Part I Syllabus

Week	Subject
Week 1 Week 2 Week 3	Introduction
	Network layers & physical resilience
	Data link layer – Flow control
	Data link layer – Error control
	Local area network – Introduction
Week 4 Week 5 Week 7 * No lecture in Week 6 due to Students' Union Day	**Local area network – Medium access control**
	Local area network – Wired
	Local area network – WLAN
	Mobile access networks: From 1G to 5G
	Network paradigms
Recess Week (e-learning)	Review and examples

How to mingle among cocktail

1) When to start speaking?
2) What to speak?
3) Whether/How to react to interruption?

CE3005/CZ3006 Computer Networks

Lecture 6
Medium Access Control (MAC) Protocols

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Contents

- **Medium Access Control Protocol**
  - Ideal MAC Protocol
  - MAC Taxonomy
- **ALOHA Protocols**
  - Slotted ALOHA
  - Pure ALOHA
- **CSMA Protocol**
  - Vulnerable time in CSMA
  - CSMA Variants
- **CSMA/CD Protocol**
  - Collision Detection

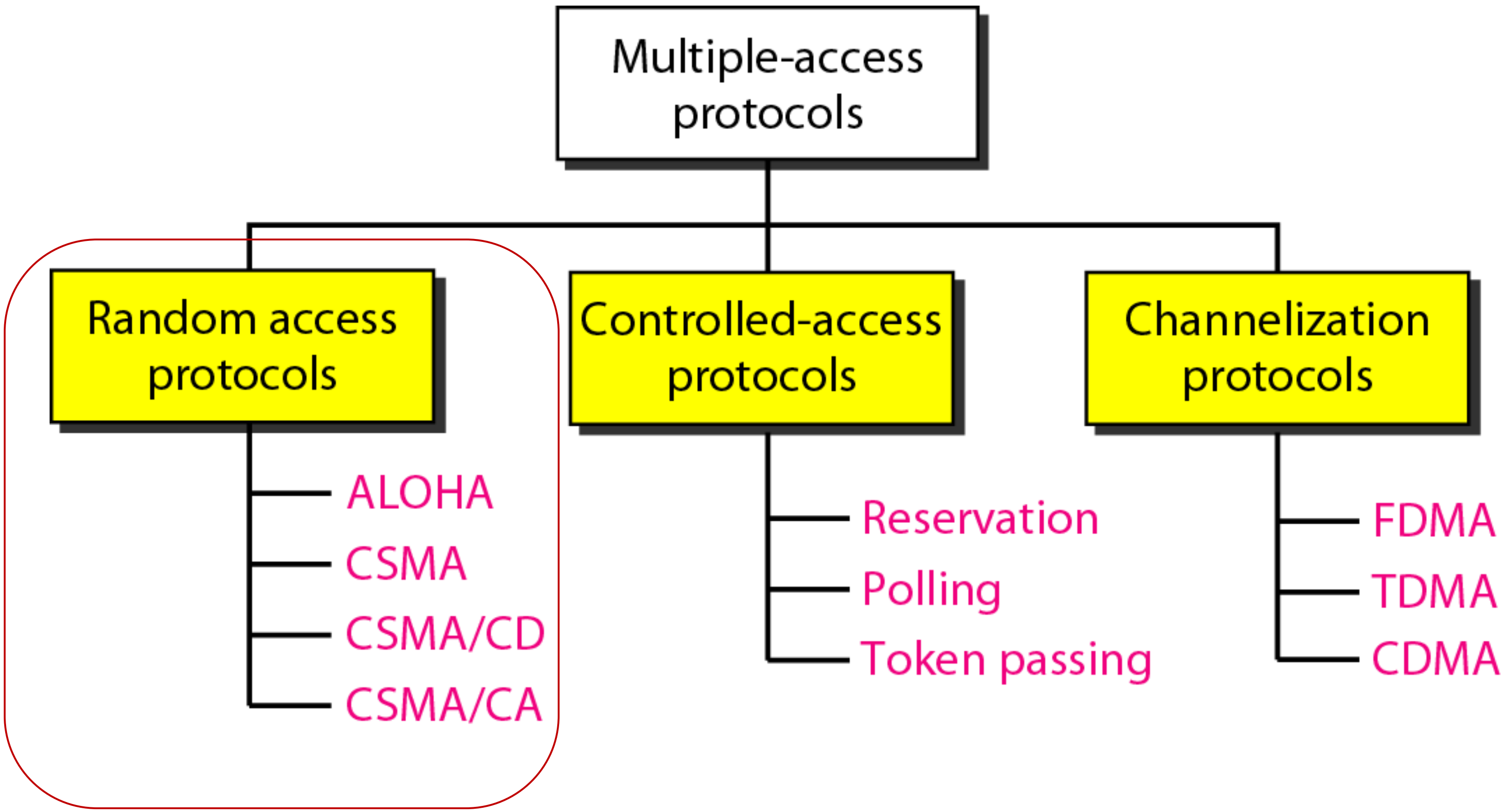
Medium Access Control Protocols

- **Single shared broadcast channel**
- **Two or more simultaneous transmissions**
  - Collision if node receives two or more signals at the same time
- **MAC Protocol**
  - Distributed algorithm to share the channel
  - ✓ In-band control
    - Coordination and data communications use the same channel
  - ✗ Out-of-band control
    - Coordination and data communications use different channels

Ideal MAC Protocols

- **Broadcast Channel of Rate *R*-bps**
  - When one node transmits, it can send at rate *R*
  - When *M* nodes want to transmit, each can send at average rate *R/M*
  - Full decentralized
    - No special node to coordinate transmissions
    - No synchronization of clocks, slots
  - Simple
  - We call this ideal protocol as "*genie-aided*" MAC

MAC Taxonomy



Random Access Protocols

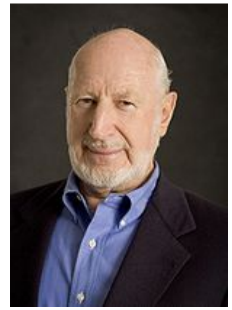
- **When node has packet to send**
  - Transmits at full channel data rate of *R*
  - No a-priori coordination among nodes
- **Two or more transmitting nodes**
  - Collision
- **Design of random MAC has 3 aspects**
  - **Whether** to sense channel before transmission?
  - **How** to transmit frames?
  - **What** to do with collisions?

ALOHA Protocols

aloha
/əˈləʊhə/
exclamation & noun
a Hawaiian word used when greeting or parting from someone.

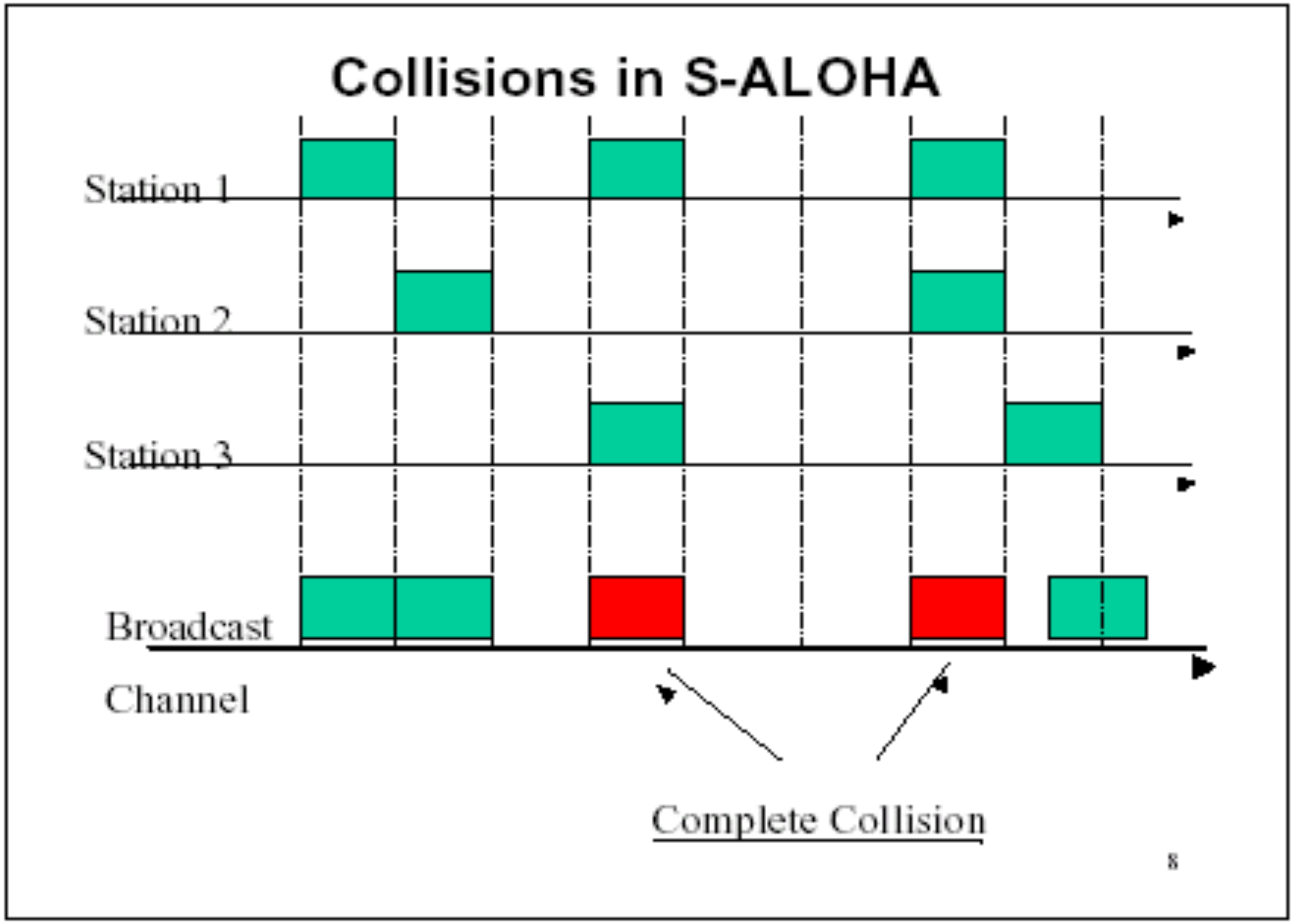
Slotted ALOHA

- **Inventor**
  - Norm Abramson
- **Assumptions**
  - All frames of the same size
  - Time is divided into equal size slots, time to transmit 1 frame
  - Nodes are synchronized
  - Nodes start to transmit frames only at beginning of slots
  - If 2 or more nodes transmit in slot, all nodes detect collision



Norman M. Abramson	
Born	April 1, 1932 (age 83) Boston, Massachusetts
Nationality	American
Fields	Electrical Engineering and Computer Sciences
Institutions	University of Hawaii
Alma mater	Stanford University Harvard University
Doctoral advisor	Willis Harman
Doctoral students	Thomas M. Cover Robert A. Scholtz
Notable awards	IEEE Alexander Graham Bell Medal (2007)

Slotted ALOHA

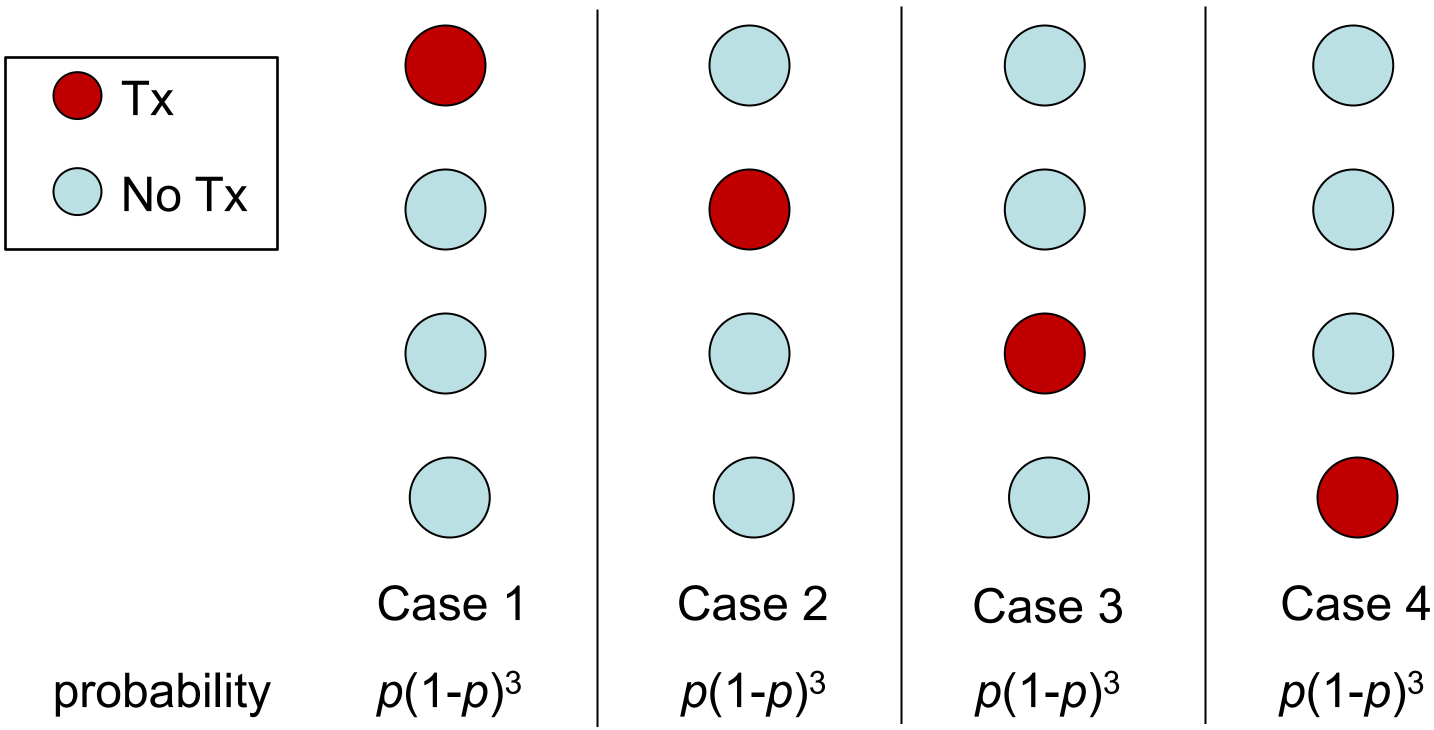


Slotted ALOHA Efficiency

- **Result of a slot**
  - Successful (S): only one node transmits
  - Collision (C): 2^+ nodes transmits
  - Empty (E): no transmission
- **If, there are *N* nodes and in each slot, each node transmits with probability *p***
  - If a node *i* transmits, the probability that the transmission is successful is $\Pr(S_i) = p\,(1-p)^{(N-1)}$
  - The probability that a slot is successful is $\Pr(S) = N\,p\,(1-p)^{(N-1)}$

Slotted ALOHA Efficiency

- **An example of 4-node network**
  - 4 cases for a successful slot



$$\Pr(S) = 4p(1-p)^3$$

Slotted ALOHA Efficiency

- **Offered load *G = Np***
  - Expected total number of transmissions in a slot
- **Slotted ALOHA efficiency when *N* is large**

$$\lim_{N\to\infty} \Pr(S) = \lim_{N\to\infty} Np(1-p)^{N-1}$$

$$\overset{*}{=} \lim_{p\to 0} G(1-p)^{\frac{G}{p}-1}$$

$$= G \cdot \left(\lim_{p\to 0}(1-p)^{1/p}\right)^{G} \cdot \left(\lim_{p\to 0}(1-p)^{-1}\right)$$

$$\overset{**}{=} Ge^{-G}$$

* When $N \to \infty$, $p \to 0$ as G is bounded

** $\lim_{p\to 0}(1-p)^{\frac{1}{p}} \to \frac{1}{e}$ by the definition of ***e***: $e = \lim_{x\to\infty}\left(1+\frac{1}{x}\right)^{x}$

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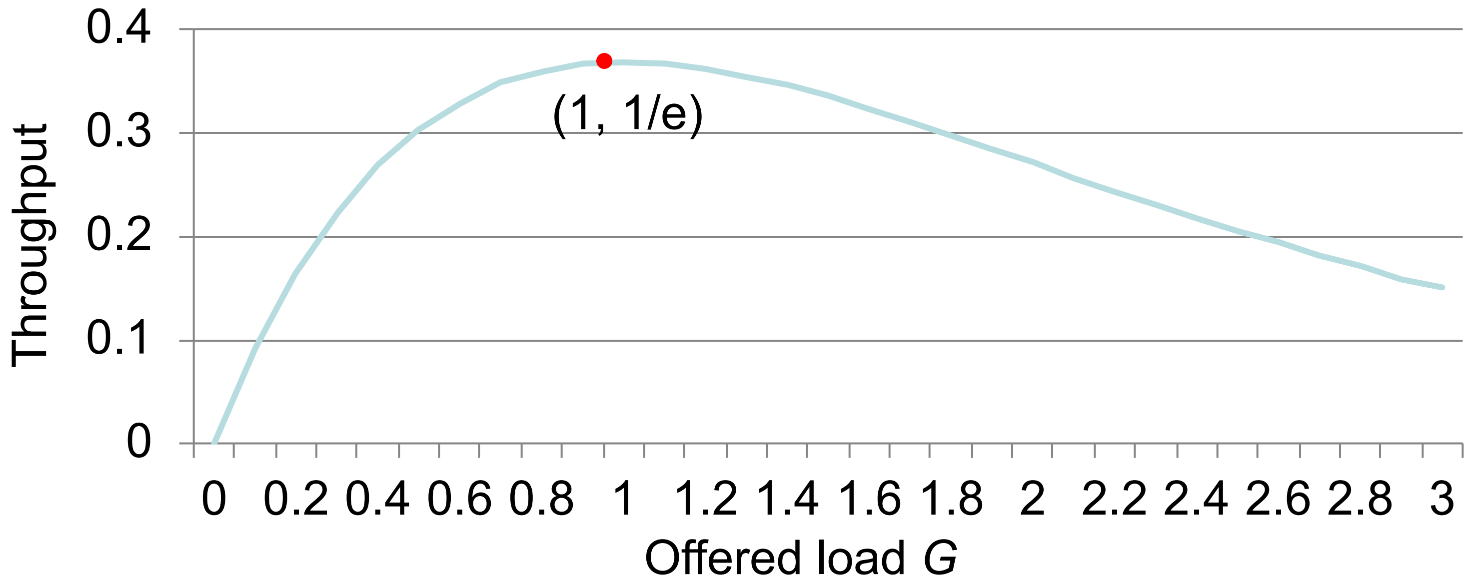
Slotted ALOHA Efficiency



- Pr(*S*) is throughput in frames per frame time
- Pr(*S*) <= 1/e (≈ 0.37) **
  - 1/e achieved when *G* = 1
  - At the same time, Pr(*E*) ≈ 0.37, Pr(*C*) ≈ 0.26

**** Tutorial 3.4**

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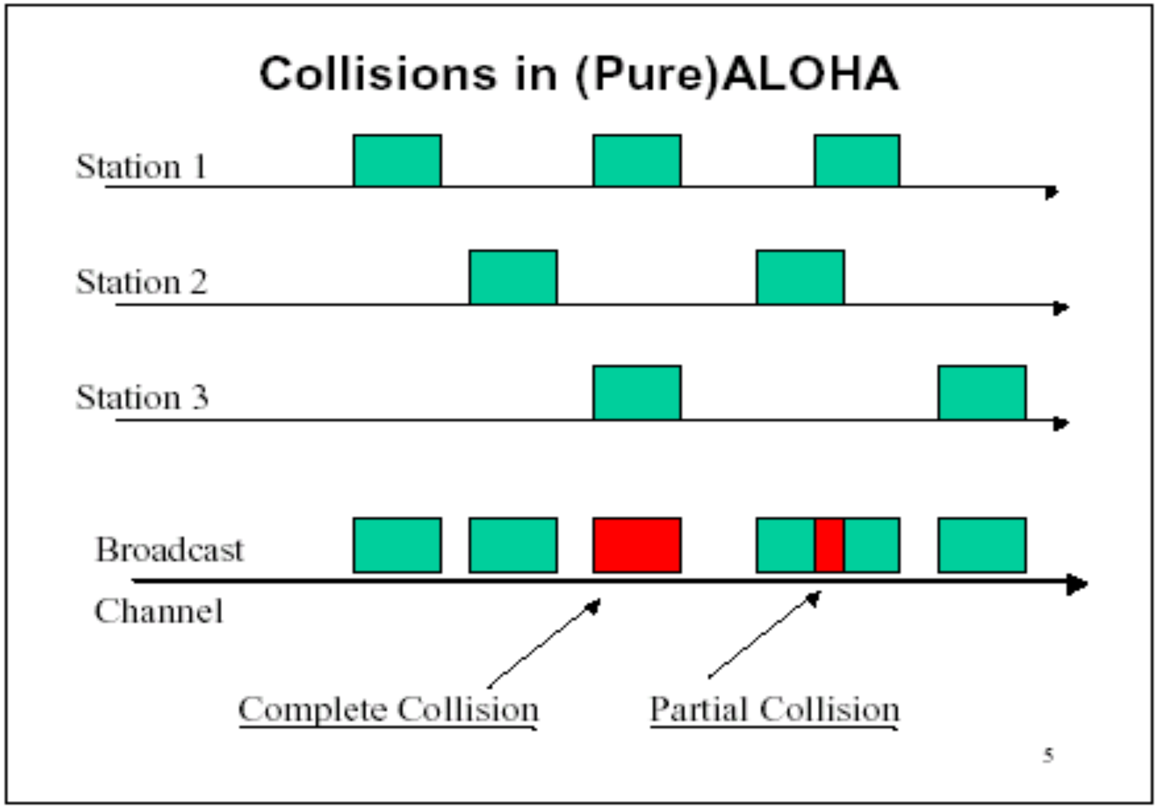
Pros and Cons of Slotted ALOHA

- **Pros**
  - Single active node can continuously transmit at full rate of channel
  - Highly decentralized: only slots need to be sync
  - Simple
- **Cons**
  - Collisions
  - Empty slots, wasting slots
  - Clock synchronization

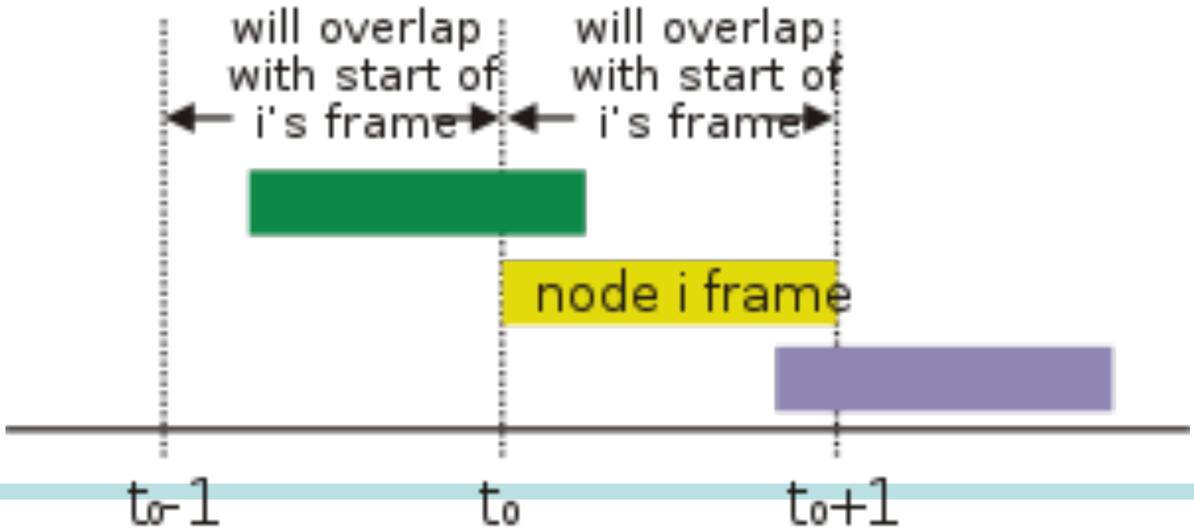
Pure ALOHA

- **In pure ALOHA, frames are transmitted at completely arbitrary times**



Pure ALOHA

- **Simpler, no synchronization**
- **When frame first arrives**
  – Transmit immediately
- **Collision probability increases:**
  – Frame sent at t_0 collides with other frames sent in $[t_0-1, t_0+1]$



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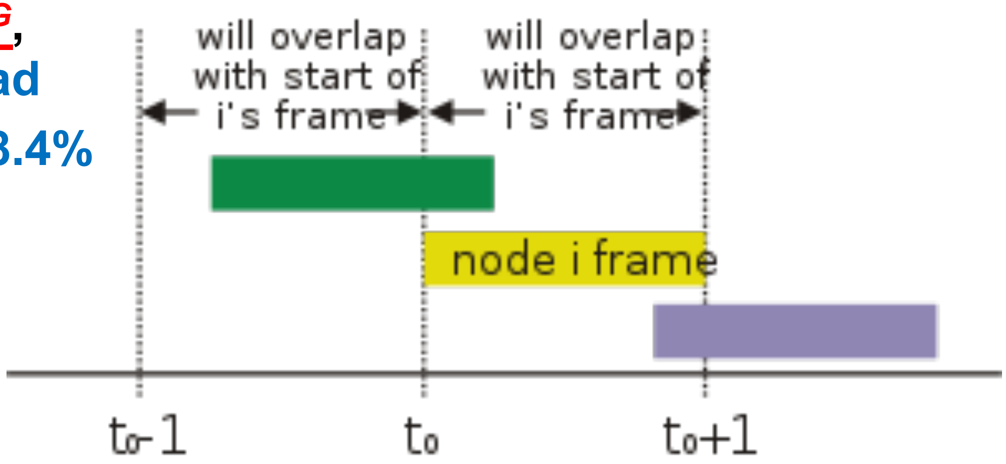
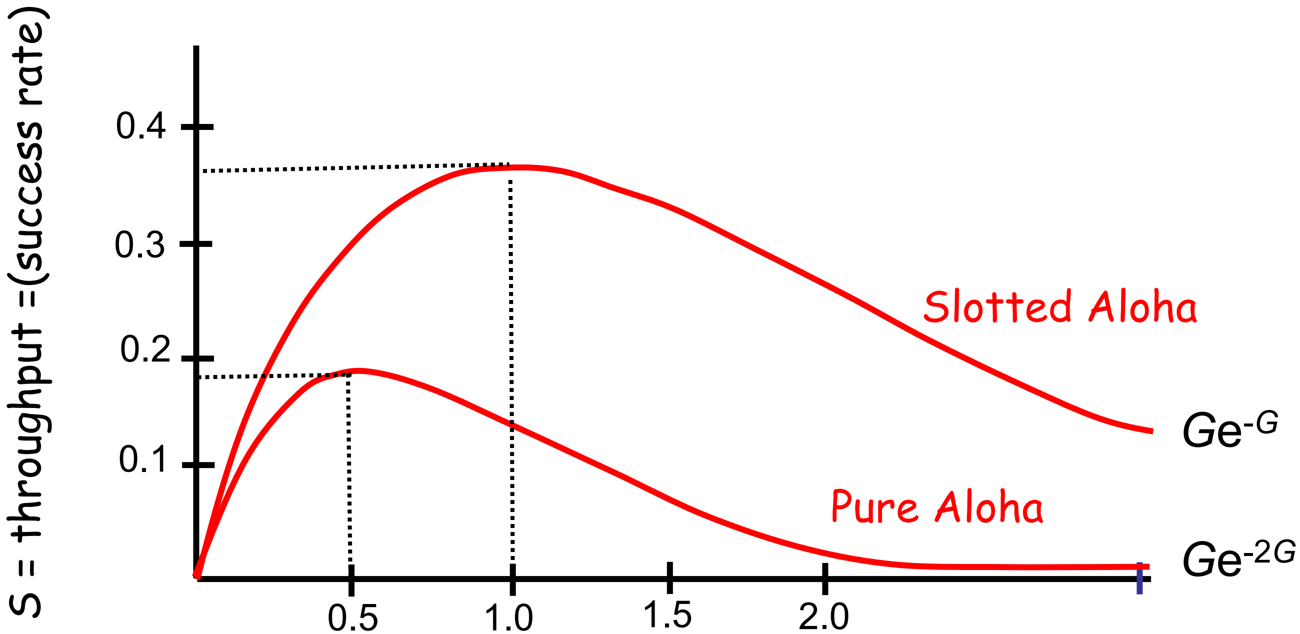
Aloha Efficiency: Pure ALOHA

Pure Aloha: Partial transmission collision can occur (i.e., my 1st half of the transmission collides with your 2nd half)

- **Pr(success by given node) = P(node transmit) ***
  P(no other node transmits in [t0-1, t0]) *
  P(no other node transmit in [t0, t0+1])
  $= p \times (1-p)^{(N-1)} \times (1-p)^{(N-1)}$
  $= p\,(1-p)^{(2N-2)}$
- So for the network, $Pr(S) = N\,p\,(1-p)^{(2N-2)}$
- **For very large N, $Pr(S) = Ge^{-2G}$, where $G=Np$ is the offered load**
- **Therefore, $Pr(S) <= 1/(2e) = 18.4\%$**



ALOHA Efficiency Comparison



G = offered load rate

= Expected total frames presented to the link per the transmission time of a single frame

Carrier-Sense Multiple-Access (CSMA)

Carrier-Sense Multiple-Access

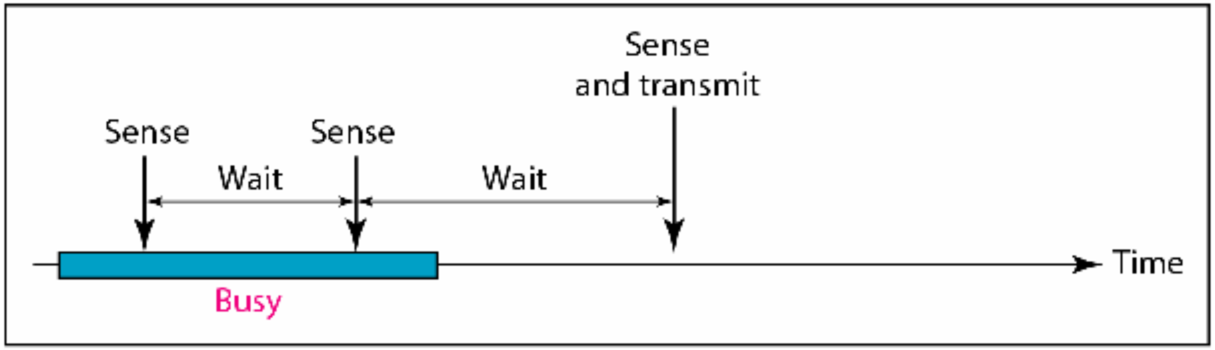
- **To improve performance, avoid transmissions that are certain to cause collisions**
- **Based on the fact that in LAN propagation time is very small**
  - If a frame was sent by a station, all stations knows immediately so they can wait before start sending
  - A station with frames to be sent, should **sense the medium** for the presence of another transmission (carrier) before it starts its own transmission
  - However, because all stations cannot know immediately, collision is still possible [ignore for now]

CSMA Variants

- **Different CSMA protocols that determine:**
  - What a station should do when the medium is idle?
  - What a station should do when the medium is busy?
- **Three Types of CSMA Protocols**
  - Non-persistent CSMA
  - 1-Persistent CSMA
  - P-Persistent CSMA

Non-persistent CSMA

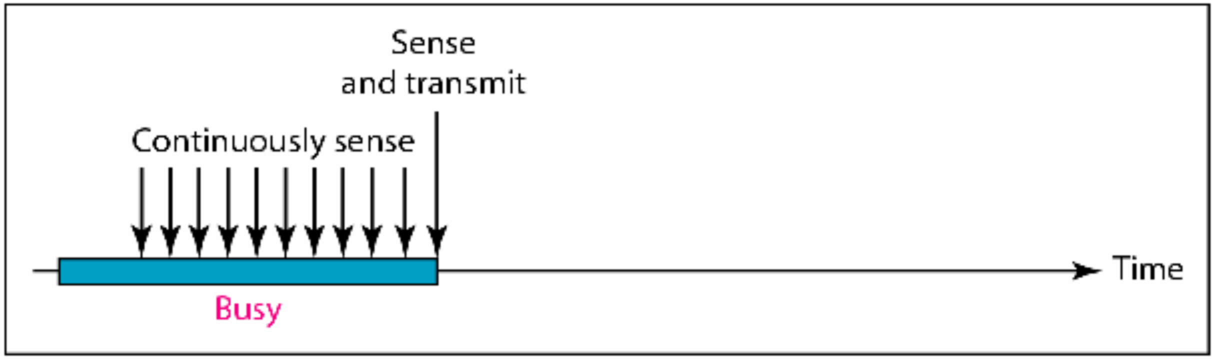
- **A station with frames to be sent, should sense the medium**
  1. If medium is idle, **transmit**; otherwise, go to 2
  2. If medium is busy, (**backoff**) wait a ***random*** **amount of time** and repeat **1**
- **Non-persistent Stations are deferential (respect others)**
- **Performance:**
  - Random delays reduces probability of collisions because two stations with data to be transmitted would wait for different amount of times.
  - Bandwidth is **wasted** if waiting time (backoff) is large because medium will remain idle following end of transmission even if one or more stations have frames to send



b. Nonpersistent

1-Persistent CSMA

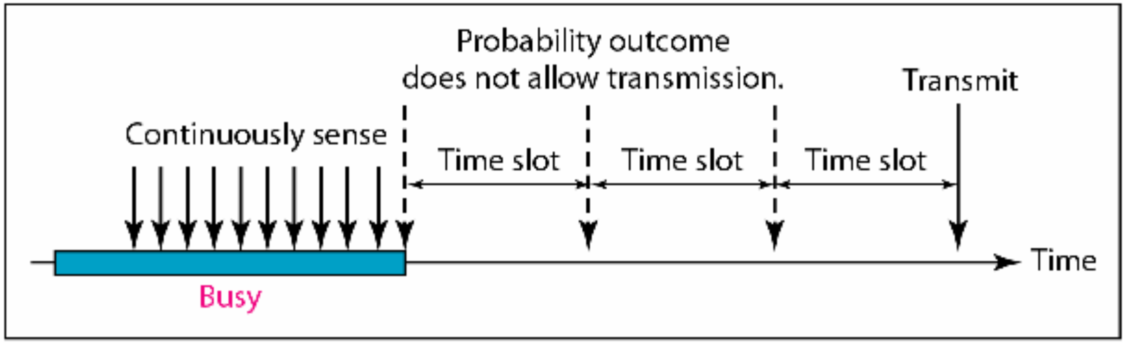
- **To avoid idle channel time, 1-persistent protocol used**
- **Station wishing to transmit listens to the medium:**
  1. If medium idle, **transmit** immediately;
  2. If medium busy, **continuously listen** until medium becomes idle; then transmit immediately with probability 1
- **1-persistent stations are selfish**
- **Performance**
  - If two or more stations becomes ready at the same time, **collision guaranteed**



a. 1-persistent

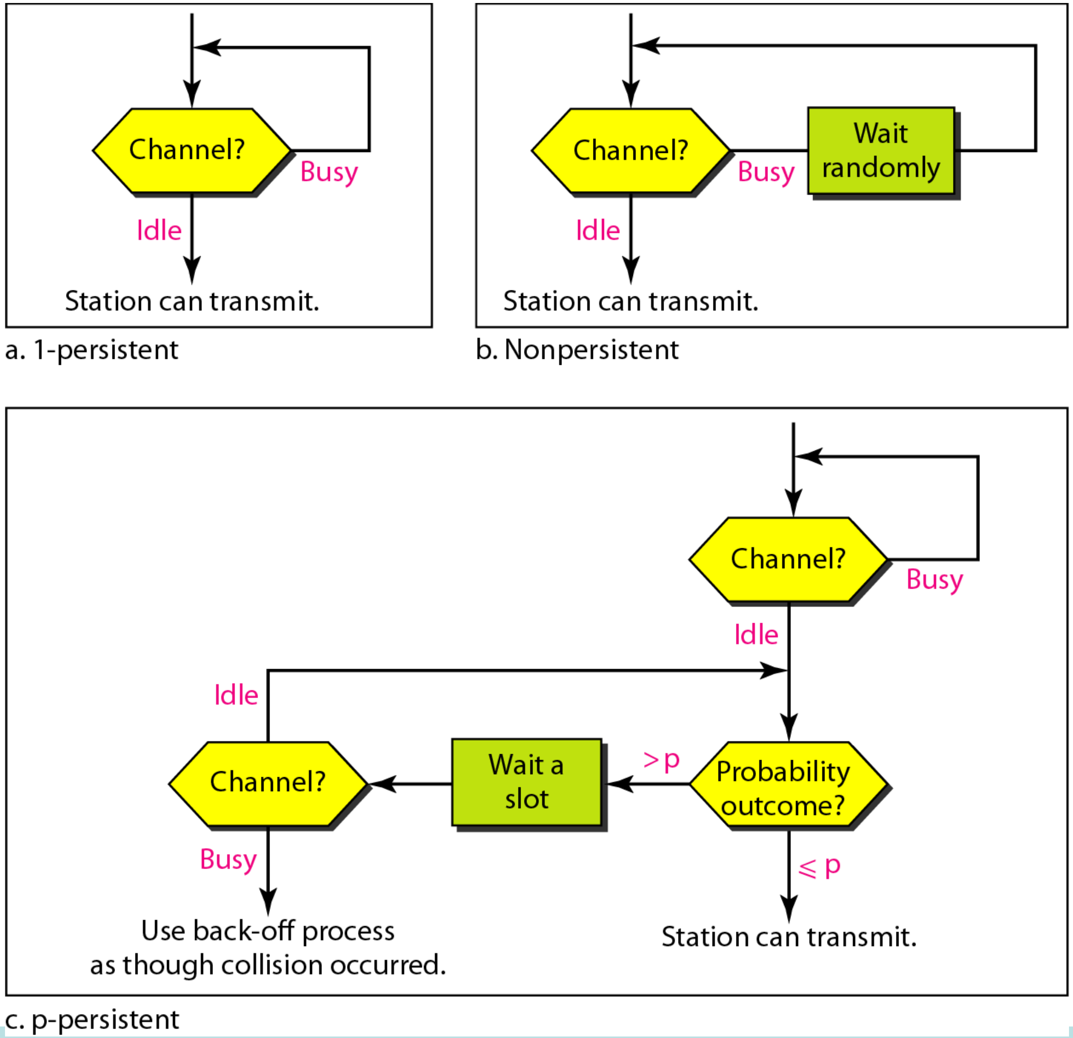
P-Persistent CSMA

- **Time is divided to slots**
- **Station wishing to transmit listens to the medium:**
  1. If medium idle,
     - transmit with probability (**p**), OR
     - wait **one time slot** with probability (**1 – p**), then repeat 1.
  2. If medium busy, continuously listen until idle and repeat step 1
- **Performance (wise guy)**
  - Reduces the possibility of collisions like **non-persistent**
  - Reduces channel idle time like **1-persistent**

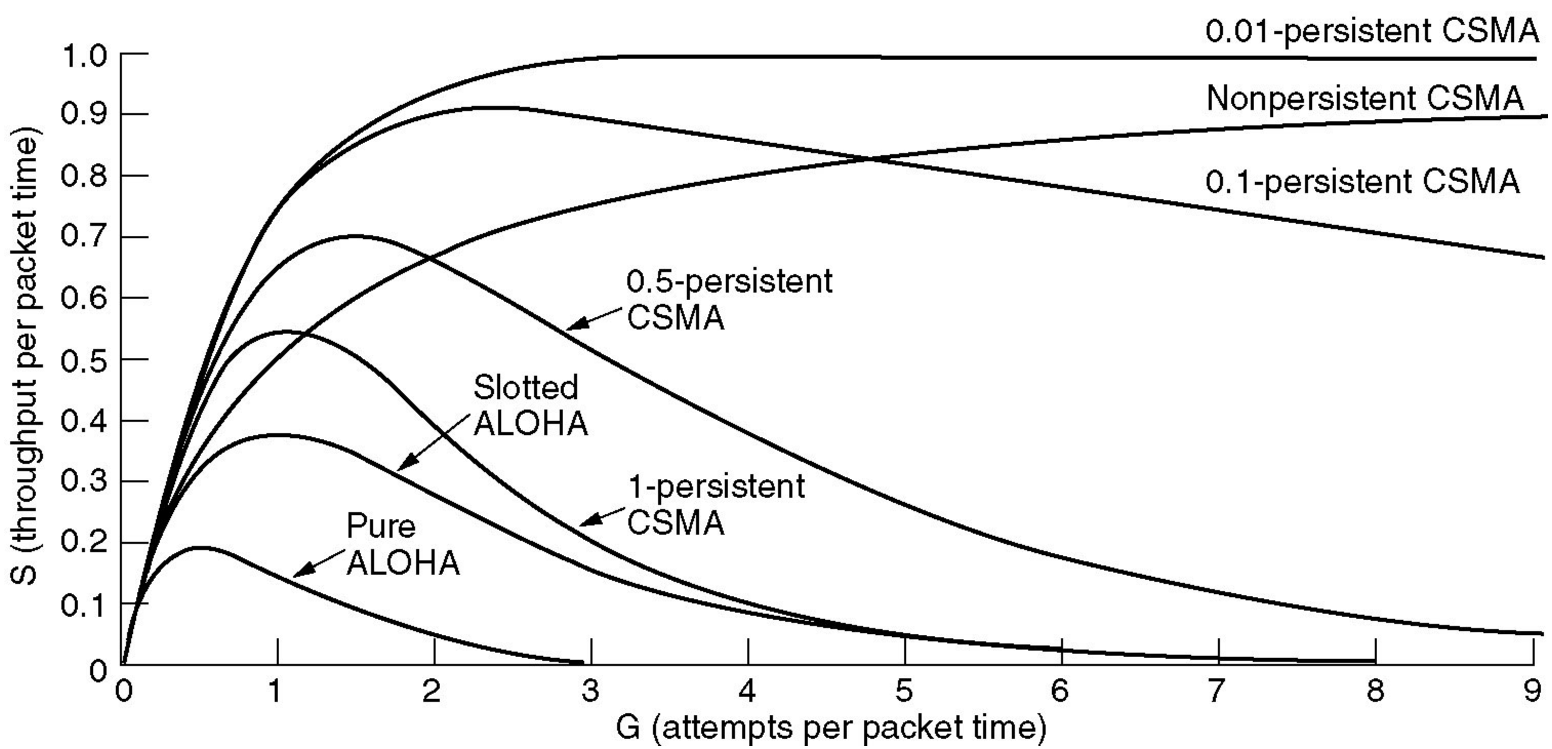


c. p-persistent

Flow Diagrams for CSMA



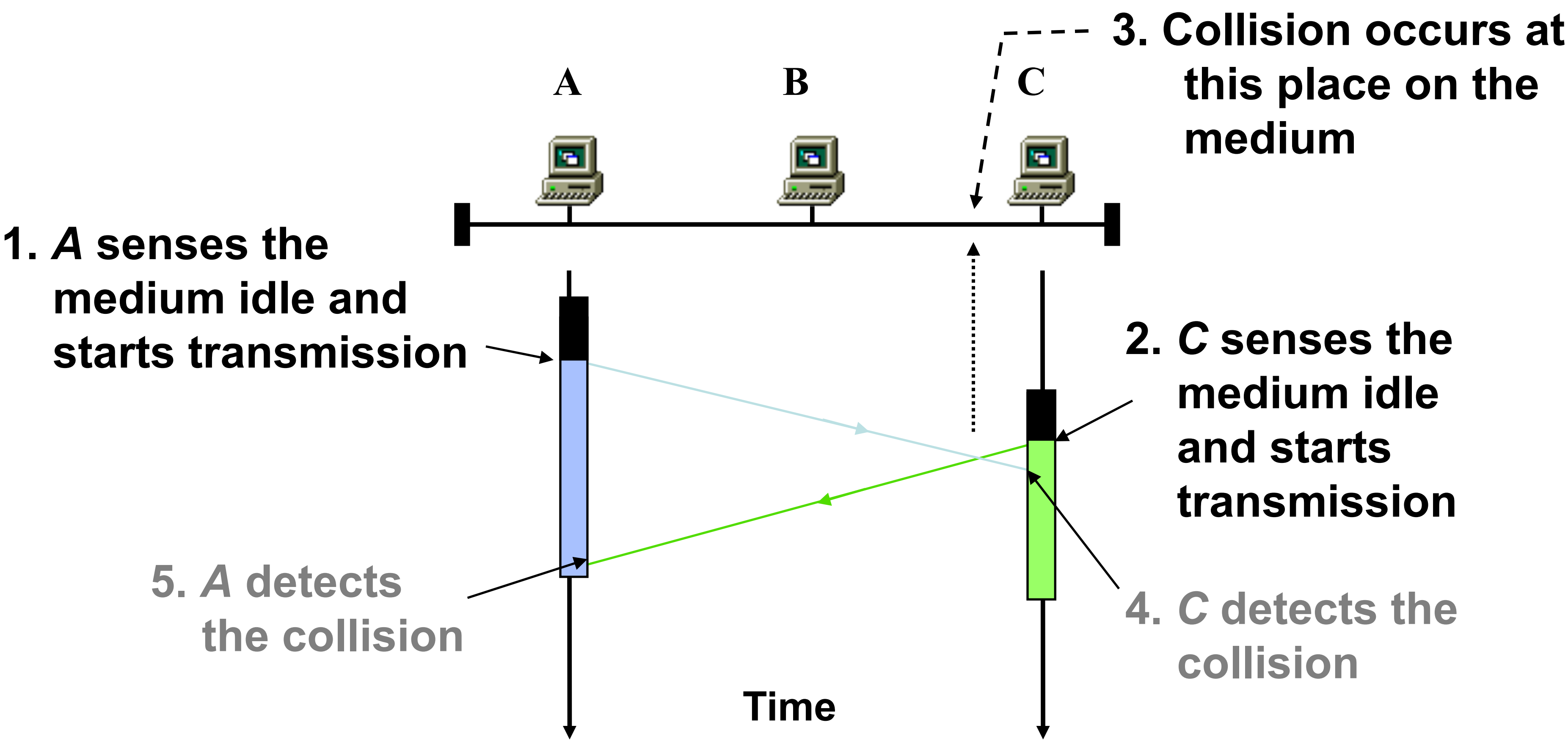
CSMA Efficiency



Comparison of the channel utilization versus load for various random access protocols.

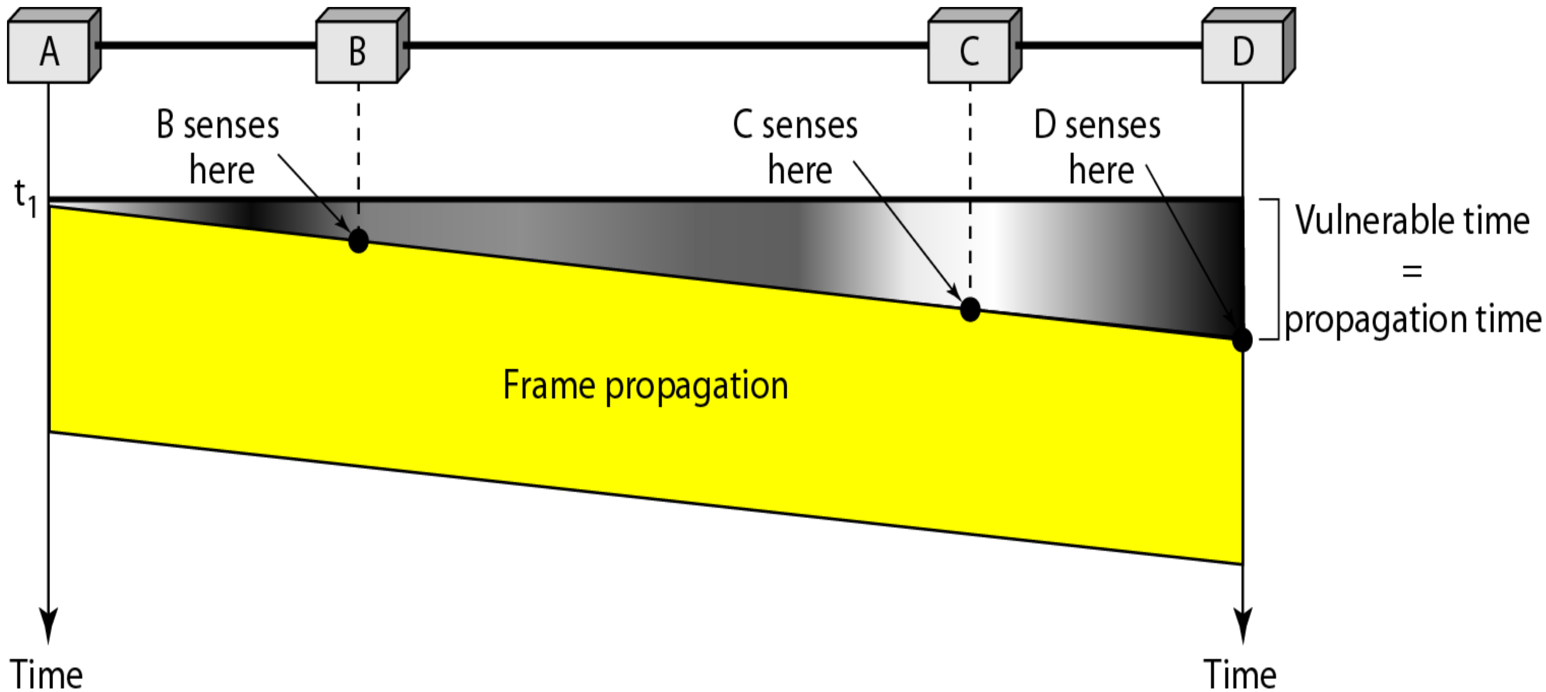
CSMA/CD Protocol

Collision in CSMA



Vulnerable Time in CSMA

- Vulnerable time for CSMA is the <u>maximum propagation time</u>
- The longer the propagation delay, the <u>worse the performance</u> of the protocol.

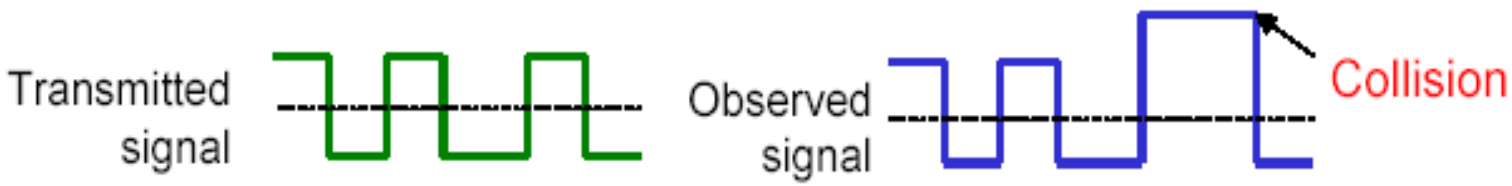


CSMA/CD (Collision Detection)

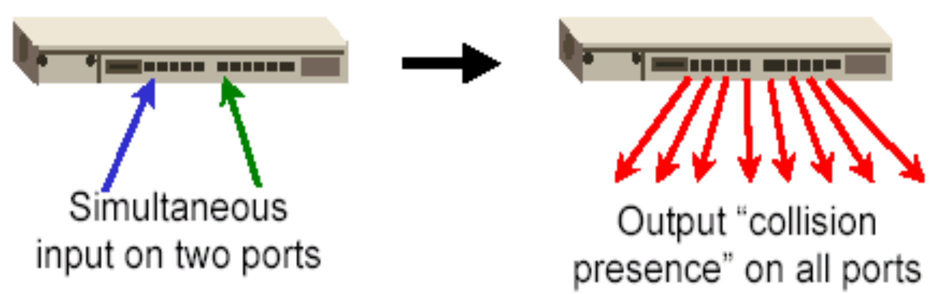
- **CSMA has channel wastage**
  – If a collision has occurred, colliding packets are still to be fully transmitted.
- **CSMA/CD (*Carrier Sense Multiple Access with Collision Detection*) overcomes this:**
  – While transmitting, the sender is listening to medium for collisions.
  – Sender stops transmission if collision has occurred, reducing channel wastage.
- **CSMA/CD is widely used for bus topology LANs (IEEE 802.3, Ethernet)**

How to detect a Collision?

- **Transceiver**
  - A node monitors the media while transmitting. If the observed power is higher than the transmitted power of its own signal, it means collision occurred.



- **Hub**
  - If input occurs simultaneously on two ports, it indicates a collision. Hub send a collision presence signal on all ports.



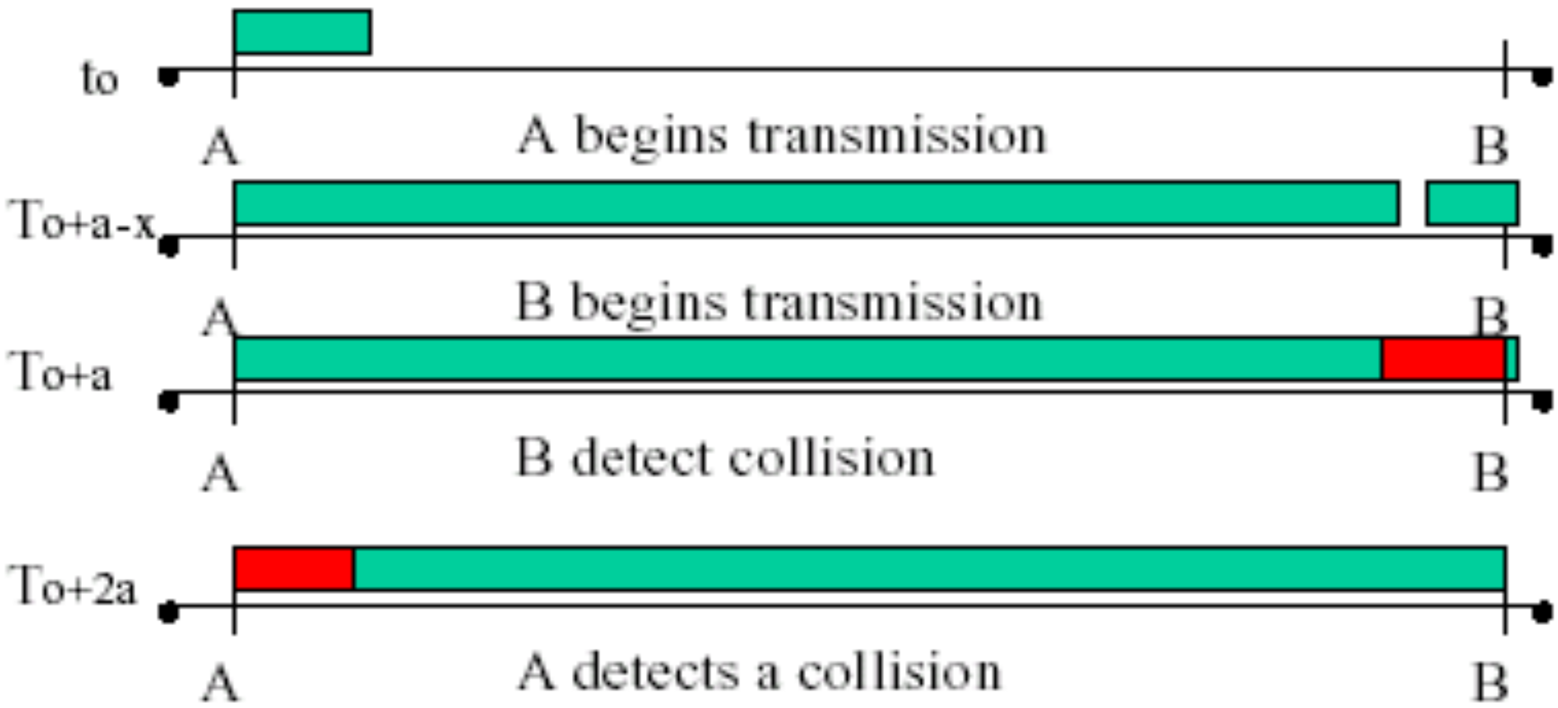
CSMA/CD Protocol

- **Transmission protocol**
  - Use one of the CSMA persistent algorithms
- **If a collision is detected by a station during its transmission, it should do the following**
  - **Abort transmission**, and
  - Transmit a *jam signal* (48 bits) to notify other stations of collision so that they will **discard the transmitted frame**
  - After sending the *jam signal*, **backoff (wait) for a *random*** amount of time, then
  - Transmit the frame again

Collision Detection

- *Question:* **How long does it take to detect a collision?**
- *Answer:* ***In the worst case*, twice the maximum propagation delay of the medium**

Note: **a = maximum propagation delay**



Learning Objectives

- **ALOHA Protocol**
  - Calculate throughput for ALOHA
  - Maximize throughput by <u>differentiation</u>
- **CSMA Protocol**
  - Protocol comparison for three flavors
- **CSMA/CD Protocol**
  - Maximum duration for collision detection