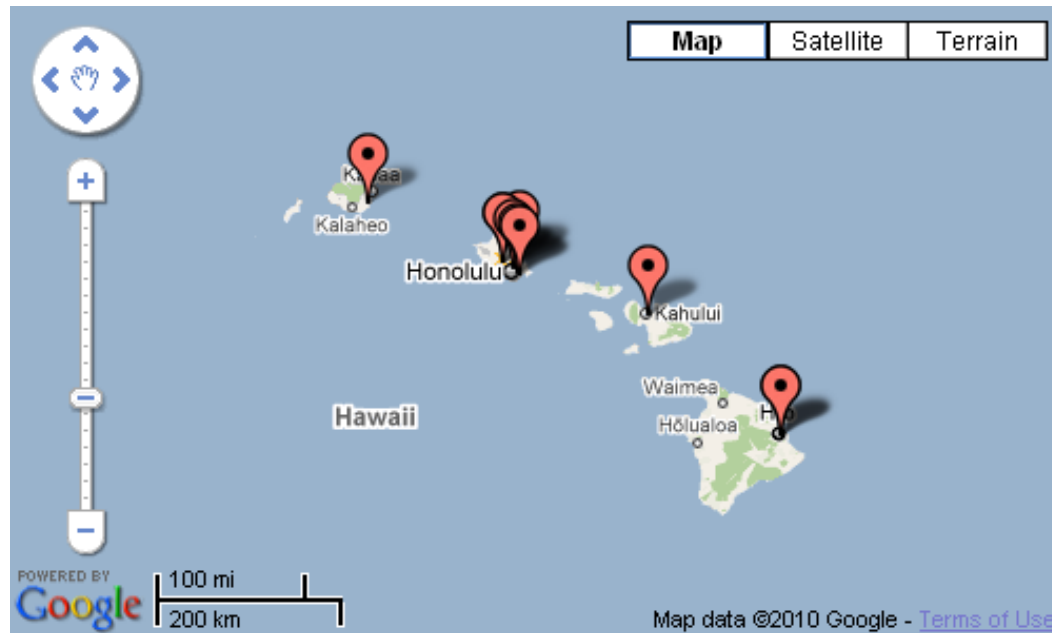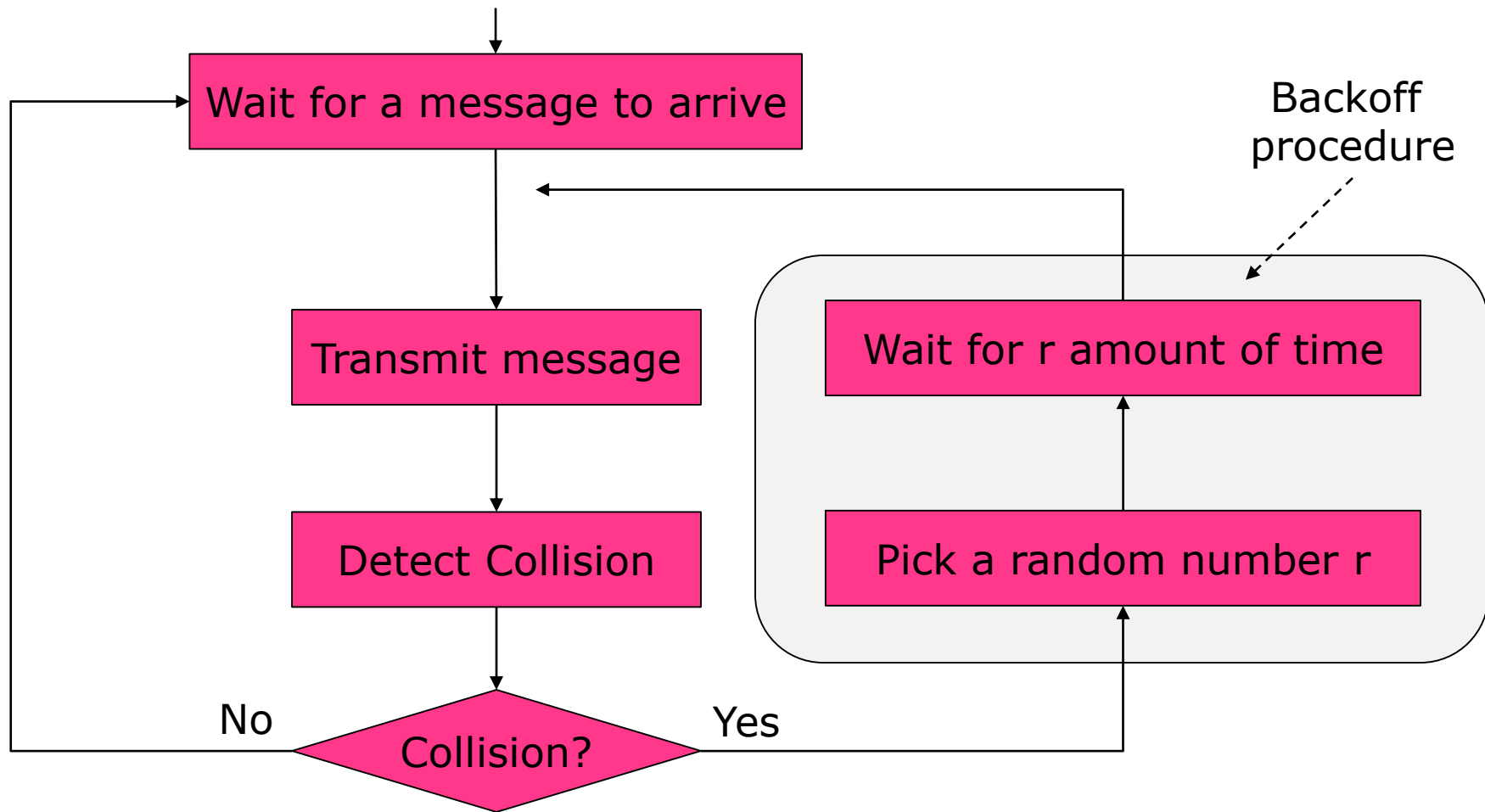
Pure ALOHA: Protocol

- ❑ Transmit message : A node transmits whenever it has data to send

- ❑ Detect collision: The sender wait 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 be?)
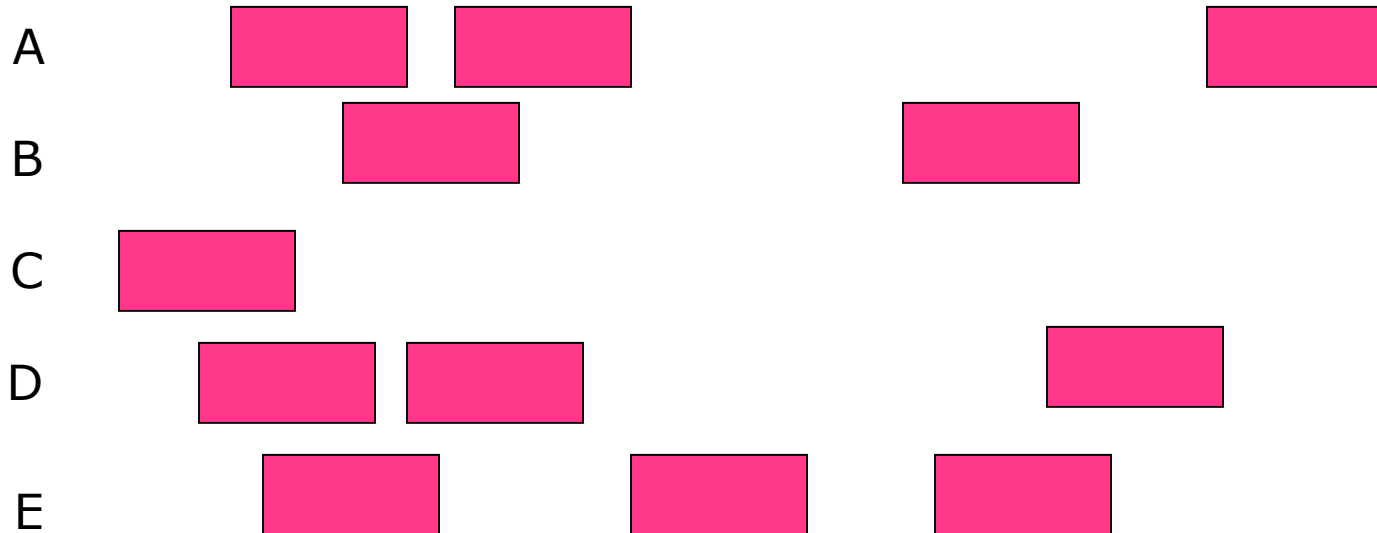 - ■ How would we choose the random amount of waiting time?

Pure ALOHA: Protocol

Wait for a message to arrive

Transmit message

Detect Collision

Collision?

No

Yes

Backoff procedure

Wait for r amount of time

Pick a random number r

Pure ALOHA: Throughput Analysis

□ Frames are transmitted and retransmitted at completely arbitrary times

Pure ALOHA: Throughput Analysis

- ❑ 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

$t-T$ t $t+T$ $t+2T$
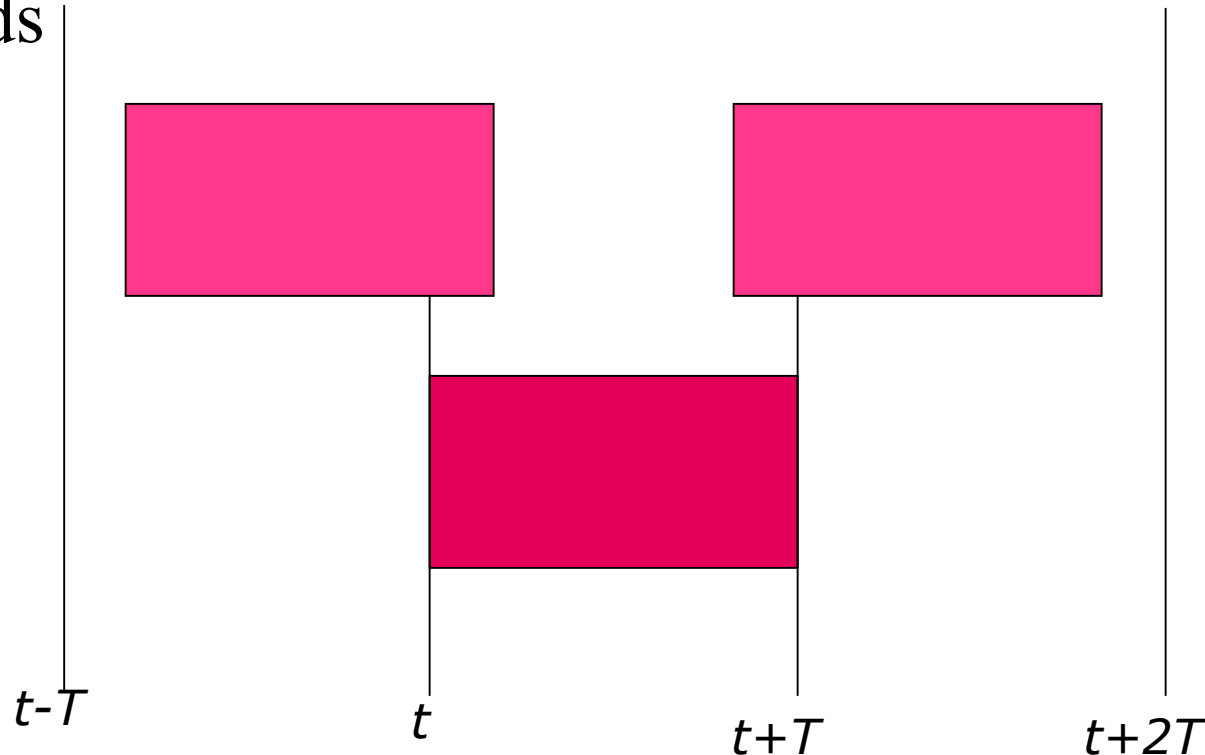
Frames Generated in Vulnerable Period

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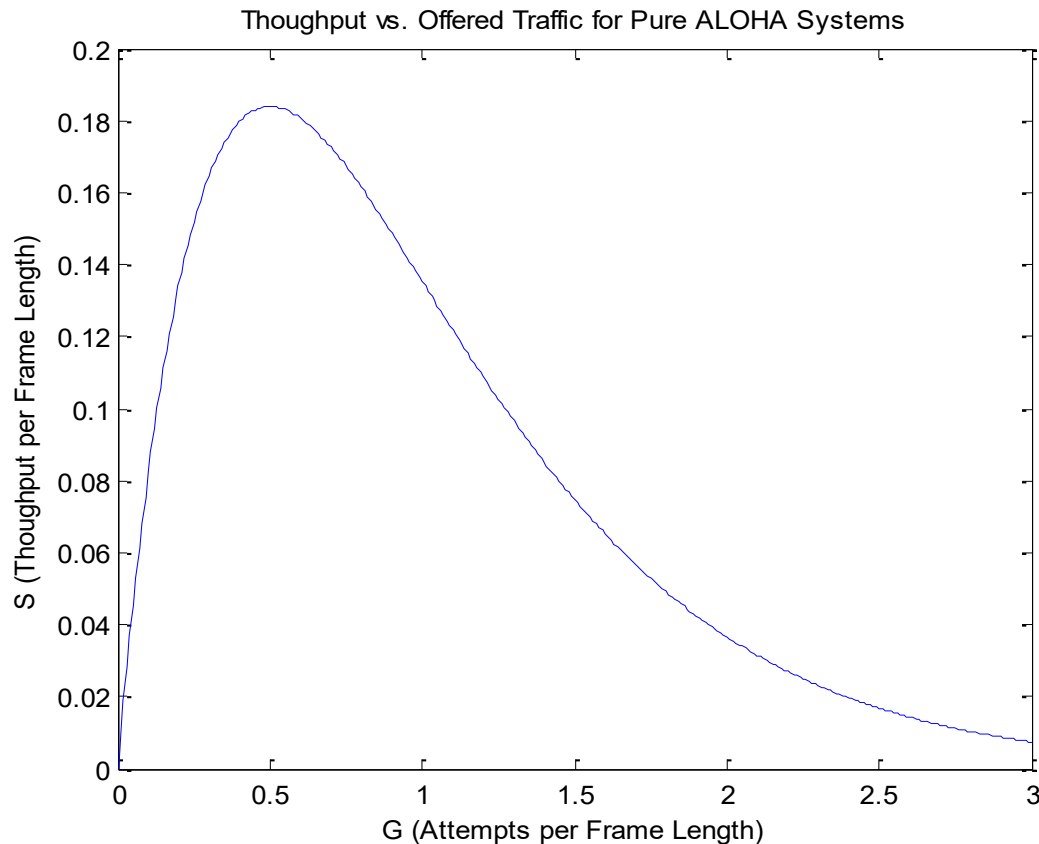
$$\Pr[k] = \frac{(2G)^k e^{-2G}}{k!}$$

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

$$S = GP_0 = G\frac{(2G)^0 e^{-2G}}{0!} = Ge^{-2G}$$
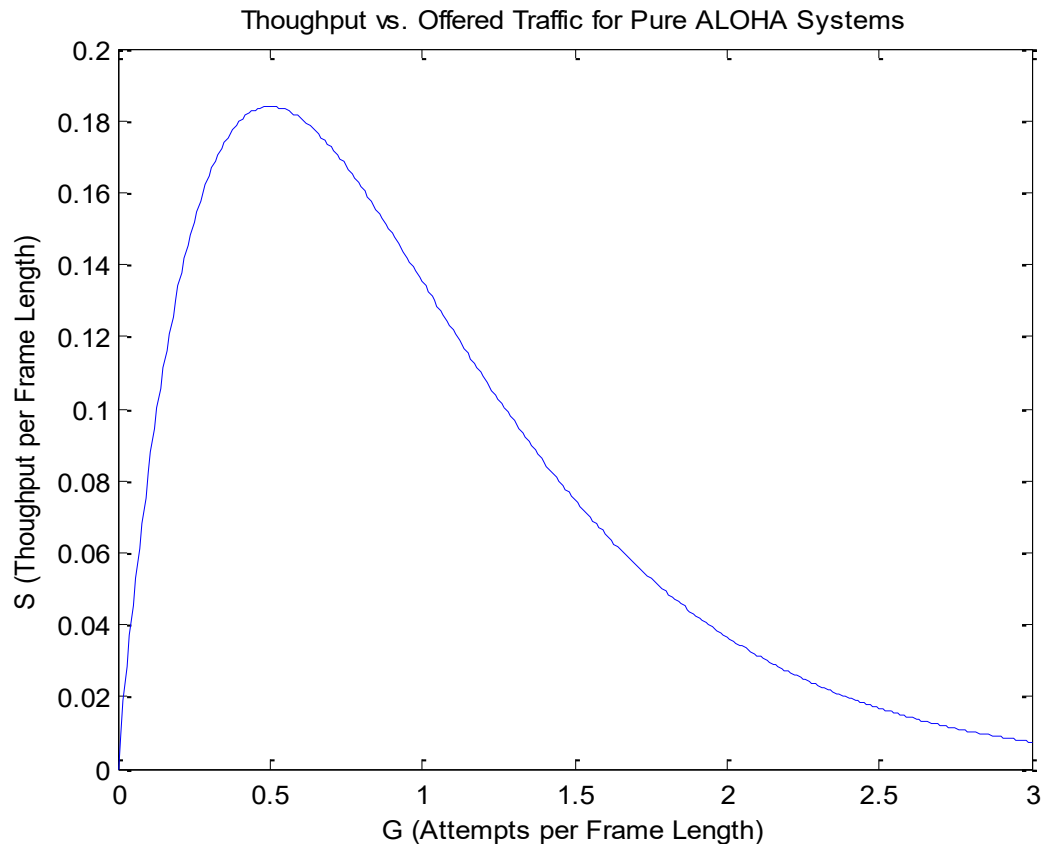
Throughput of Pure ALOHA
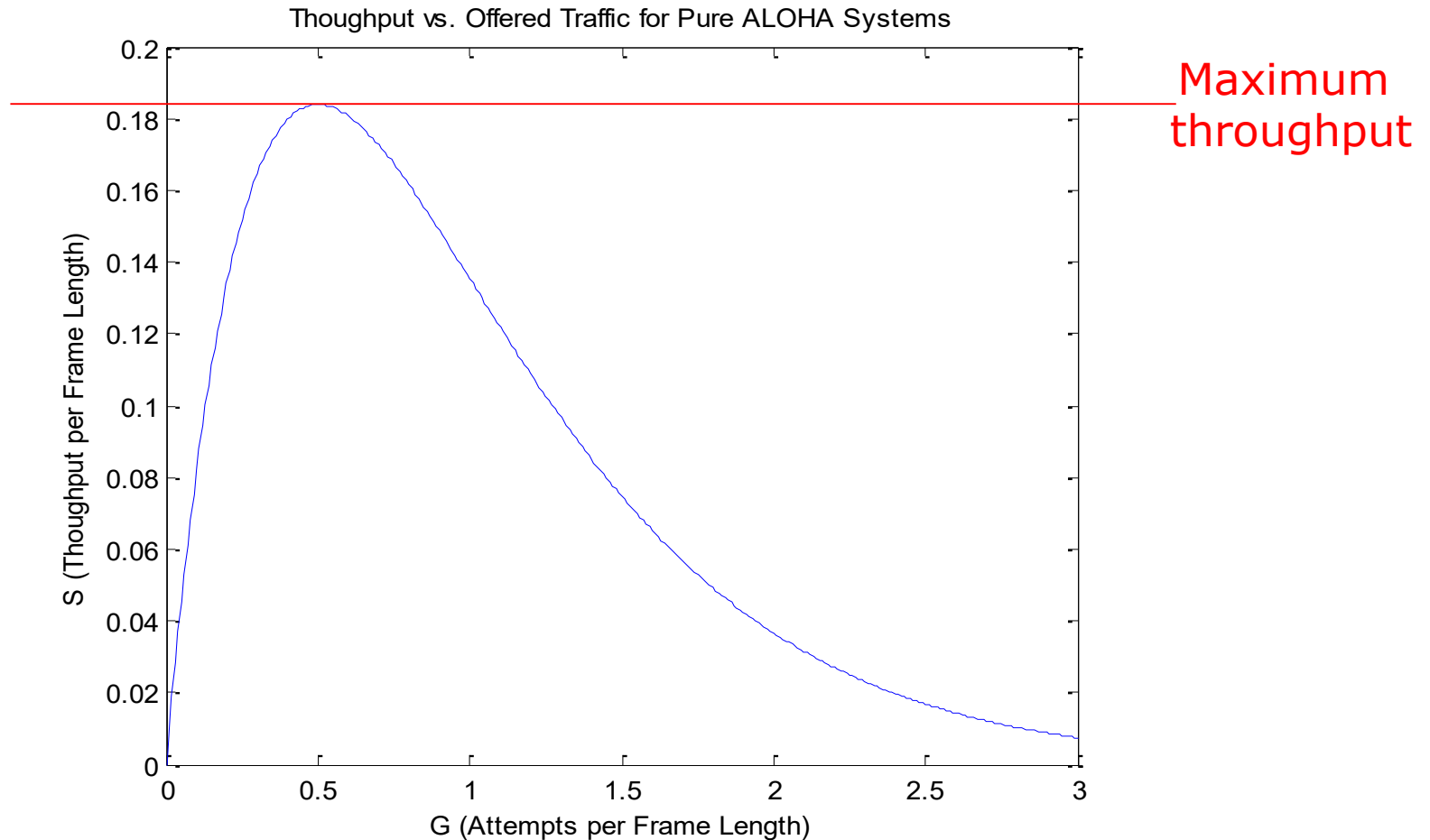
□ Let us graph it $\qquad S = Ge^{-2G}$

Thoughput vs. Offered Traffic for Pure ALOHA Systems

(graph: S (Thoughput per Frame Length) vs. G (Attempts per Frame Length); curve rises to a peak of about 0.184 at G ≈ 0.5, then decreases toward 0 as G approaches 3)

Throughput of Pure ALOHA

- ❑ What is the implication?

Thoughput vs. Offered Traffic for Pure ALOHA Systems

Maximum Throughput of Pure ALOHA

Thoughput vs. Offered Traffic for Pure ALOHA Systems

S (Thoughput per Frame Length) vs G (Attempts per Frame Length)

Maximum throughput

Maximum Throughput of Pure ALOHA

□ The derivative is 0
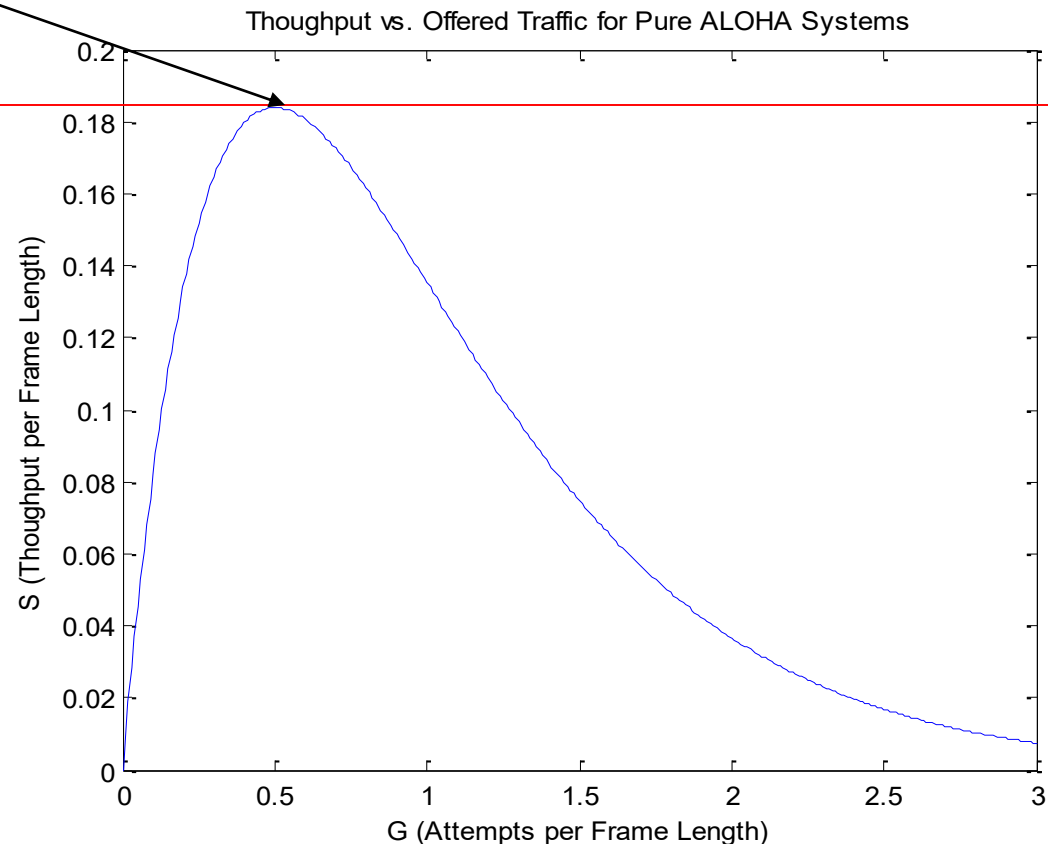
$$S = Ge^{-2G}$$

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

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

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

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

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

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

Thoughput vs. Offered Traffic for Pure ALOHA Systems

S (Thoughput per Frame Length) vs. G (Attempts per Frame Length)

Pure ALOHA: Remark

- Considered a simplified analysis of a pure Aloha
  - Found that the maximum throughput is limited to be at most $1/(2e)$.
  - 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
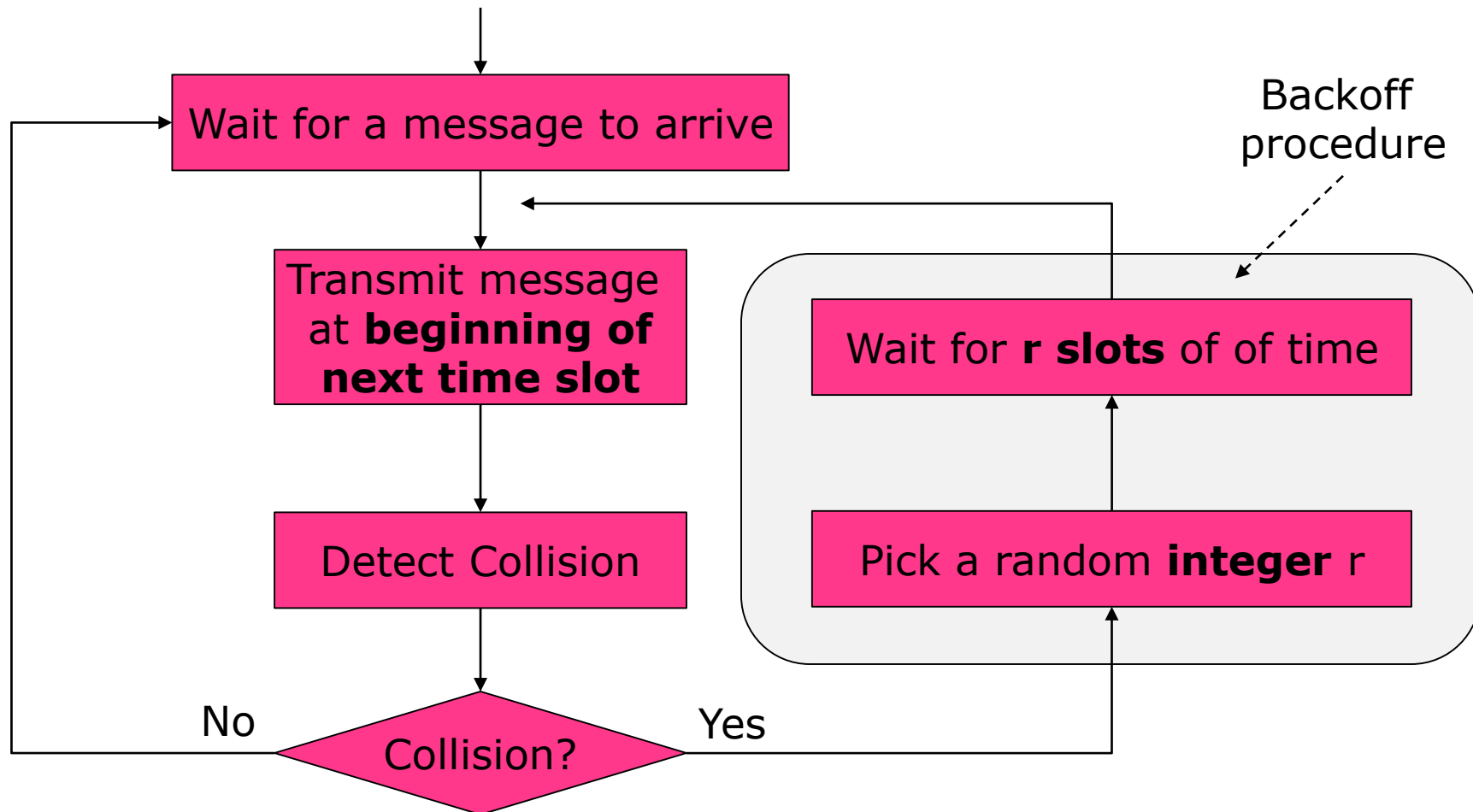
- What improvement can we make?
  - Collision causes retransmission and reduces throughput
  - Can we reduce chance of collisions?
    - Collisions happen within the <u>Vulnerable Period/Contention Window</u>.
    - Can we shorten the <u>Vulnerable Period/Contention Window</u>?
    - Slotted ALOHA

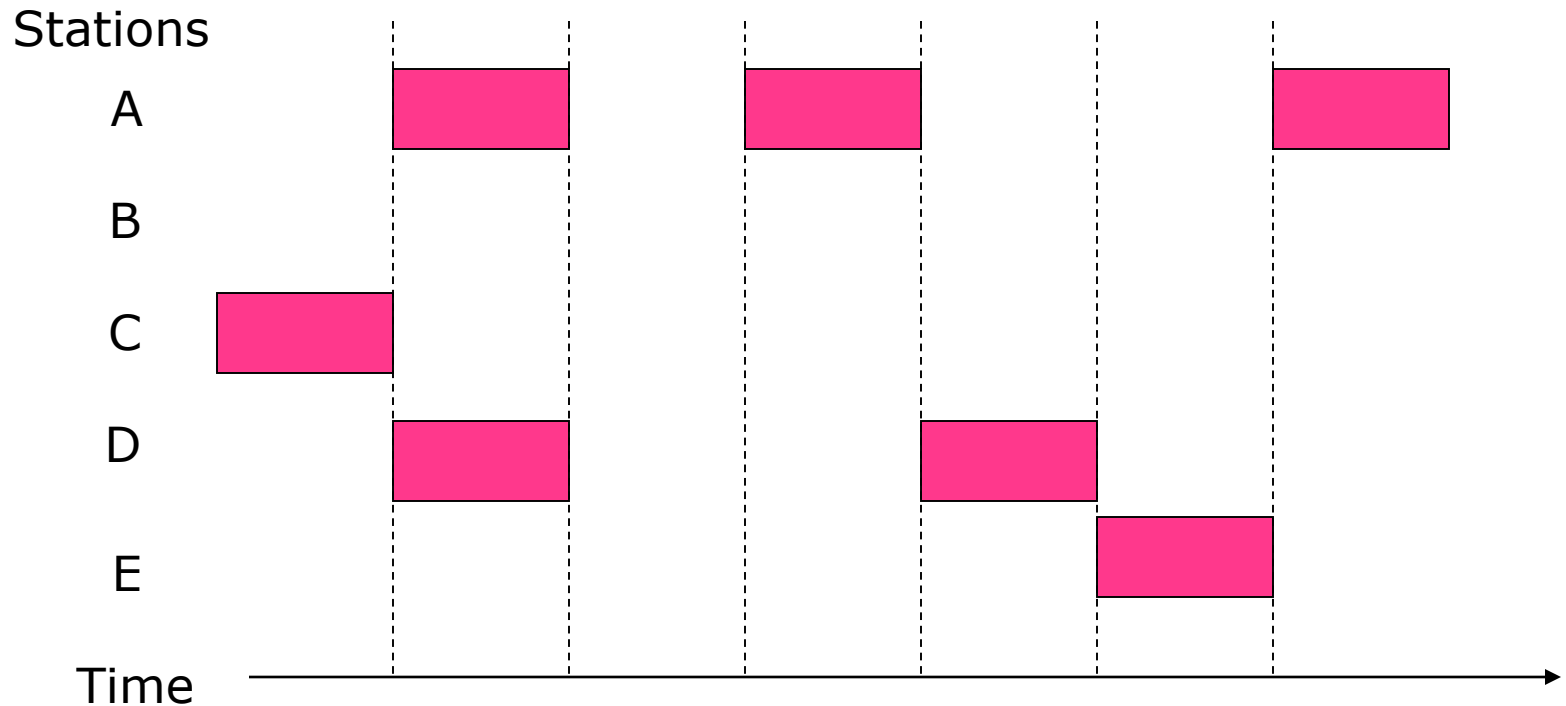# Slotted ALOHA

□ Improvement to Pure ALOHA

- ■ Divided time into discrete intervals

- ■ Each interval corresponds to a frame

- ■ Require stations agree on slot boundaries

Slotted ALOHA: Protocol

Wait for a message to arrive

Transmit message at **beginning of next time slot**

Detect Collision

Collision?

No

Yes

Backoff procedure

Wait for **r slots** of of time

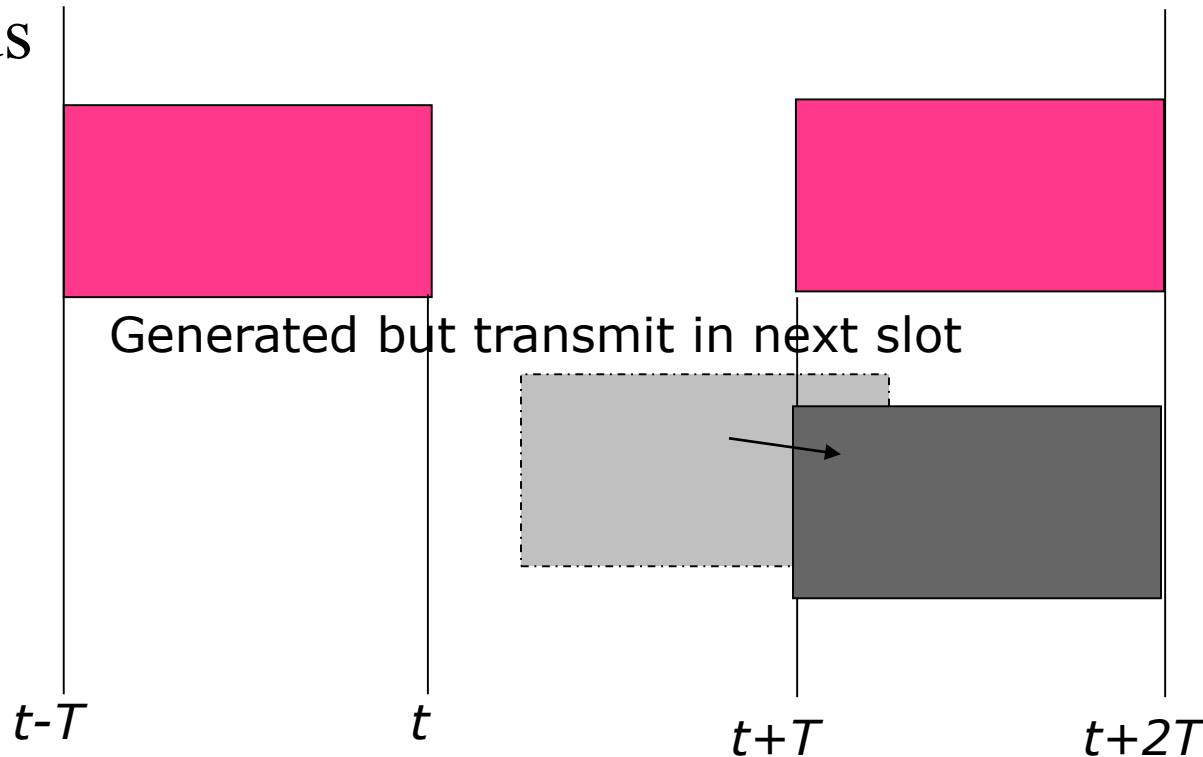Pick a random **integer** r

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

Generated but transmit in next slot

$t-T$ t $t+T$ $t+2T$

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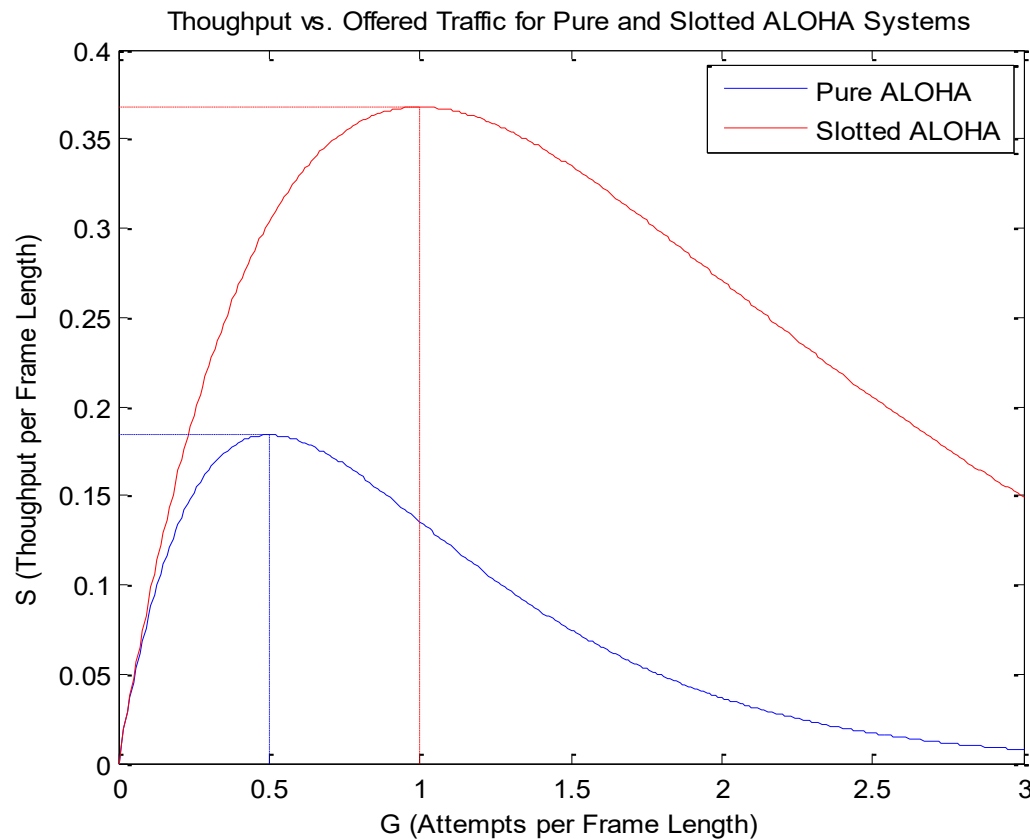
$$\Pr[k] = \frac{G^k e^{-G}}{k!}$$

- 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

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

Thoughput vs. Offered Traffic for Pure and Slotted ALOHA Systems

Exercise L6-1

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

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

Implications of Performance Analysis (1)

- 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}

  - $k_{max}\lambda\tau = 1/(2e)$

  - $k = 1/(2e\lambda\tau) \approx 1/(2\times2.7183\times1/60\times0.034) \approx 324$
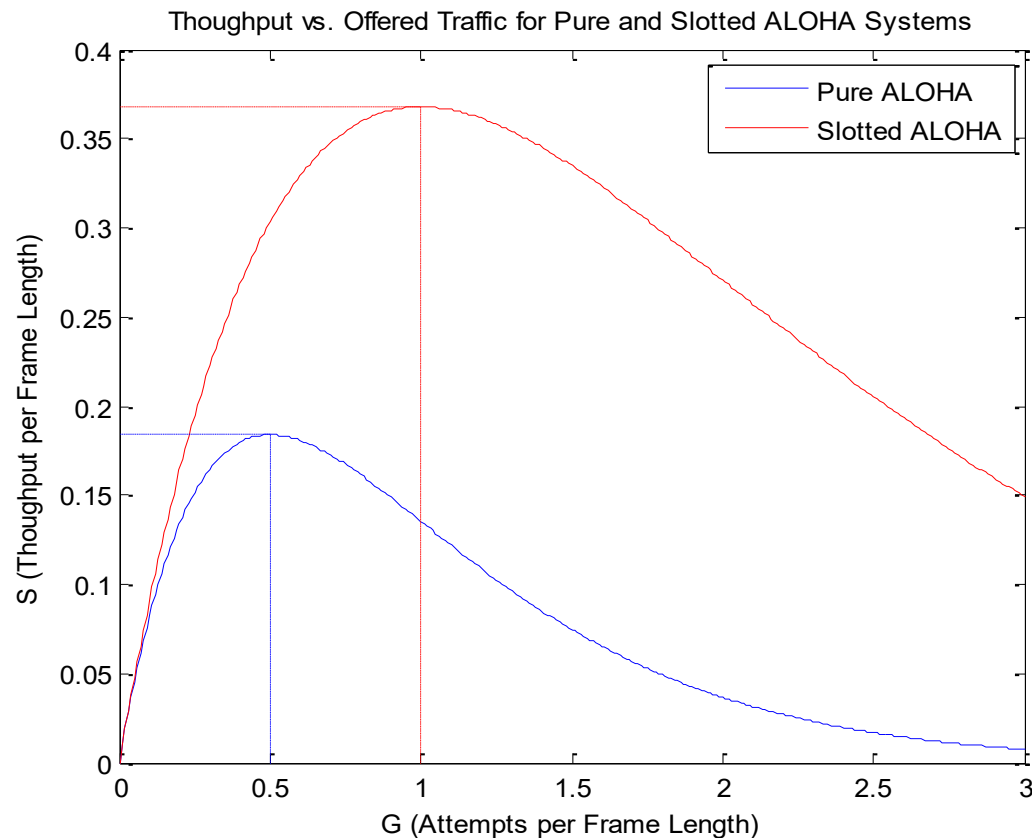
Application of Performance Analysis (2)

- 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}
    - $k_{max}\lambda\tau = 1/(2e)$
    - $k = 1/(2e\lambda\tau) \approx 1/(2 \times 2.7183 \times 1/60 \times 0.034) \approx 324$
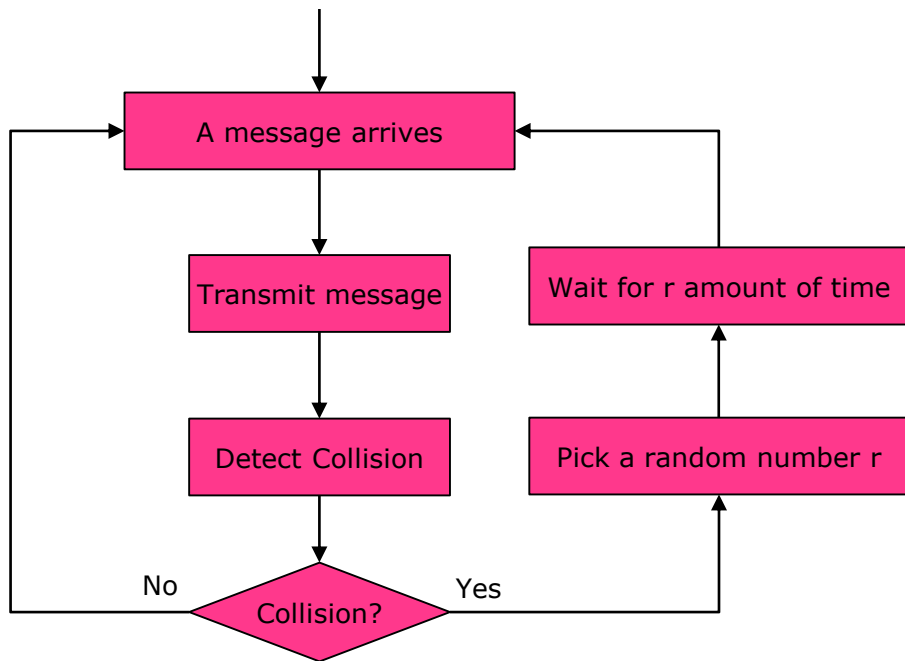
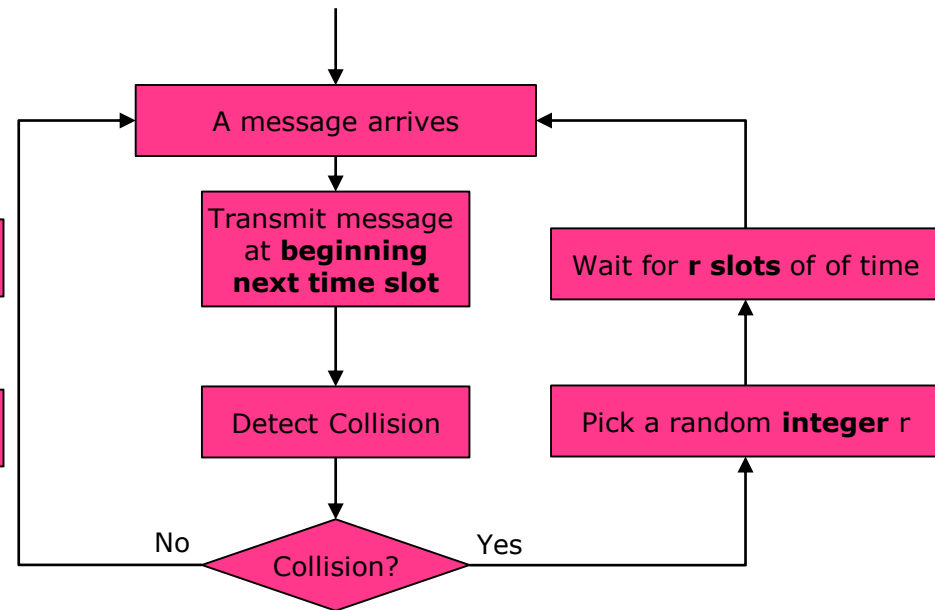# Making Further Improvements?

❑ Maximum throughputs are small

Thoughput vs. Offered Traffic for Pure and Slotted ALOHA Systems

Making Further Improvements?

Pure ALOHA

```
        ┌──────────────────┐
   ┌───►│ A message arrives │◄───┐
   │    └──────────────────┘    │
   │             │              │
   │             ▼              │
   │    ┌──────────────────┐    ┌──────────────────────┐
   │    │ Transmit message │    │ Wait for r amount of time │
   │    └──────────────────┘    └──────────────────────┘
   │             │                        ▲
   │             ▼                        │
   │    ┌──────────────────┐    ┌──────────────────────┐
   │    │ Detect Collision │    │ Pick a random number r │
   │    └──────────────────┘    └──────────────────────┘
   │             │                        ▲
   │   No        ▼          Yes           │
   └────────◄ Collision? ►────────────────┘
```

A message arrives

Transmit message

Detect Collision

Wait for r amount of time

Pick a random number r

No   Collision?   Yes

Slotted ALOHA

A message arrives

Transmit message at **beginning next time slot**

Detect Collision

Wait for **r slots** of of time

Pick a random **integer** r

No   Collision?   Yes

Making Further Improvements?

Pure ALOHA

```
         ↓
┌─────────────────────┐
│   A message arrives  │ ◄──────────────┐
└─────────────────────┘                 │
         │ ?                             │
         ↓                               │
┌──────────────────┐   ┌──────────────────────────┐
│ Transmit message  │   │ Wait for r amount of time │
└──────────────────┘   └──────────────────────────┘
         │                         ↑
         ↓                         │
┌──────────────────┐   ┌──────────────────────────┐
│ Detect Collision  │   │ Pick a random number r    │
└──────────────────┘   └──────────────────────────┘
         │                         ↑
         ↓                         │
     No  ◇ Collision?  Yes ────────┘
```

Slotted ALOHA

```
              ↓
┌─────────────────────┐
│   A message arrives  │ ◄──────────────┐
└─────────────────────┘                 │
         │ ?                             │
         ↓                               │
┌──────────────────────┐   ┌────────────────────────────┐
│ Transmit message      │   │ Wait for r slots of of time │
│ at beginning          │   └────────────────────────────┘
│ next time slot        │             ↑
└──────────────────────┘             │
         │                           │
         ↓                           │
┌──────────────────┐   ┌────────────────────────────┐
│ Detect Collision  │   │ Pick a random integer r     │
└──────────────────┘   └────────────────────────────┘
         │                         ↑
         ↓                         │
     No  ◇ Collision?  Yes ────────┘
```

□ ALOHA transmits even if another node is transmitting → collision

Carrier Sense

□ 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
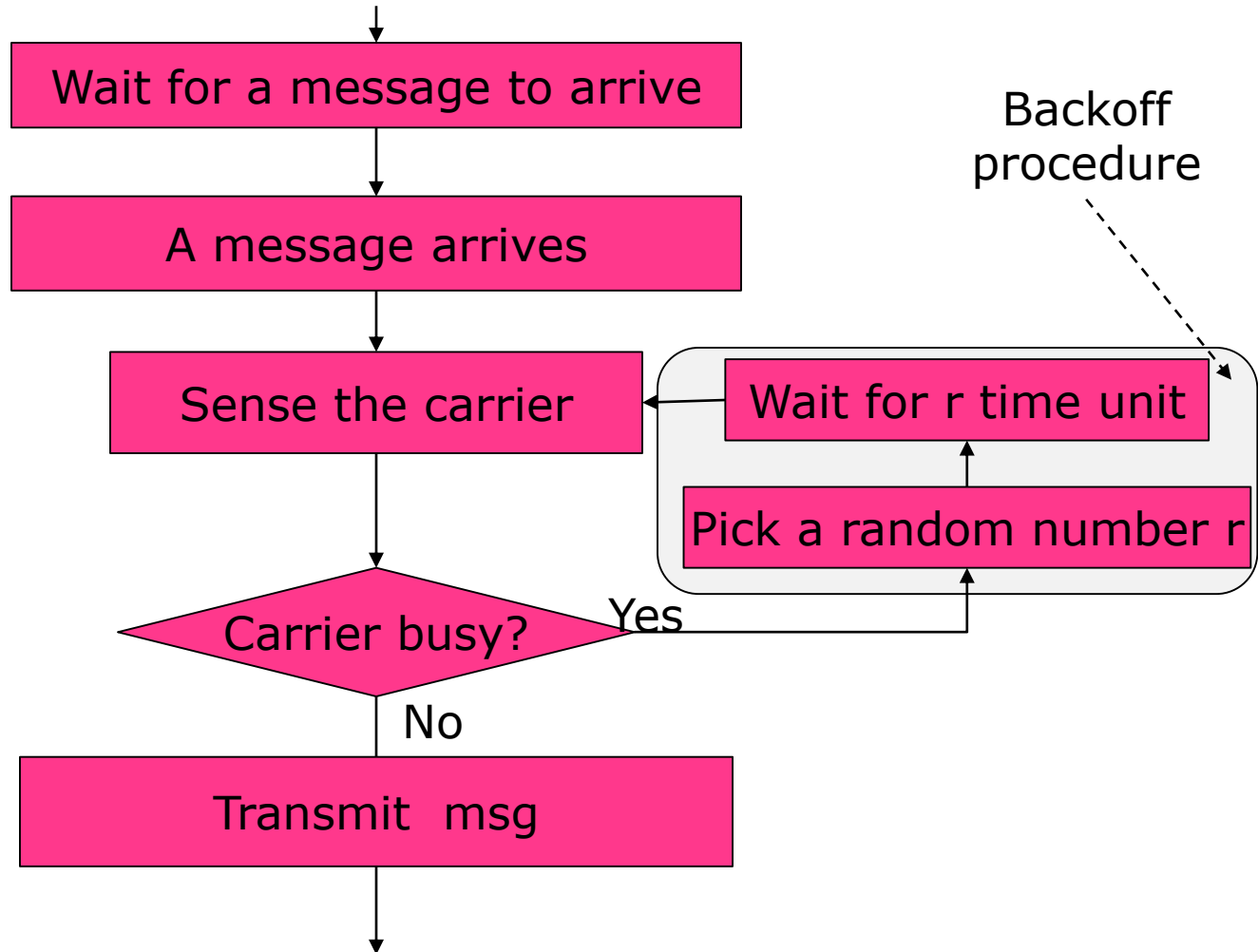 - Collision happens when two or more nodes all want to transmit
- p-persistent CSMA
  - If idle, transmit the frame with a probability p

1-persistent CSMA

```
            ┌──────────────────────────────────┐
            │   Wait for a message to arrive    │
            └──────────────────────────────────┘
                            │
                            ▼
            ┌──────────────────────────────────┐
            │        A message arrives          │
            └──────────────────────────────────┘
                            │
                            ▼
            ┌──────────────────────────┐
            │     Sense the carrier     │◄──────────┐
            └──────────────────────────┘            │
                            │                        │
                            ▼                        │
                      ╱──────────╲       Yes         │
                     ╱ Carrier busy? ╲───────────────┘
                      ╲──────────╱
                            │ No
                            ▼
            ┌──────────────────────────────────┐
            │          Transmit  msg            │
            └──────────────────────────────────┘
                            │
                            ▼
```
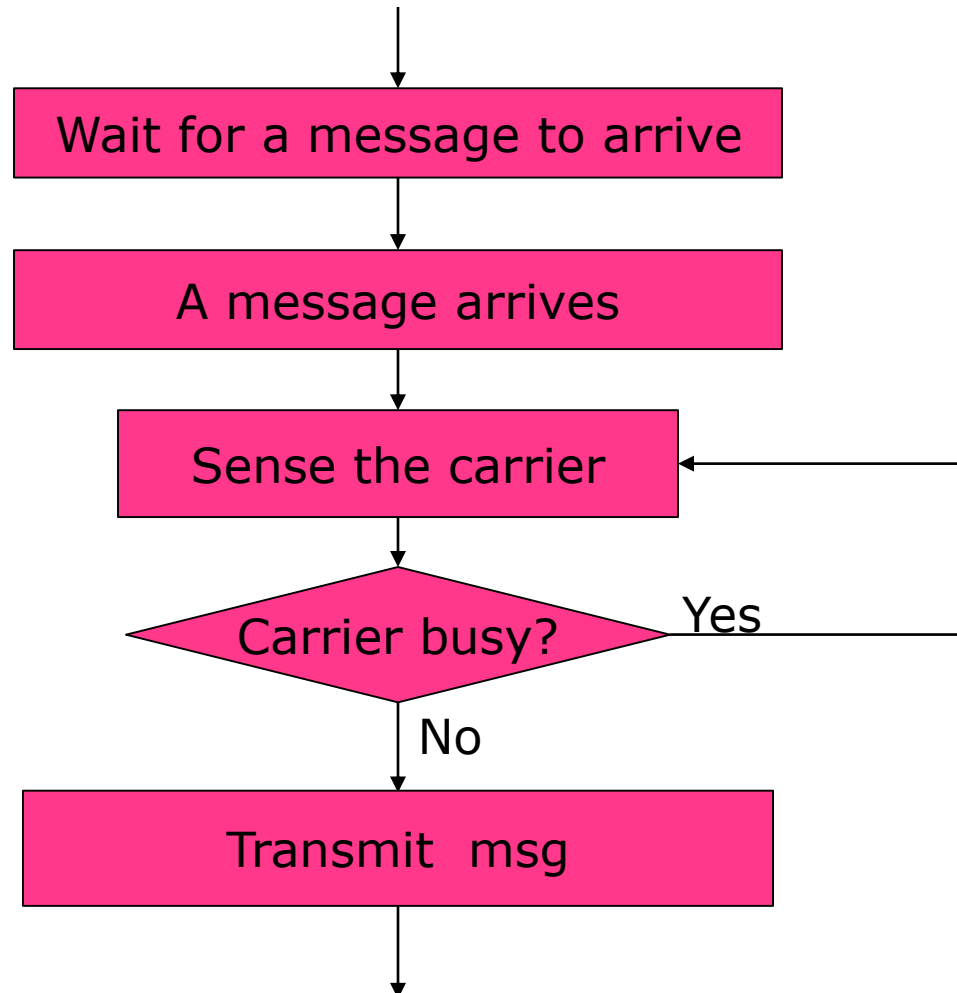
Non-persistent CSMA

p-persistent CSMA


```
           Wait for a message to arrive
                        ↓
               A message arrives
                        ↓
    ┌──────────► Sense the carrier
    │                   ↓
    │            < Carrier busy? > ──Yes──┐
    │                   │ No              │
    │          Pick a random number r     │
    │             between 0 and 1         │
    │                   ↓                 │
    └──No────────    < r < p? >           │
                        │ Yes             │
                   Transmit  msg          │
                        ↓                 │
```
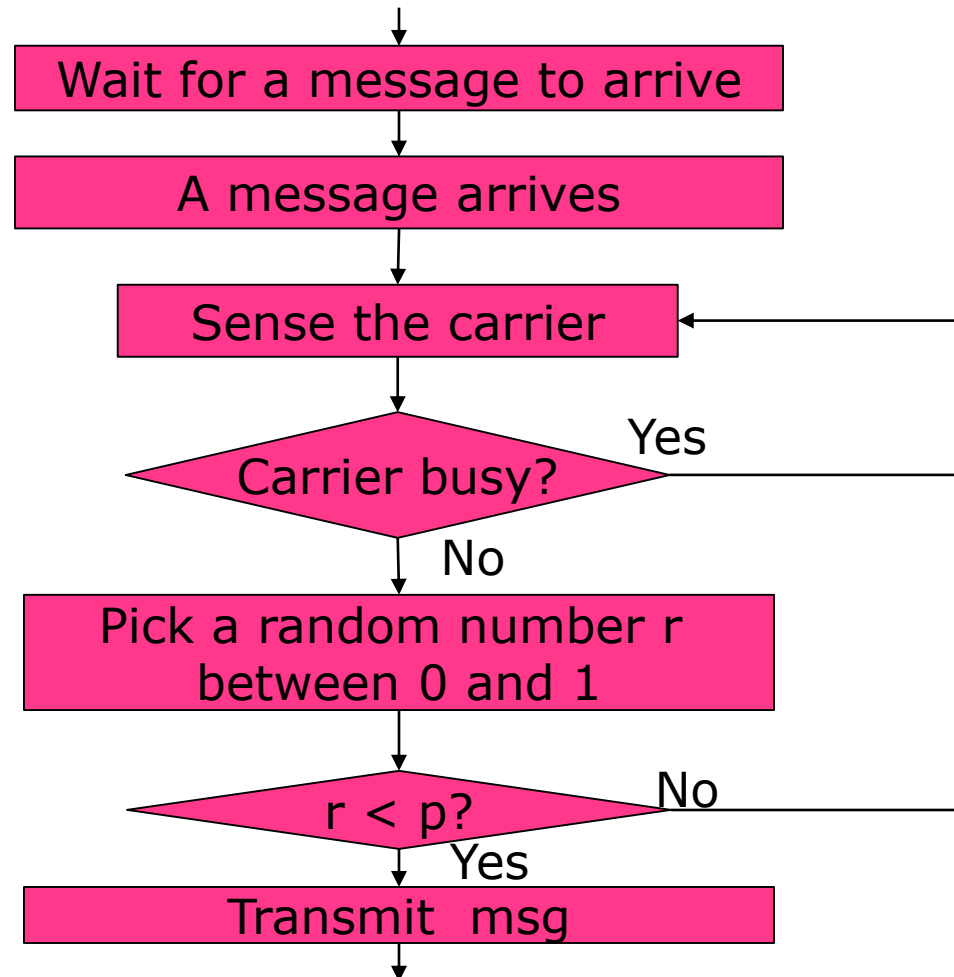
Comparison of Throughput

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

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

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

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

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

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

Comparison of Throughput
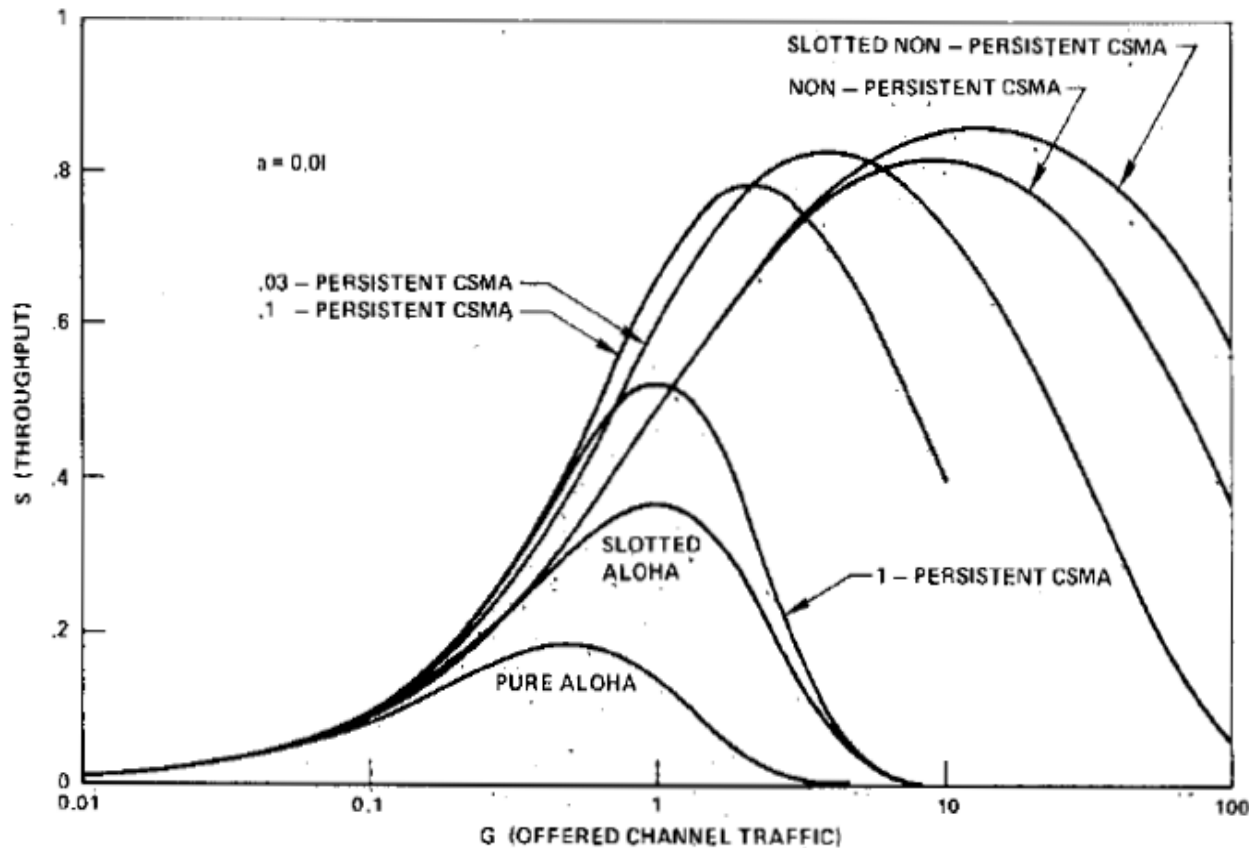
Fig. 9. Throughput for the various access modes ($a = 0.01$).
From LEONARD KLEINROCK, 1975

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?

Carrier Sense and Collision

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

Collision Detection

- If nodes can 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
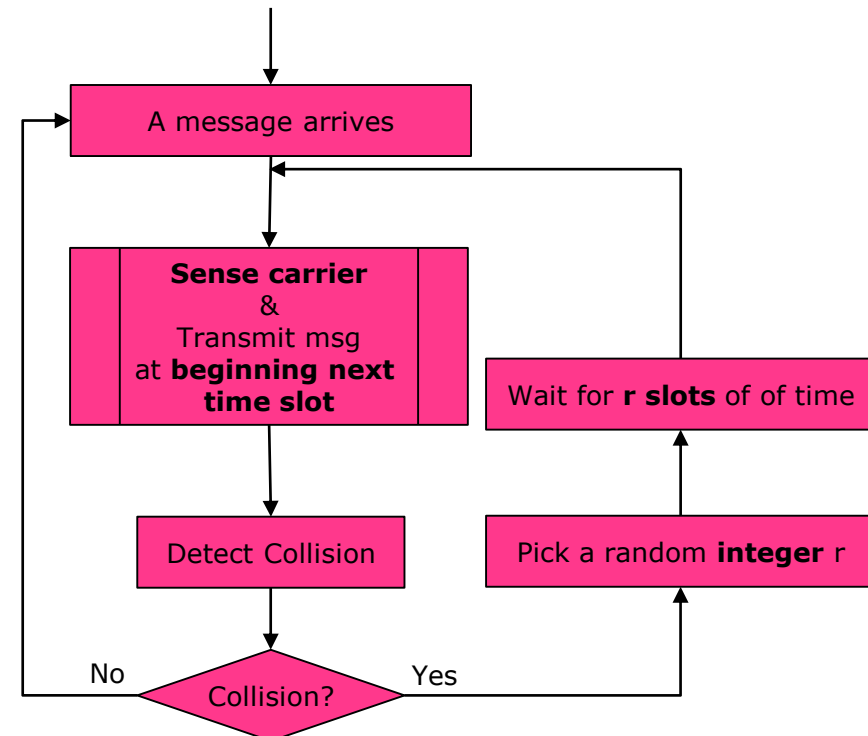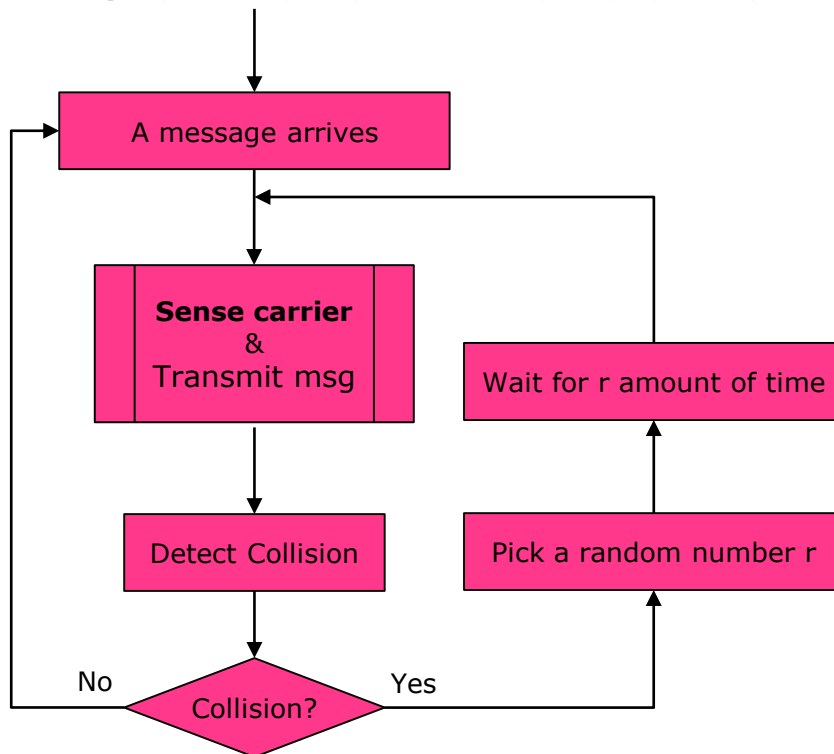
CSMA/CD

❑ 1-Persistent CSMA and CD
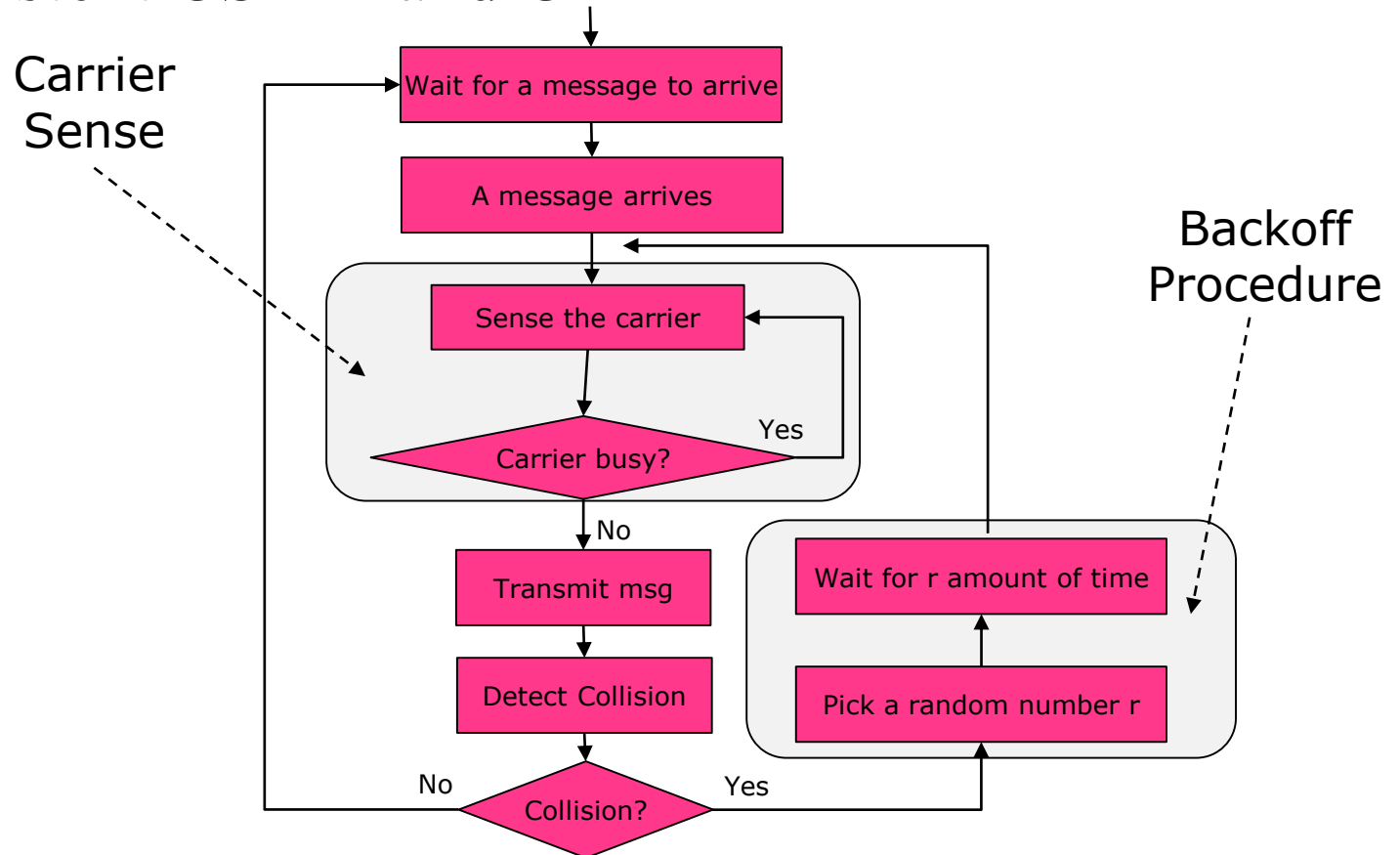
Ethernet

- Multiple Access Networks
- Carrier Sense Multiple Access and Collision Detection (CSMA/CD) with Exponential Backoff
  - Inspired by the ALOHA network at the University of Hawaii
  - Developed by Robert Metcalfe and Bob Boggs at Xerox PARC

Ethernet: Carrier Sensing

- ❑ If line is idle
  - ◼ Send immediately
  - ◼ Upper bound message size = 1500 bytes
- ❑ If line is busy
  - ◼ Wait until idle and transmit immediately
  - ◼ 1-persistent (a special case of p-persistent)
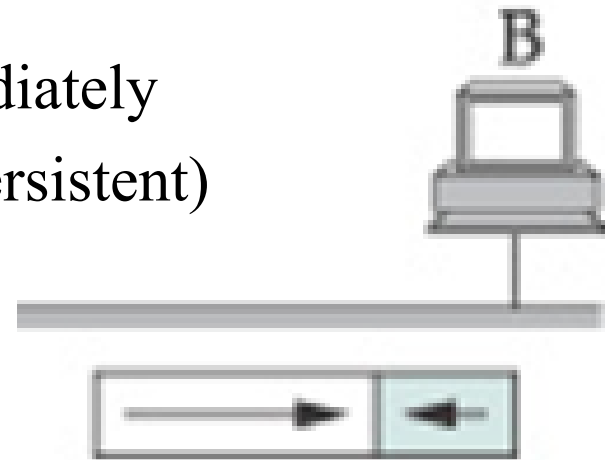
Collision Detection on Ethernet

- No centralized control, distributed algorithm
- Two nodes may transmit almost at the same time → collision
- Worst case scenario
  - (a) A sends a frame at time t
  - (b) A's frame arrives at B at t + d
  - (c) B begins transmitting at time t + d and collides with A's frame. Upon detecting the collision, B sends a _runt_ (32-bit frame) to A
  - (d) B's runt frame arrive at A at t + 2d
  - **Why does B need to send a runt to A?**
  - **How long does it take for A to detect the collision?**

(a)

(b)

(c)

(d)
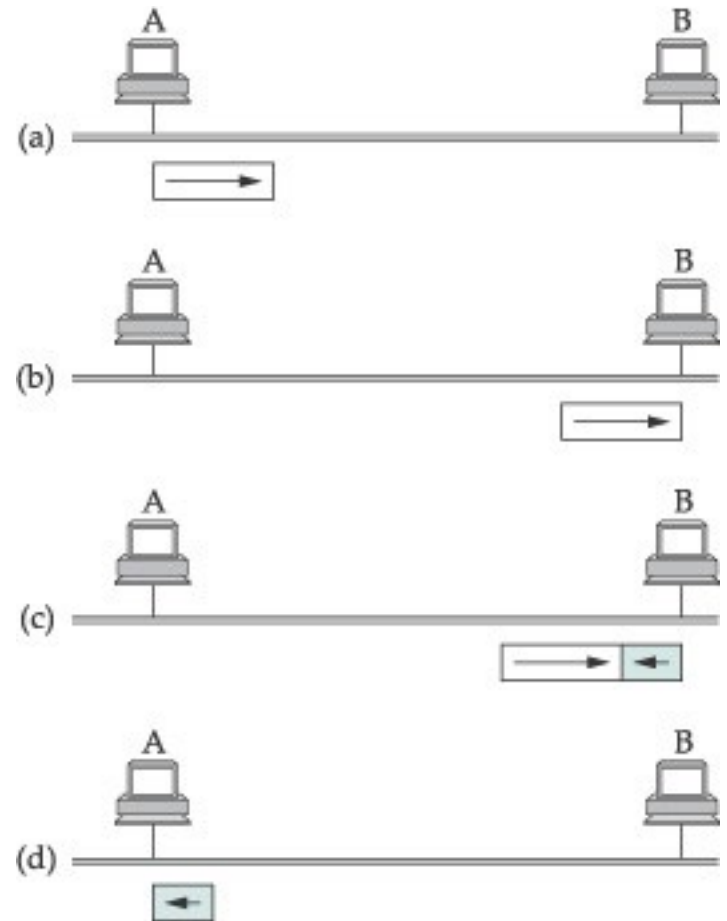
Collision Detection on Ethernet

- Want the nodes that collide to know that a collision happened
  - Time during which a node (the transmitting node) may hear of a collision is $1 \times$ RTT
    - Recall: under what condition can a network be benefited most from "carrier sense"?
  - Impose a minimum frame size that lasts for $1 \times$ RTT
    - So the node can not finish transmitting before a collision takes place → carrier sense benefits the network the most
    - Consider an Ethernet: minimum frame is 64 bytes, longest link 2500 meters (4 repeaters, 500 meter segment), 10-Mbps bandwidth
      - $1 \times$ RTT = 51.2 μs and $1 \times$ RTT $\times$ Bandwidth = 512 bits = 64 bytes

Ethernet: Collision Detection with Binary Exponential Backoff

- □ If collision
  - ■ Jam for 32 bits (by sending a runt), and stop transmitting frame
  - ■ Minimum frame is 64 bytes (14 bytes header + 46 bytes of data + 4 bytes CRC) for 10 Mbps Ethernet
  - ■ Exponential backoff
    - □ 1st time: 0 or 51.2 μs
      - ▪ Randomly select one of these two: imagine throwing an evenly made coin, if it lands tail, choose 0; otherwise, 51.2 μs
    - □ 2nd time: 0, 51.2, or 51.2 x 2 μs
      - ▪ Randomly select one of these two: imagine throwing a 3-sided die whose three faces are labeled as 0, 1, and 2. If it lands on side 0, choose 0; on side 1, 51.2 μs; on side 2, 51.2 x 2 μs
    - □ 3rd time: 0, 51.2, 51.2 x 2, or 51.2 x 3 μs
      - ▪ Similar process with 4-sided die
    - □ n-th time: k x 51.2 μs, randomly select k from $0..2^n-1$
      - ▪ Similar as before, you die (very strange die) has 2^n sides labeled from 0 to 2^n-1
    - □ Give up after 16 times

Ethernet: CSMA/CD with Exponential Backoff

□ 1-Persistent CSMA and CD

Carrier Sense

Wait for a message to arrive
c = 0

A message arrives

Sense the carrier

Carrier busy? — Yes

No

Transmit msg

Detect Collision

Collision? — No / Yes

Wait for r $\times \tau$ amount of time
τ = 51.2 μs

Pick a random integer
$r \in \{0, 2^c-1\}$

Yes

$c \leq 16$? — No

$c = c + 1$

Exponential Backoff Procedure
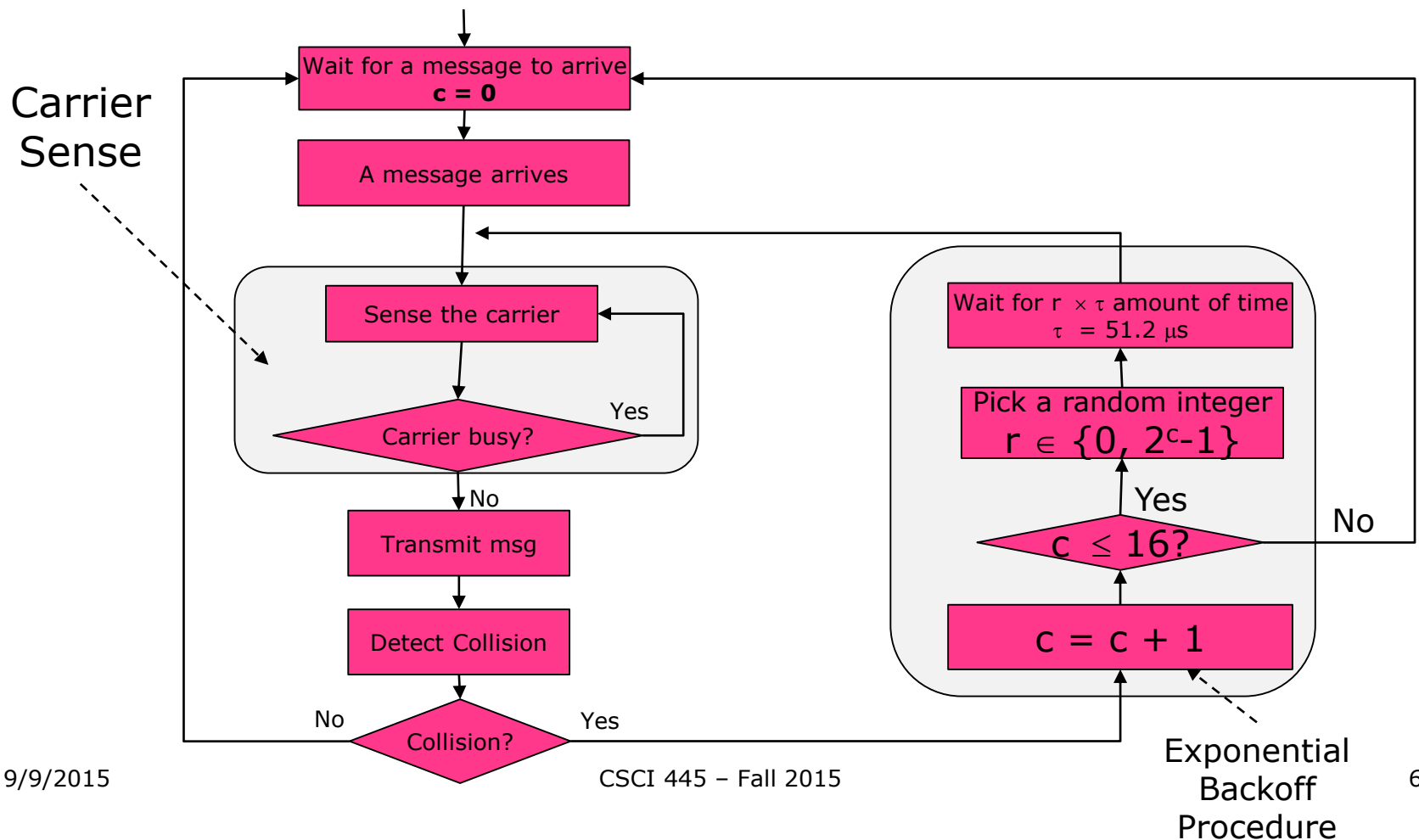
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IEEE 802.11™: Wireless

IEEE 802.15™: Wireless Personal Area Networks

IEEE 802.16™: Broadband Wireless Metropolitan Area Networks

IEEE 802.17™. Resilent Packet Rings

Ethernet (IEEE 802.3) (1)

- □ History
  - ■ U. of Hawaii (Aloha, early 1970's) →Xerox PARC (mid 1970's) → Xerox PARC, DEC, and Intel (1978) → IEEE 802.3
- □ CSMA/CD
  - ■ Carrier Sense (CS)
  - ■ Multiple Access (MA)
  - ■ Collision Detection (CD)

Ethernet (IEEE 802.3) (2)

□ Transmission Media: guided
- Coaxial cable
  - 10Base5 (thick, 500m)
  - 10Base2 (thin, 200m)
- Twisted pair cable
  - 10BaseT (100m)
  - 100BaseT (100m)
  - 1000BaseT (100m)
- Optic fiber
  - 100BASE-FX
  - 10GBASE-R
  - ……

Copper core   Insulating material   Braided outer conductor   Protective plastic covering

Core (glass)   Cladding (glass)   Jacket (plastic)
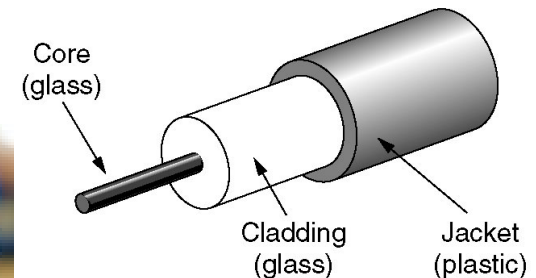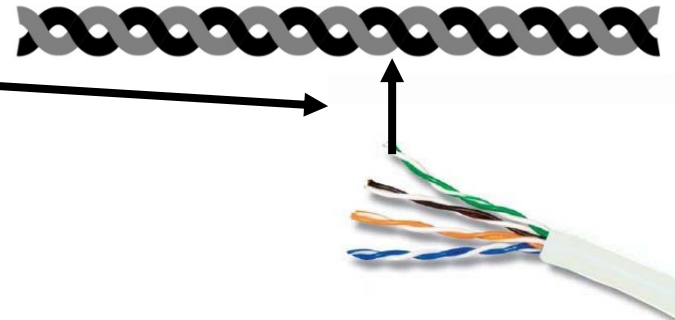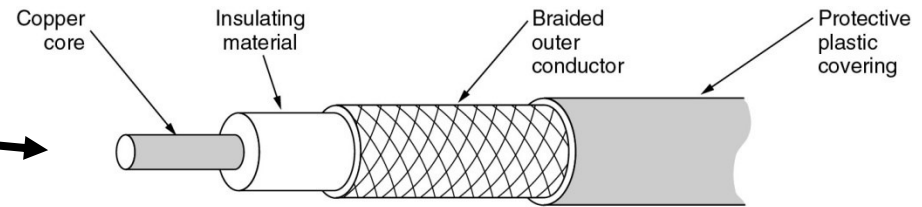
Ethernet (IEEE 802.3) (3)

CSCI 445 – Fall 2015
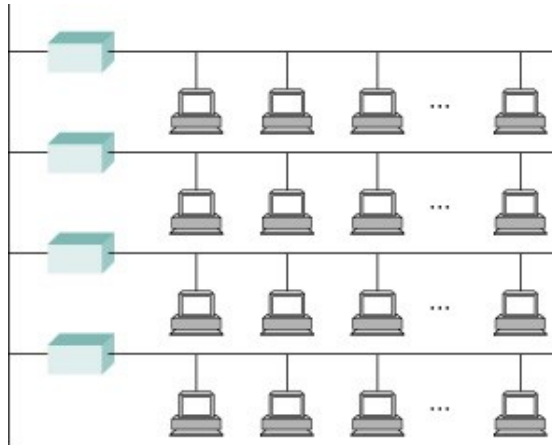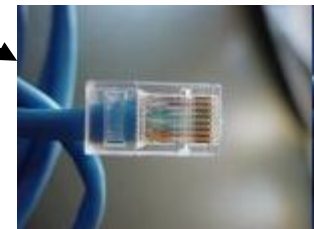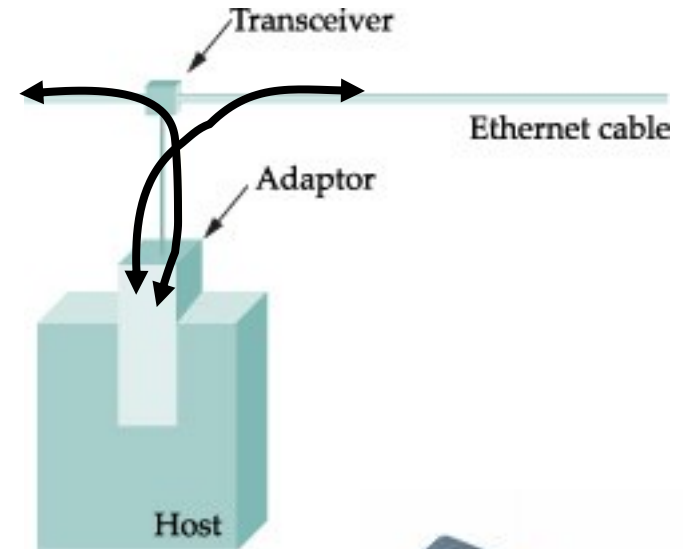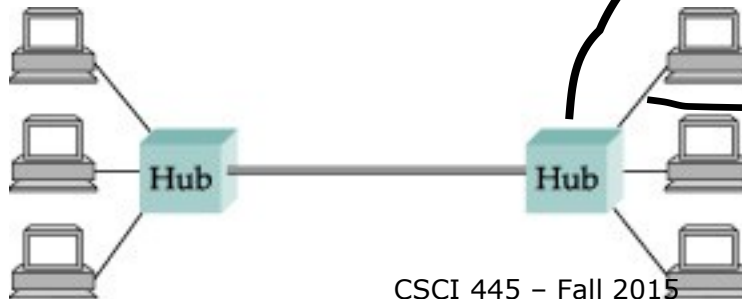
Ethernet: Frame Format

- Bit-oriented framing
  - Preamble (64 bits): 101010… for signal synchronization
  - Destination address (48 bits)
  - Source address (48 bits)
  - Type/length (16 bits)
  - Body (46 – 1500 bytes)
  - CRC (32 bits)
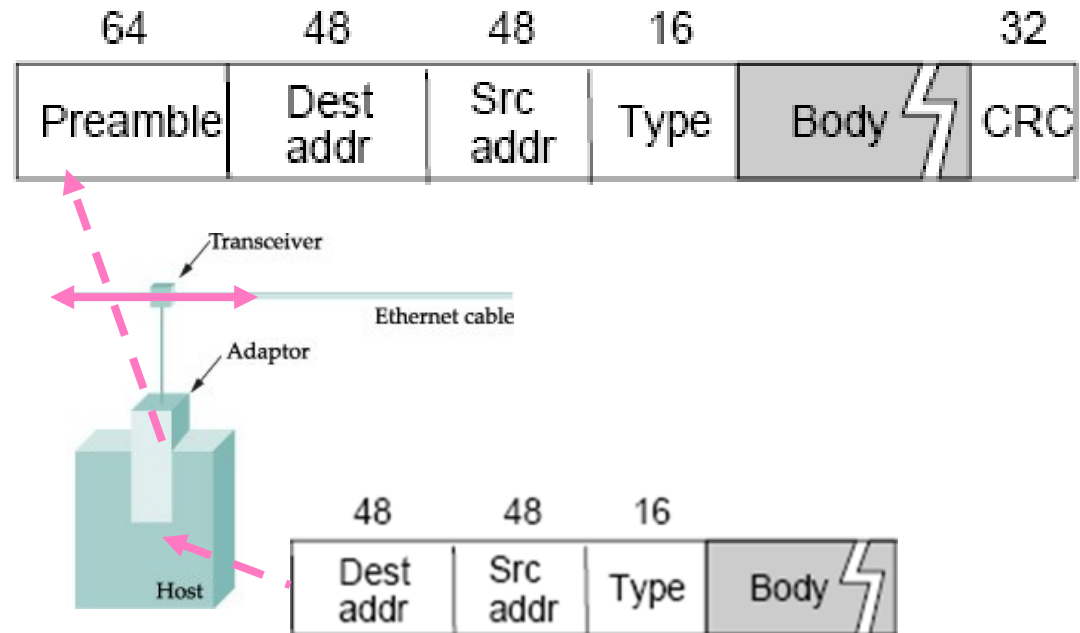
Ethernet Address

- ☐ Unique in the world
- ☐ Assigned to adaptors
- ☐ 48-bit
    - ▪ 0000 1000 0000 0000 0010 1011 1110 0100 1011 0001 0000 0010
    - ▪ 08:00:2b:e4:b1:02 (human-friendly form)

24-bit Organization Unique Identifier (OUI)

Checkout: http://standards.ieee.org/regauth/oui/oui.txt

Experiment (1): Windows

□ On MS Windows (various version of NT systems, including 2000, XP, Vista etc)

- Start Windows Command Prompt
  - □ Click "Start Button", then click "run", enter "cmd", hit "OK"
- In the Windows Command Prompt
  - □ Enter a command "ipconfig /all"
  - □ Look for "Physical Address"

```
C:\WINDOWS\system32\cmd.exe                                          _ □ ×

        Connection-specific DNS Suffix   . :
        Description . . . . . . . . . . . : Microsoft Loopback Adapter
        Physical Address. . . . . . . . . : 02-00-4C-4F-4F-50
        Dhcp Enabled. . . . . . . . . . . : Yes
        Autoconfiguration Enabled . . . . : Yes
        Autoconfiguration IP Address. . . : 169.254.25.129
        Subnet Mask . . . . . . . . . . . : 255.255.0.0
        Default Gateway . . . . . . . . . :

Ethernet adapter Local Area Connection:

        Connection-specific DNS Suffix   . :
        Description . . . . . . . . . . . : Broadcom NetXtreme 57xx Gigabit Cont
roller
        Physical Address. . . . . . . . . : 00-13-72-8F-BA-11
        Dhcp Enabled. . . . . . . . . . . : No
        IP Address. . . . . . . . . . . . : 192.168.1.52
        Subnet Mask . . . . . . . . . . . : 255.255.255.0
        Default Gateway . . . . . . . . . : 192.168.1.1
        DNS Servers . . . . . . . . . . . : 150.174.192.21
                                            150.174.192.53
                                            128.143.2.7

H:\>
```

Look the vendor prefix code 00-13-72 from IEEE website
at http://standards.ieee.org/regauth/oui/oui.txt

Experiment (2): Unix/Linux

- Similar query can be done on Unix/Linux systems
- Log onto a Linux/Unix box, and issue command
  - ifconfig
  - ip (on latest versions of Linux)

Look the vendor prefix code 00-23-AE from IEEE website
at http://standards.ieee.org/regauth/oui/oui.txt

Look the vendor prefix code 00-23-AE from IEEE website
at http://standards.ieee.org/regauth/oui/oui.txt

Exercise L6-2

- □ Q1: How many Ethernet adapters (NICs) does the Windows computer on your desk have? What are their Ethernet addresses (i.e., physical addresses as reported by Windows)?

- □ Q2: Who is the vendors of the adapters you listed? Use the following to look up the vendors

  - ■ http://standards.ieee.org/regauth/oui/oui.txt

Ethernet: Unicast/Broadcast/Multicast

- Unicast address: address of an adaptor
  - If dest_addr == my_addr, deliver the frame to the host
- Broadcast address: ff:ff:ff:ff:ff:ff
  - If dest_addr == 0xff ff ff ff ff ff, deliver the frame to the host
- Multicast address (group address): the low-order bit of the high-order byte as 1 (Ethernet transmits bytes from low-order bit to high-order bit)
  - If (dest_addr & 0x01 00 00 00 00 00) && (it has been instructed to listen to that address), deliver the frame to the host
  - Complex and requires group management

Promiscuous Mode

❑ All frames will be delivered to the host

Ethernet: Experience

- ❑ Work best under lightly loaded conditions
  - ▪ Utilization > 30% → too much collisions
- ❑ Great success
  - ▪ In practice, observations
    - ❑ fewer than 200 hosts
    - ❑ Far shorter than 2,500 m (RTT ~ 5 μs)
    - ❑ Host implements end-to-end flow control (such as TCP/IP), hosts do not pumping frames to NIC when busy
    - ❑ *Extended LANs using Ethernet switches (2 nodes on an Ethernet) → future discussions*
  - ▪ Easy to administer and maintain
    - ❑ no routing
    - ❑ no configuration
  - ▪ Simple: hardware such as adaptors are cheap
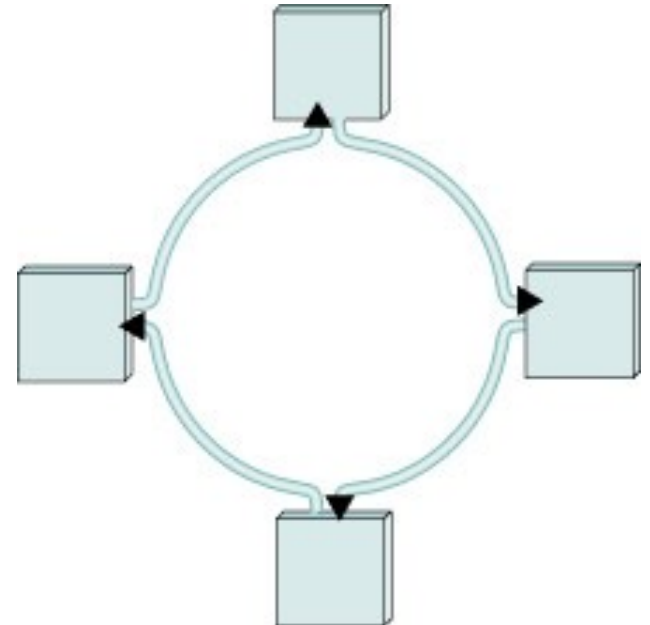
Contention Free Approaches

◻ Token-based approaches
  ▪ Token ring (IEEE 802.5)
  ▪ Token bus (IEEE 802.4)

Rings (802.5, FDDI, RPR)

- ☐ Token rings
  - ■ Token: a special bit string
  - ■ Nodes are organized as a ring
  - ■ Nodes receive and forward token if no frame to send
  - ■ Node grabs the token, send the frame, then puts the token back to the ring

Media Access Control in Wireless Networks

☐ Wireless PAN (Example: 802.15)

☐ Wireless LAN (Example: 802.11)

☐ Wireless MAN (Example: WiMax/802.16)

☐ Wireless WAN (Personal Communications System, a.k.a., cell phone networks, such as GSM, CDMA)

Summary

- ❑ Media access control
- ❑ Ethernet
- ❑ Ring
- ❑ Wireless networks
  - ◼ CSCI 647: Wireless Networks and Mobile Computing

Direct Link Networks: Summary

- ❑ Encoding
  - ■ Encoding bits onto transmission medium
- ❑ Framing
  - ■ Delineating sequence of bits into messages
- ❑ Error detection
  - ■ Detecting errors and acting on them
- ❑ Reliable delivery
  - ■ Making links appear reliable despite errors
- ❑ Media access control
  - ■ Mediating access to shared link
- ❑ Q: how many hosts an Ethernet can have? What is the approximate perimeter of an Ethernet? What if we want to have a network that covers entire campus, a city, a nation, a continent, a planet, or the galaxy? → network of networks: Switched Networks