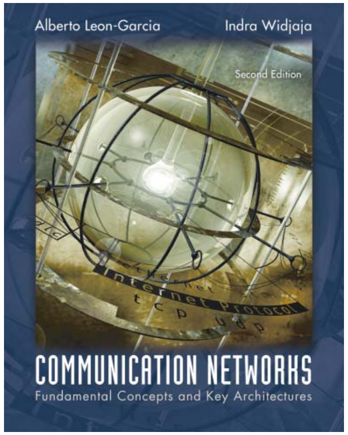
Chapter 6
Medium Access Control Protocols and Local Area Networks



Part I: Medium Access Control

Part II: Local Area Networks

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Chapter Overview

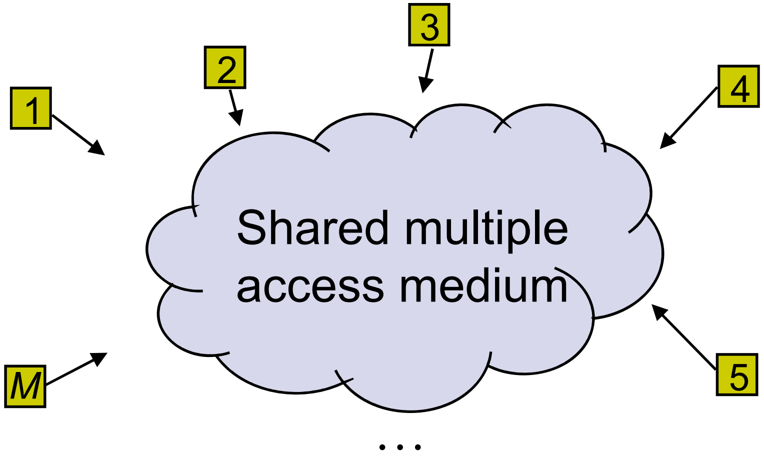
- **Broadcast Networks**
  - All information sent to all users
  - No routing
  - Shared media
  - Radio
    - Cellular telephony
    - Wireless LANs
  - Copper & Optical
    - Ethernet LANs
    - Cable Modem Access
- ***Medium Access Control***
  - To coordinate access to shared medium
  - Data link layer since direct transfer of frames
- ***Local Area Networks***
  - High-speed, low-cost communications between co-located computers
  - Typically based on broadcast networks
  - Simple & cheap
  - Limited number of users

Part I: Medium Access Control

Multiple Access Communications
Random Access
Scheduling
Channelization

Multiple Access Communications

- Shared media basis for broadcast networks
  - Inexpensive: radio over air; copper or coaxial cable
  - M users communicate by broadcasting into medium
- Key issue: How to share the medium?



Approaches to Media Sharing

Medium sharing techniques

- Static channelization
- Dynamic medium access control
  - Scheduling
  - Random access

Static channelization

- Partition medium
- Dedicated allocation to users
- Satellite transmission
- Cellular Telephone

Scheduling

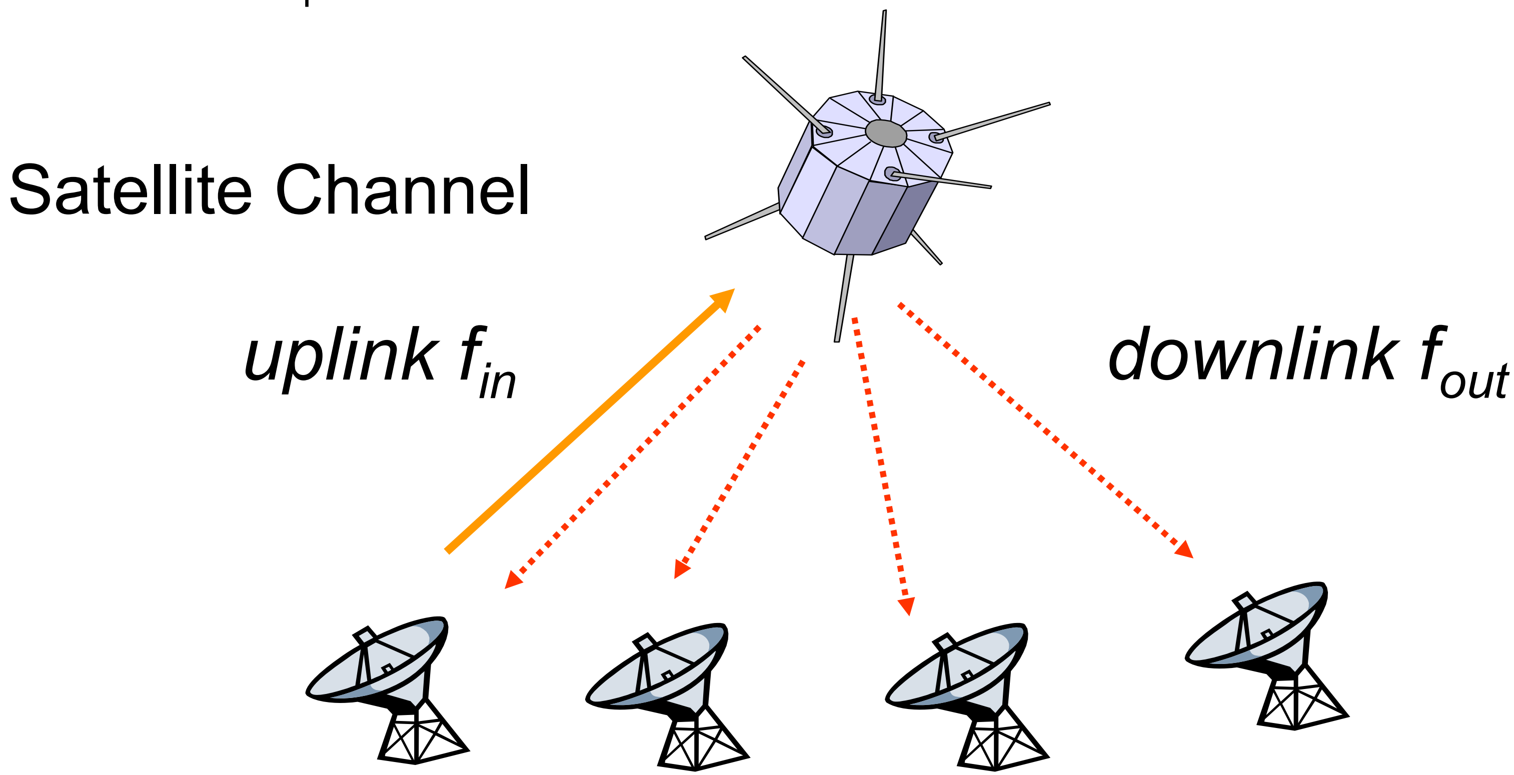
- Polling: take turns
- Request for slot in transmission schedule
- Token ring
- Wireless LANs

Random access

- Loose coordination
- Send, wait, retry if necessary
- Aloha
- Ethernet

Channelization: Satellite

- two frequency bands: one for uplink and one for downlink
- each station is allocated a channel in the uplink and in the downlink frequency band
- different approaches can be employed to create uplink/downlink channels (FDMA, TDMA, CDMA)
- although each station can theoretically transmit to and listen to any channel, stations remain within their pre-allocated channels to avoid interference

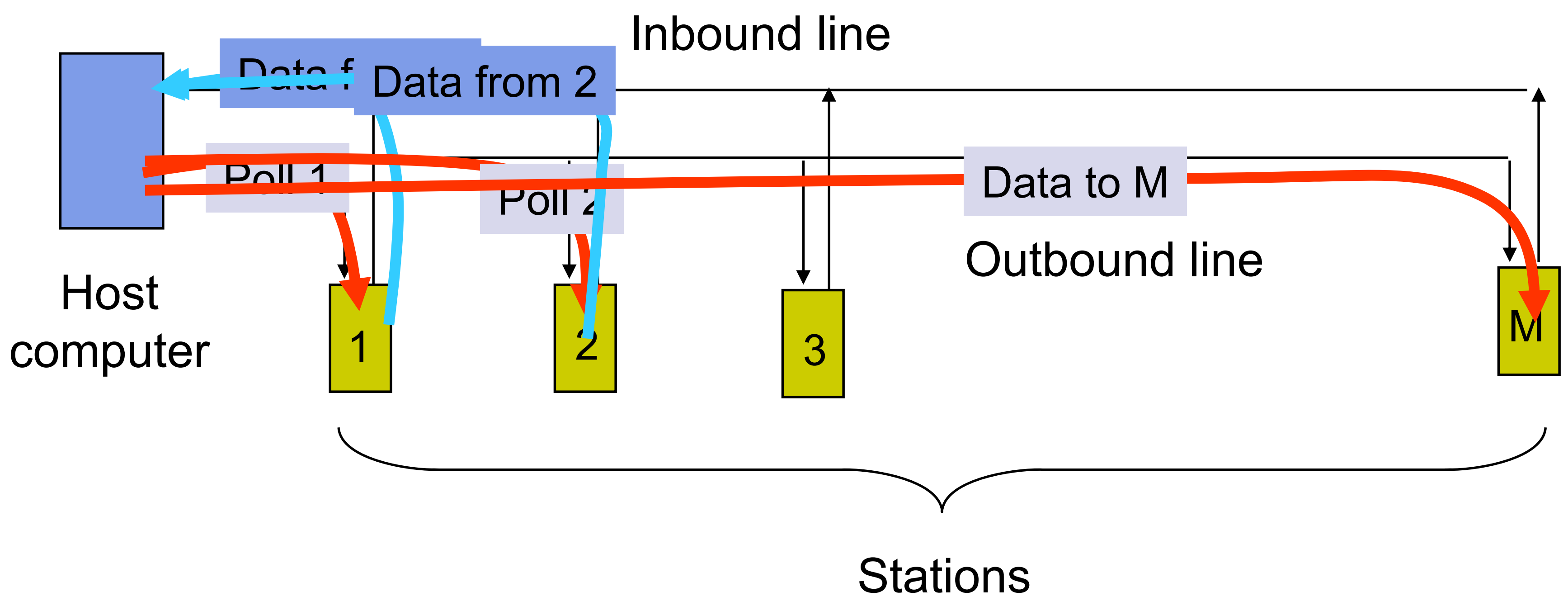


Channelization: Cellular

uplink f_1 ; *downlink f_2*

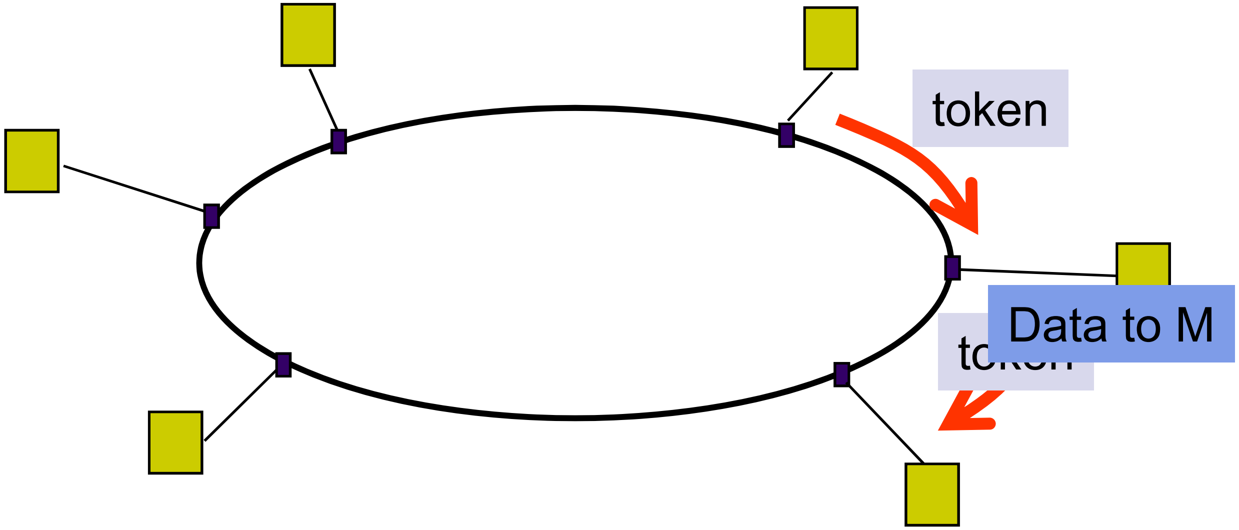
uplink f_3 ; *downlink f_4*

Scheduling: Polling



Scheduling: Token-Passing

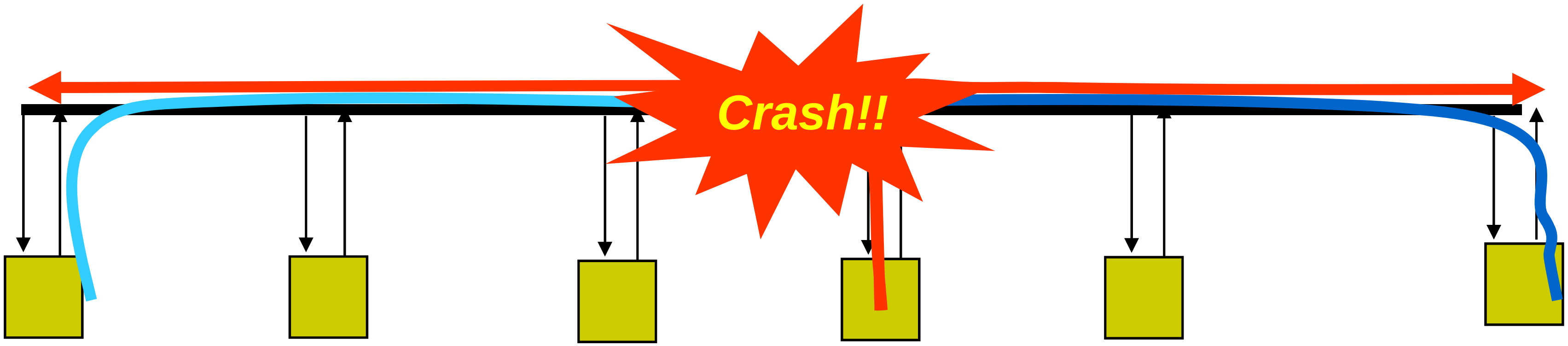
Ring networks



Station that holds token transmits into ring

Random Access

Multitapped Bus

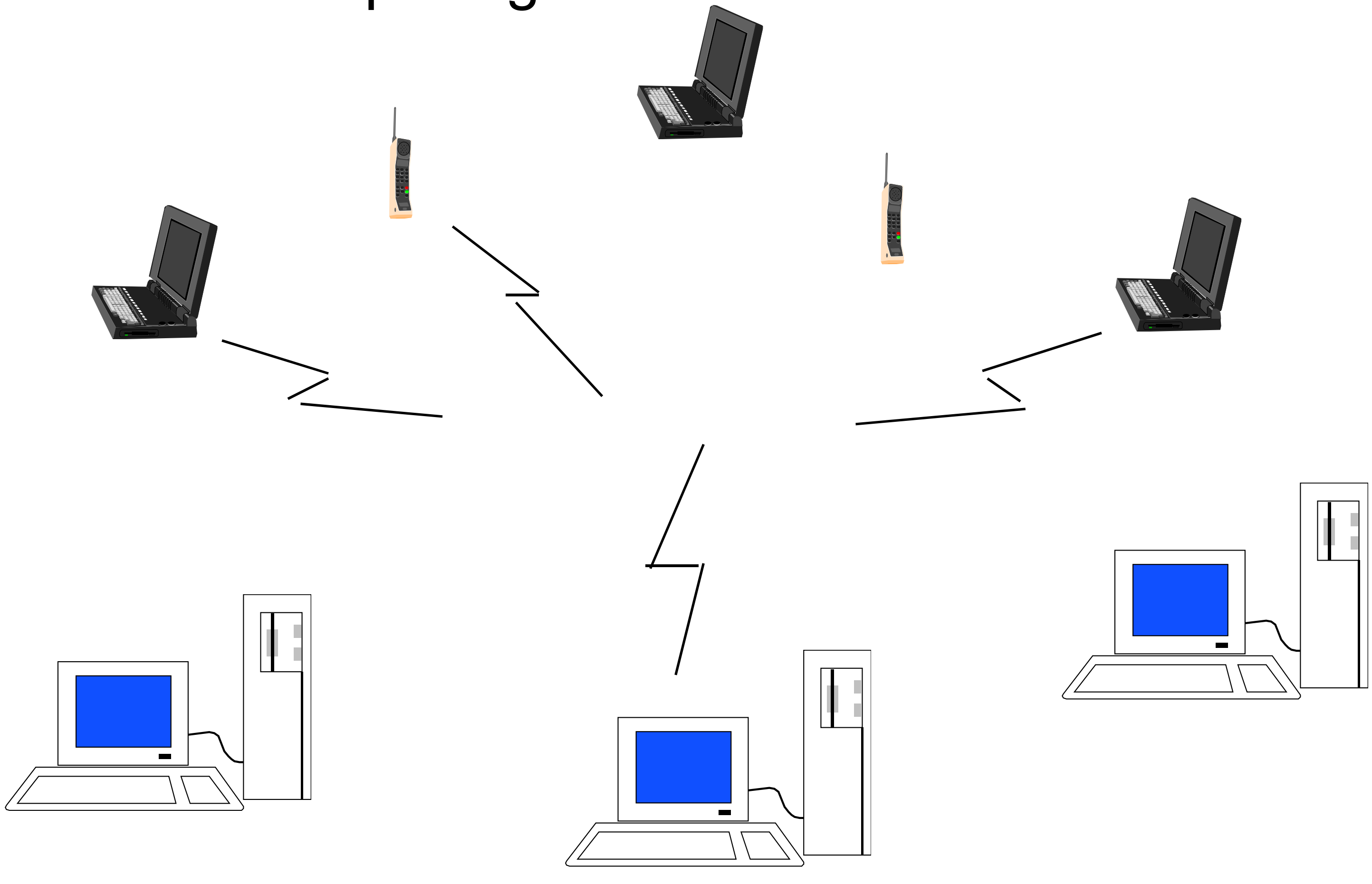


Transmit when ready

Transmissions can occur; need retransmission strategy

Wireless LAN

AdHoc: station-to-station
Infrastructure: stations to base station
Random access & polling

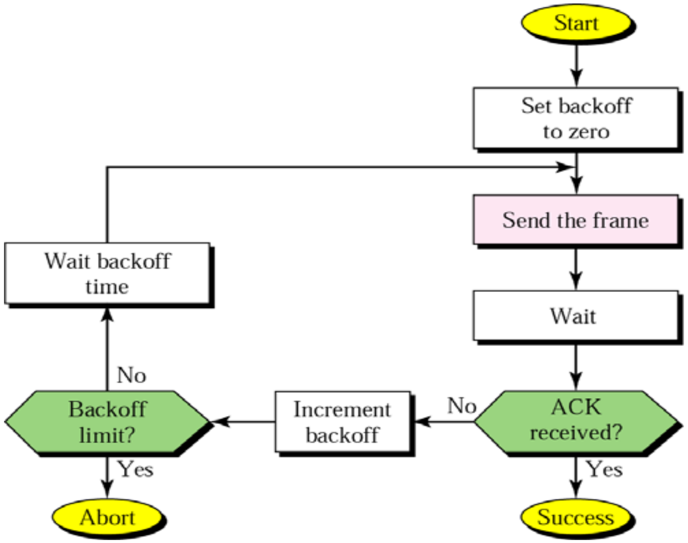


Chapter 6
Medium Access Control Protocols and Local Area Networks

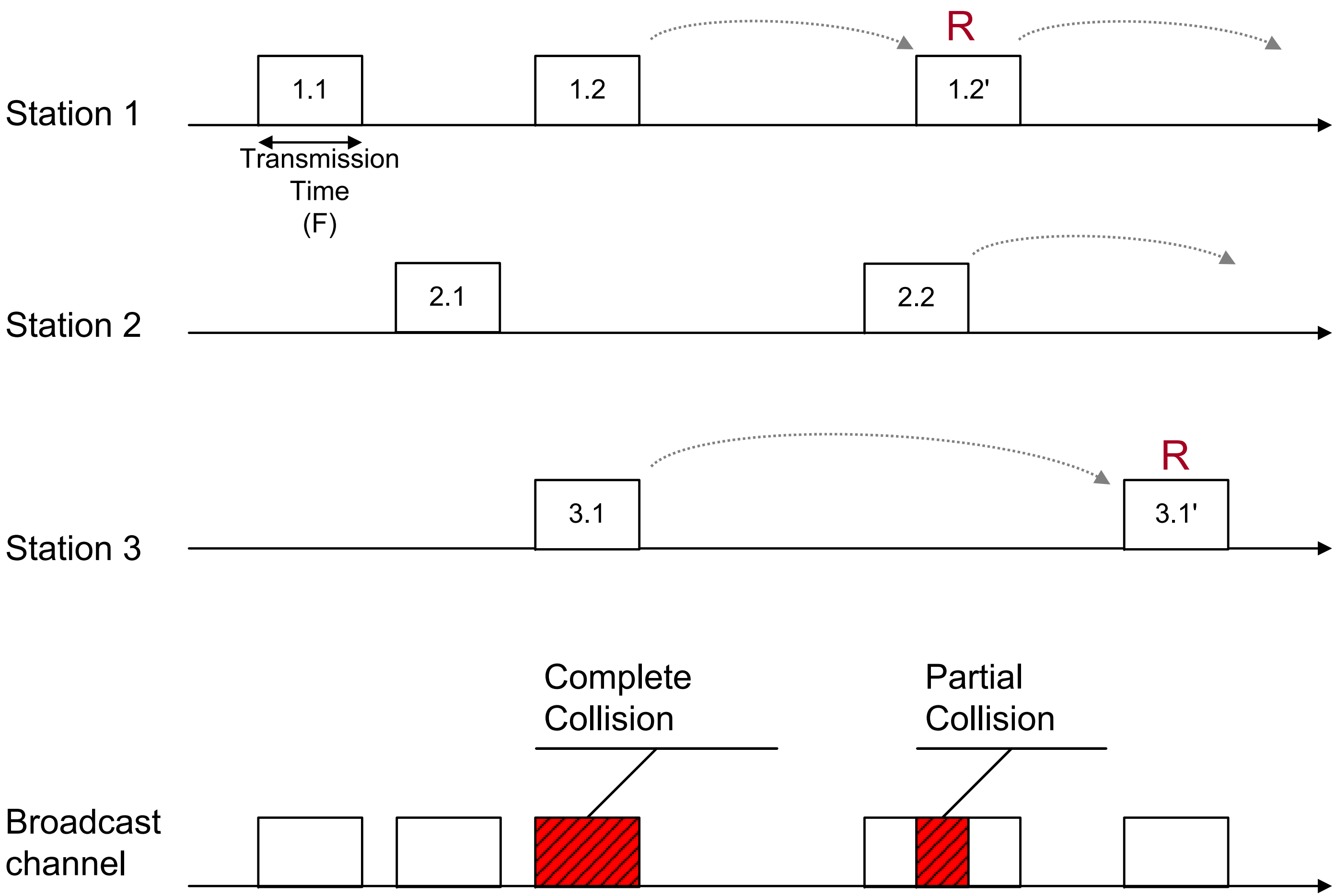
Random Access

ALOHA

- Simplest solution: just do it
  - A station transmits whenever it has data to transmit
  - If more than one frames are transmitted, they interfere with each other (collide) and are lost
  - If ACK not received within timeout, then a station picks random backoff time (to avoid repeated collision)
  - Station retransmits frame after backoff time



Example [Aloha throughput]

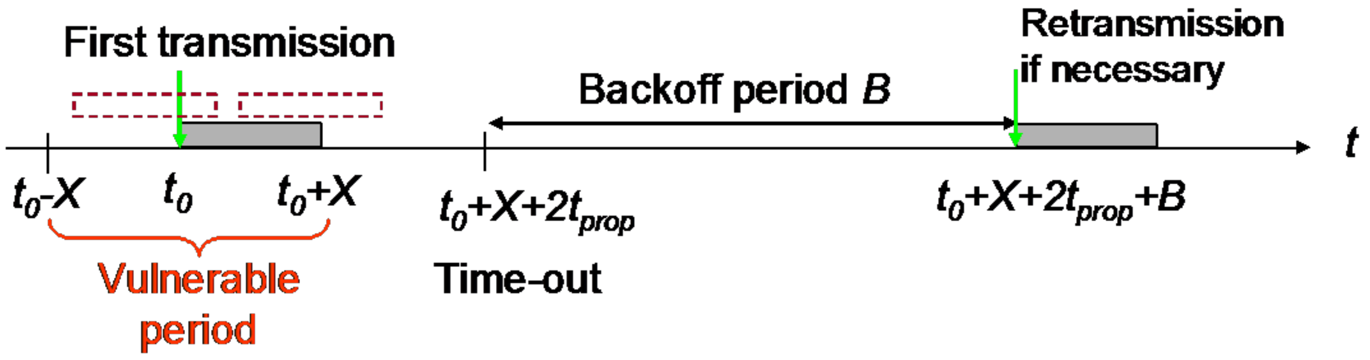


http://www.invocom.et.put.poznan.pl/~invocom/C/P1-4/p1-4_en/p1-4_3_7.htm#pureAapplet

Vulnerable Period

- assume frames of constant length (L) and transmission time (X=L/R)
- consider a frame with starting transmission time t_o – the frame will be successfully transmitted if no other frame collides with it
  - any transmission that <u>begins</u> in interval [t_0, t_0+X], or in the prior X seconds leads to collision

vulnerable period = [t_0 – X, t_0+ X]



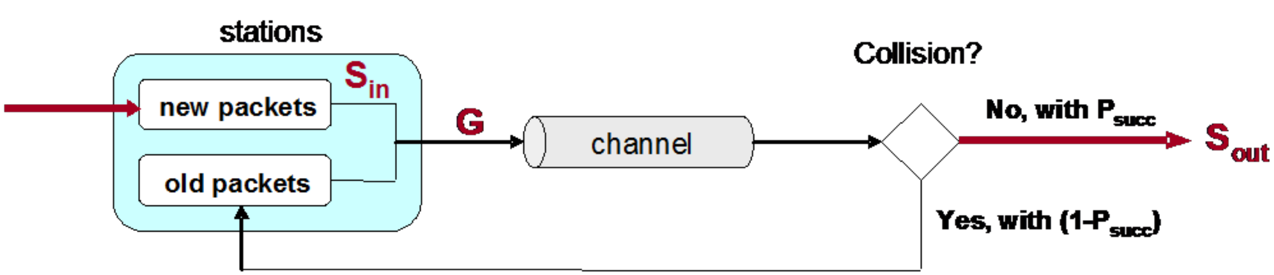
What is the probability of no other transmission, i.e. no collision, in the vulnerable period?!

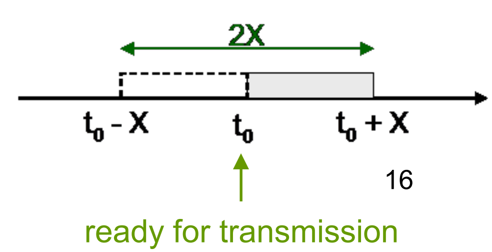
Throughput

- definitions and assumptions:
  - S – (S_{out}) throughput – average # of successful frame transmissions per *X* sec (if network operates under 'stable conditions' $S_{out} = S_{in}$, where S_{in} represents arrival rate of new frames to the system)
  - G – load – average # transmission attempts! per X sec
  - P_{succ} – probability of a successful frame transmission

$$S = P_{succ} \cdot G$$

  - How to find P_{succ}? – suppose a frame is ready for transmission at time t_0 – frame will be transmitted successfully if no other frame attempts transmission X sec before and after t_0
  - random backoff spreads retransmissions so that frame transmission (arrivals) are equally likely at any instant in time – Poisson process !!!





Random Access Techniques: ALOHA (cont.)

- if general, if frame arrivals are <u>equally likely</u> at any instant in time, and arrivals occur at an average rate of λ [arrivals per sec]

Poisson process →

$$P[\text{k arrivals in T seconds}] = \frac{(\lambda T)^k}{k!} e^{-\lambda T}$$

- in our case, λ=G/X [arrivals per second] and T=2X, hence

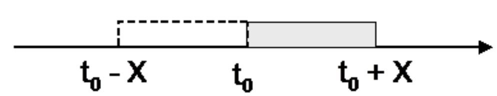
$$P[\text{k transmissions in 2X seconds}] = \frac{(2G)^k}{k!} e^{-2G}$$

- accordingly, the probability of successful transmission (no collision) is:

$$P_{succ} = P[\text{0 transmissions in 2X seconds}] = e^{-2G}$$

and throughput

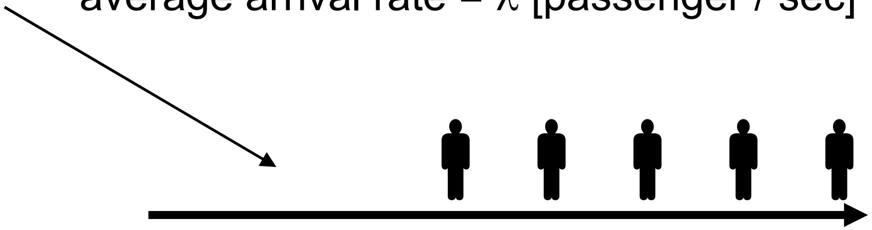
$$S = G \cdot P_{succ} = G \cdot e^{-2G}$$



Arrival: passengers arrive randomly and independently – a **Poisson process**.

Passenger arrivals are equally likely at any instant in time.

average arrival rate = λ [passenger / sec]



average # of arrived passengers in T [sec]:

$$\text{average \# of passengers in T [sec]} = \lambda T$$

probability of having exactly k passengers in line after T [sec]:

$$P[\text{k arrivals in T seconds}] = \frac{(\lambda T)^k}{k!} e^{-\lambda T}$$

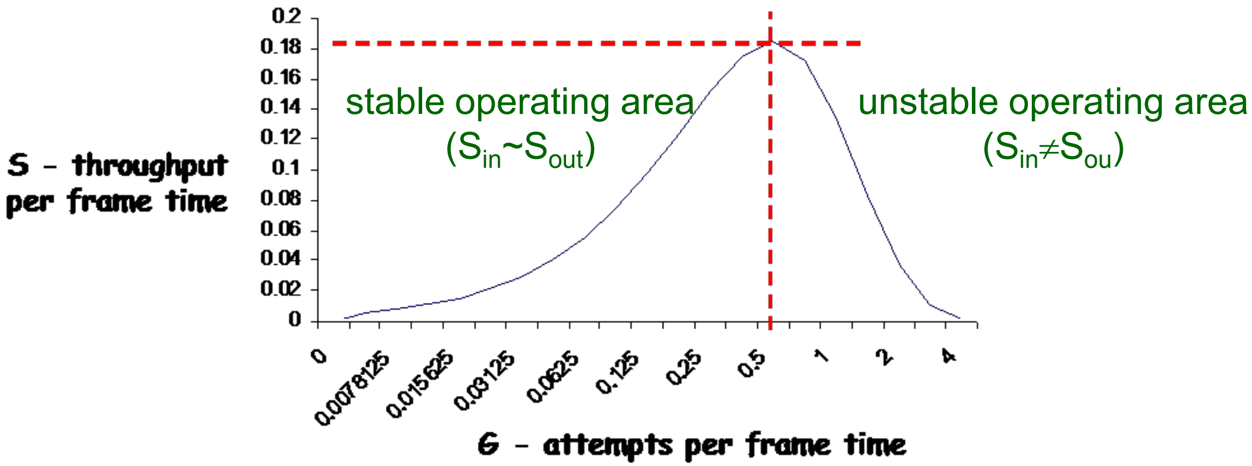
Departure: What is the probability that exactly 1 passenger arrives to the station, off the buss, in T sec?

λ [passenger / sec]

Throughput of ALOHA

S vs. G in Pure ALOHA

- NOTE: our analysis assumed that many nodes share a common channel and have comparable transmission rates (if only one node uses the medium, S=1)
- initially, as G increases S increases until it reaches S_{max} – after that point the network enters 'unstable operating conditions' in which collisions become more likely and the number of backlogged stations increases (consequently, $S_{in} > S_{out}$)
- max throughput of ALOHA (S_{max} = 0.184) occurs at G=0.5, which corresponds to a total arrival rate of 'one frame per vulnerable period'
- S_{max} = 0.184 ⇒ max ALOHA throughput = 18% of channel capacity



18% of channel utilization, with Aloha, is not encouraging.
But, with everyone transmitting at will we could hardly expected a 100% success rate.

Example [Aloha]

a) What is the vulnerable period (in milliseconds) of a pure ALOHA broadcast system with R=50-kbps wireless channel, assuming 1000-byte frames.

b) What is the maximum throughput S of such a channel (system), in kbps?

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a) (frame transmission time =) X = 1000 bytes / 50 kbps = 8000 bits / 50 kbps

$\Rightarrow$ X = 160 milliseconds

vulnerable period = 2*X = 320 milliseconds

b) From theory, max throughput = 0.18 * R = 0.18 * 50 kbps = 9.179 kbps

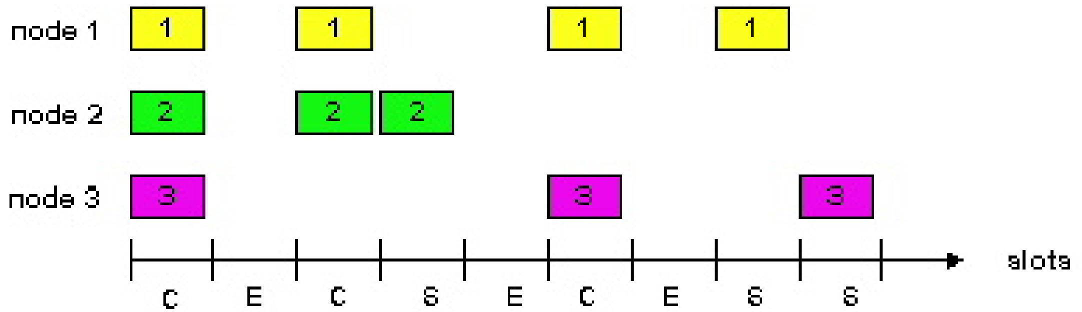
Slotted ALOHA

– "improved ALOHA", with reduced prob. of collision

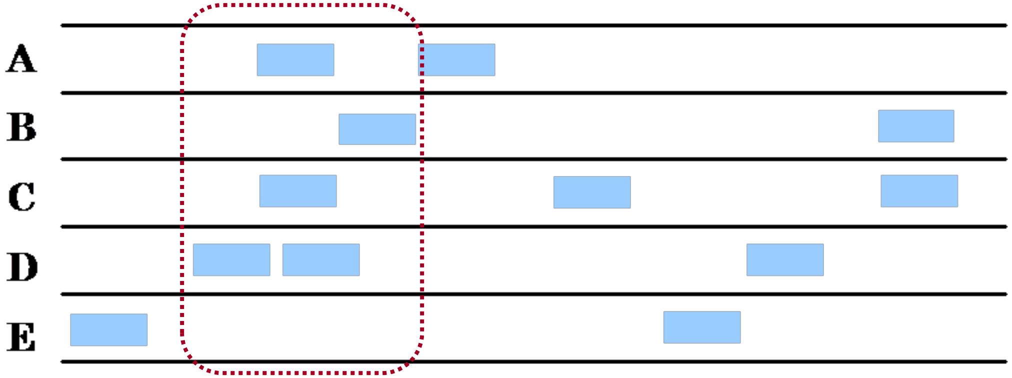
- assumptions:
  - time is divided into slots of size X=L/R (one frame time)
  - nodes start to transmit only at the beginning of a slot
  - nodes are synchronized so that each node knows when the slots begin
- operation:

  1) when node has a fresh frame to send, it waits until next frame slot and transmits

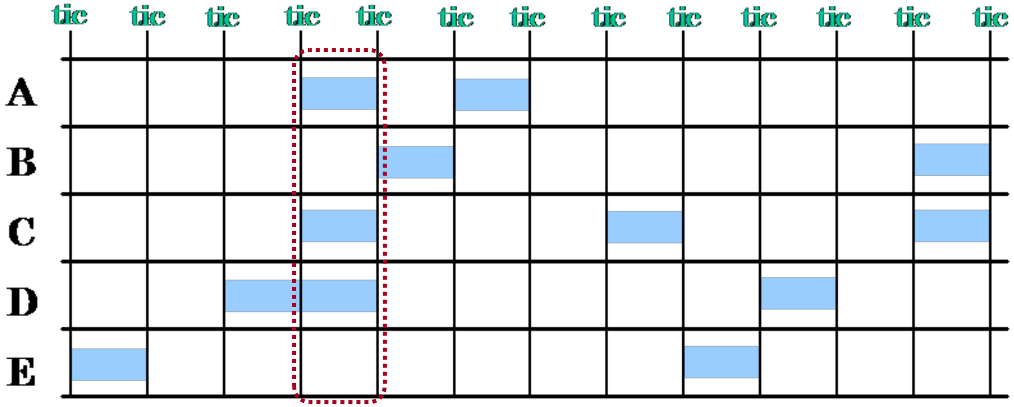
  3) if there is a collision, node retransmits the frame after a backoff-time (backoff-time = multiples of time-frames)



Example **[Aloha vs. Slotted Aloha]**



Pure ALOHA



Slotted ALOHA

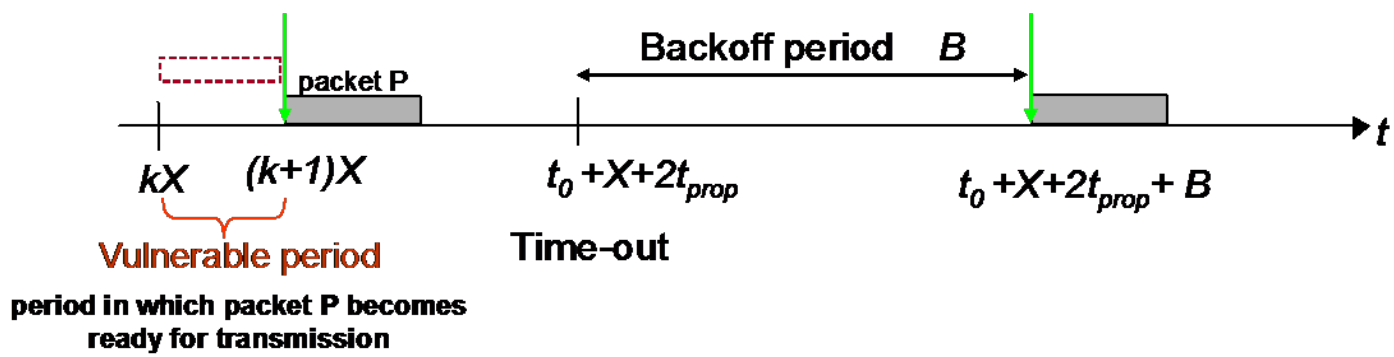
Vulnerable Period of Slotted ALOHA

- consider one arbitrary packet P that becomes ready for transmission at some time t during the time slot [k, k+1]
- packet P will be transmitted successfully if no other packet becomes available for transmission during the same time slot

vulnerable period = [$t_0 - X$, t_0]

$$P_{succ} = P[0 \text{ arrivals in } X \text{ seconds}] = e^{-G}$$

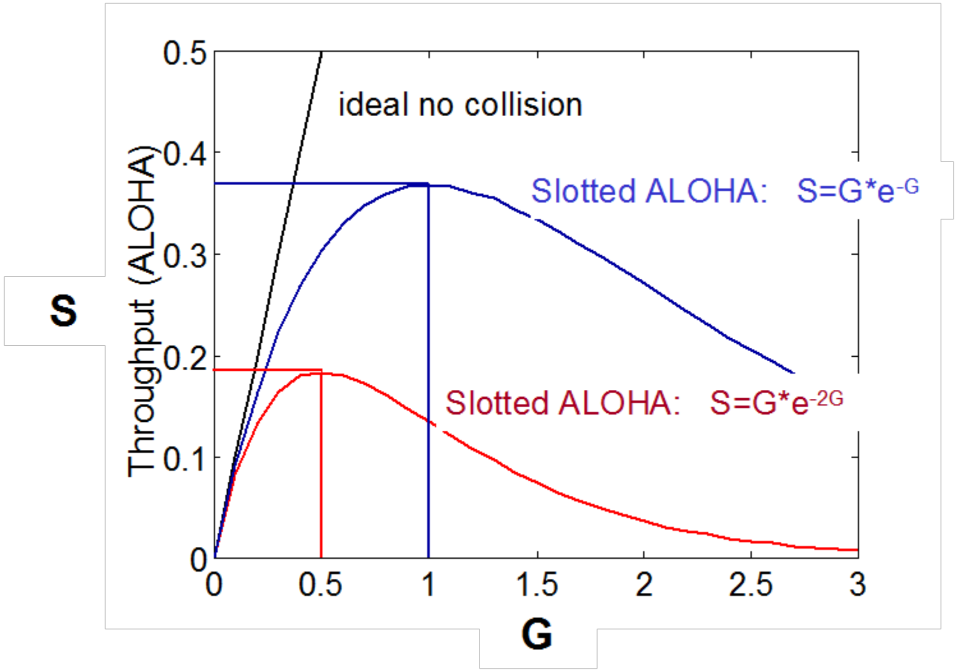
$$S = G \cdot P_{succ} = G \cdot e^{-G}$$



Random Access Techniques: Slotted ALOHA (cont.)

S vs. G in Slotted ALOHA

- max throughput of Slotted ALOHA (S_{max} = 0.36) occurs at G=1, which corresponds to a total arrival rate of 'one frame per vulnerable period'
- S_{max} = 0.36 $\Rightarrow$ max Slotted ALOHA throughput = 36% of actual channel capacity



Slotted ALOHA vs. Pure ALOHA

- slotted ALOHA reduces vulnerability to collision, but also adds a waiting period for transmission
- if contention is low, it will prevent very few collisions, and delay many of the (few) packets that are sent

Random Access Techniques: Slotted ALOHA (cont.)

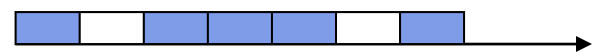
Example [slotted Aloha]

Measurements of slotted ALOHA channel with an infinite number of users show that 10% of the slots are idle.

a) What is the channel load, G?

b) What is the throughput, S?

c) Is the channel underloaded or overloaded?



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a) 10% of slots idle $\Rightarrow$

frame will be successfully transmitted if sent in those 10% of slots $\Rightarrow$

$P_{succ} = 0.1$

According to theory, $P_{succ} = e^{-G}$ $\Rightarrow$ $G = -\ln(P_{succ}) = -\ln(0.1) = 2.3$

b) According to theory, $S = P_{succ} * G = G * e^{-G}$

as $G=2.3$ and $e^{-G}=0.1$ $\Rightarrow$ $S = 0.23$

c) Whenever G>1, the channel is overloaded, so it is overloaded in this case.

Carrier Sensing Multiple Access (CSMA)

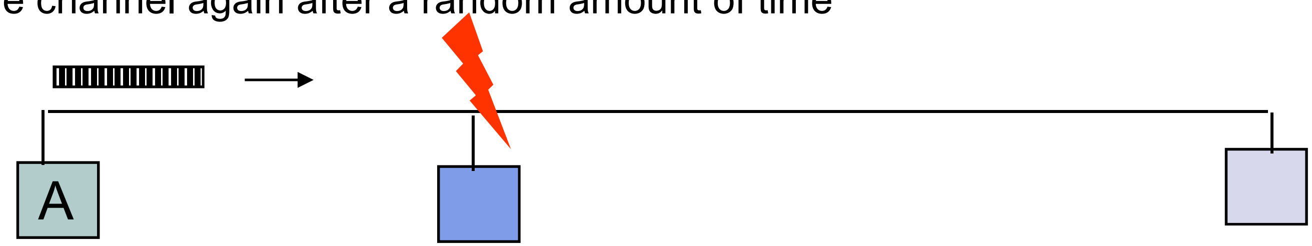
– in ALOHA, node decides to transmit independently of other nodes attached to the broadcast channel

- node does not pay attention whether another node is transmitting (CSMA)
- node does not stop transmitting if another node begins to interfere with its transmission (CSMA/CD)

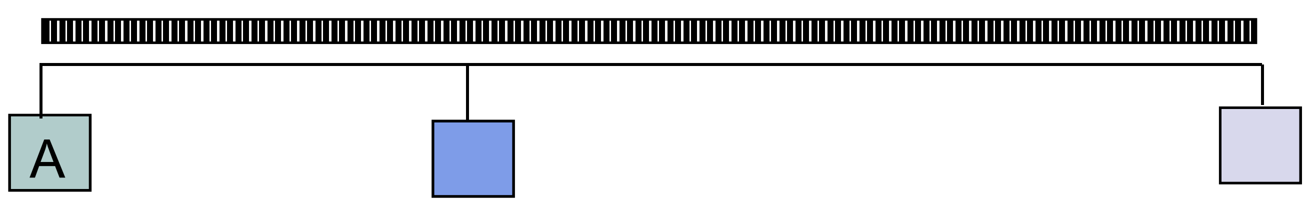
CSMA – 'polite version of ALOHA' – decreases the probability of collision by implementing the following rule:

- carrier sensing – node <u>listens</u> to the channel before transmitting
  - if sensed channel idle $\Rightarrow$ transmit entire frame
  - if sensed channel busy $\Rightarrow$ back-off (defer transmission), and sense the channel again after a random amount of time

Station A begins transmission at $t = 0$



Station A captures channel at $t = t_{prop}$



Carrier Sense Multiple Access (cont.)

Vulnerable Period

– suppose station A begins transmission at one extreme end of a broadcast medium

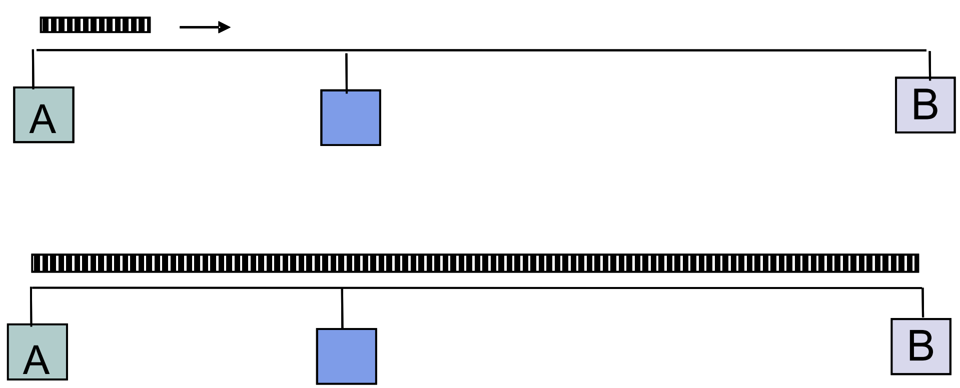
- as signal propagates through the medium, stations become aware of A's transmission
- at time $t=t_{prop}$ A's transmission reaches the other end of medium – if no other station initiates transmission during that period, station A will successfully capture the channel

vulnerable period = t_{prop}

- NOTE: if $t_{prop} > t_{frame}$, CSMA provides no advantage over slotted ALOHA

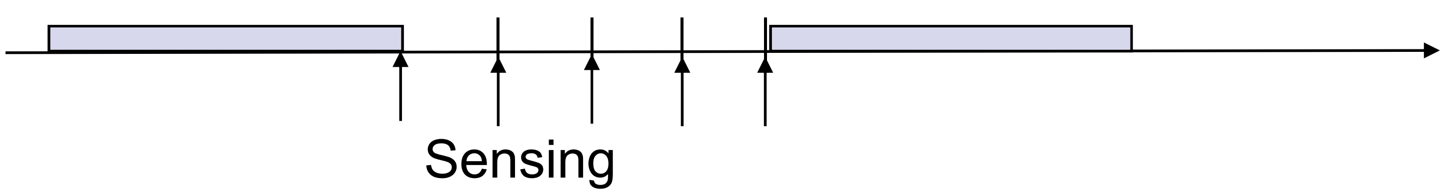
Station A begins transmission at $t = 0$

Station A captures channel at $t = t_{prop}$



CSMA Options

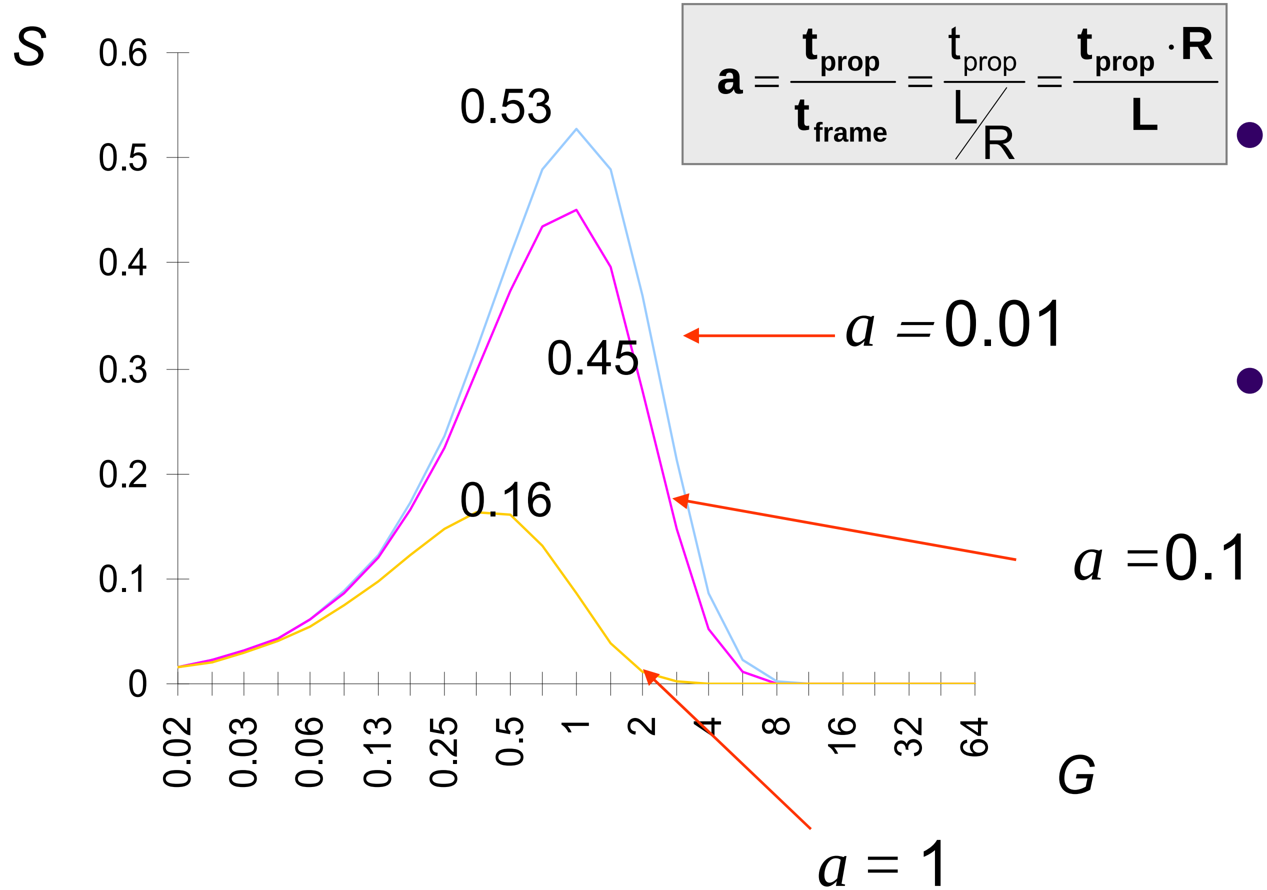
- Transmitter behavior when busy channel is sensed
  - 1-persistent CSMA (most greedy)
    - Start transmission as soon as the channel becomes idle
    - Low delay and low efficiency
  - Non-persistent CSMA (least greedy)
    - Wait a backoff period, then sense carrier again
    - High delay and high efficiency
  - p-persistent CSMA (adjustable greedy)
    - Wait till channel becomes idle, transmit with prob. p; or wait one mini-slot time & re-sense with probability 1-*p*
    - Delay and efficiency can be balanced



1-Persistent CSMA Throughput

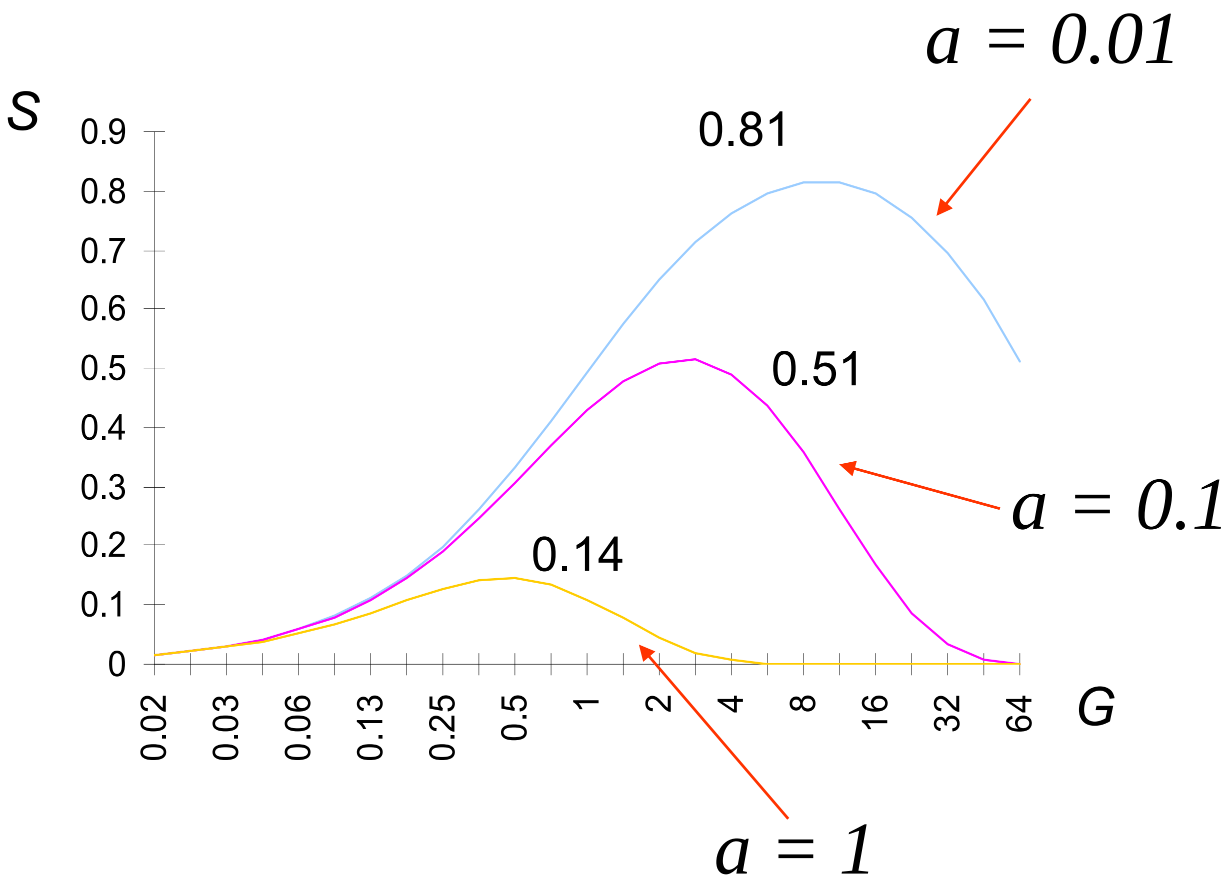
- *a* annotates '*propagation delay normalized to frame transmission time*' or so called '*normalized bandwidth-delay product*'

$$a = \frac{t_{prop}}{t_{frame}} = \frac{t_{prop}}{L/R} = \frac{t_{prop} \cdot R}{L}$$



- Better than Aloha & slotted Aloha for small a
- Worse than Aloha for $a > 1$

Non-Persistent CSMA Throughput



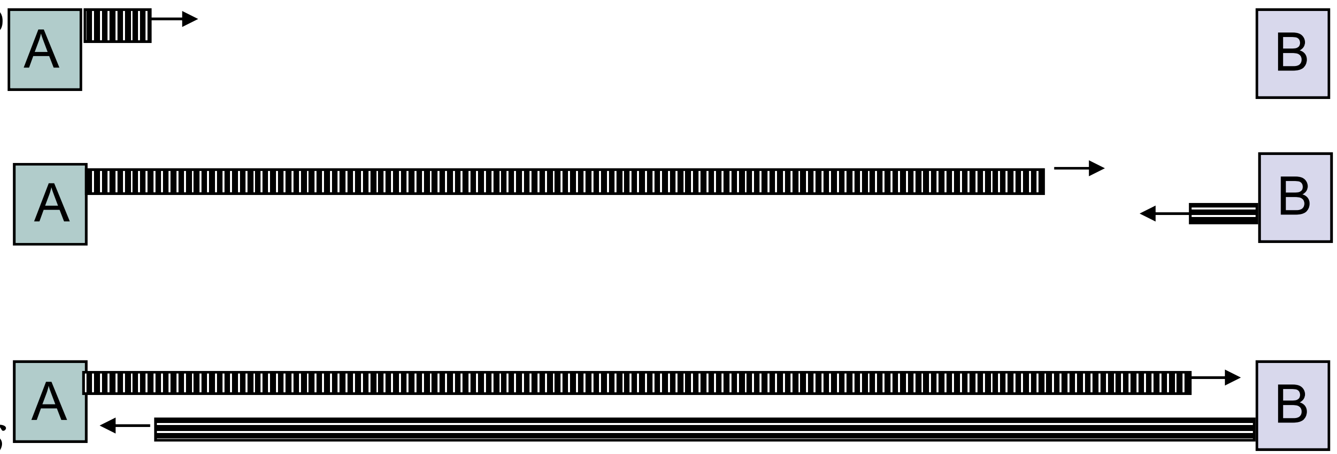
- Higher maximum throughput than 1-persistent for small *a*
- Worse than Aloha for *a* > *1*

CSMA with Collision Detection (CSMA/CD)

- Monitor for collisions & abort transmission
  - Stations with frames to send, first do carrier sensing
  - After beginning transmissions, stations continue listening to the medium to detect collisions
  - If collisions detected, all stations involved stop transmission, reschedule random backoff times, and try again at scheduled times
- In CSMA collisions result in wastage of X seconds spent transmitting an entire frame
- CSMA-CD reduces wastage to time to detect collision and abort transmission

CSMA/CD reaction time

A begins to transmit at $t = 0$



B begins to transmit at $t = t_{prop} - \delta$;

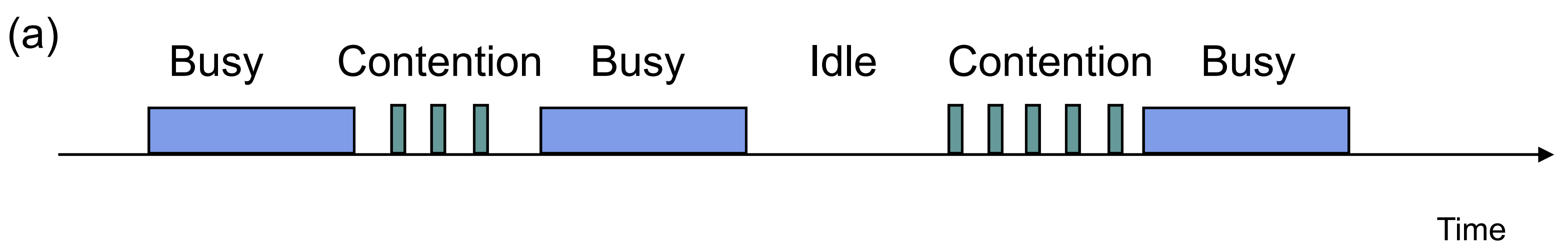
B detects collision at $t = t_{prop}$

A detects collision at $t = 2\ t_{prop} - \delta$

It takes $2\ t_{prop}$ to find out if channel has been captured

CSMA-CD Model

- Assumptions
  - Collisions can be detected and resolved in $2t_{prop}$
  - Time slotted in $2t_{prop}$ slots during contention periods
  - Assume n busy stations, and each may transmit with probability p in each contention time slot
  - Once the contention period is over (a station successfully occupies the channel), it takes X seconds for a frame to be transmitted
  - It takes t_{prop} before the next contention period starts.



Contention Resolution

- How long does it take to resolve contention?
- Contention is resolved ("success') if exactly 1 station transmits in a slot:

$$P_{success} = np(1-p)^{n-1}$$

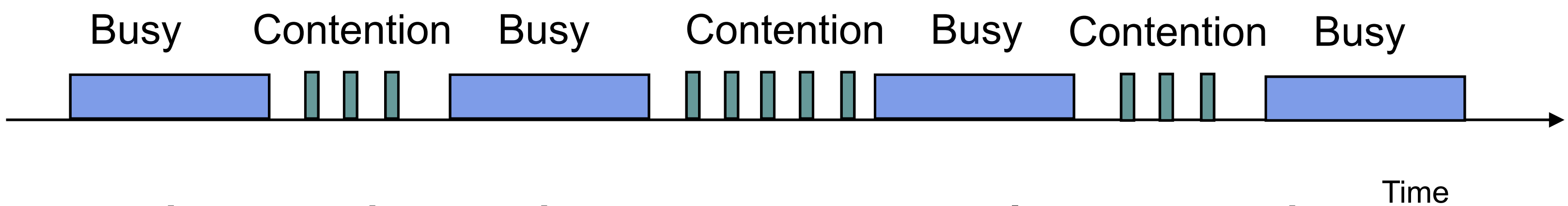
- By taking derivative of $P_{success}$ we find max occurs at p=1/n

$$P_{success}^{\max} = n\frac{1}{n}(1-\frac{1}{n})^{n-1} = (1-\frac{1}{n})^{n-1} \rightarrow \frac{1}{e}$$

- On average, $1/P^{max} = e = 2.718$ time slots to resolve contention

$$\textit{Average Contention Period} = 2t_{prop}e \textit{ seconds}$$

CSMA/CD Throughput



- At maximum throughput, systems alternates between contention periods and frame transmission times

$$\rho_{\max} = \frac{X}{X + t_{prop} + 2et_{prop}} = \frac{1}{1+(2e+1)a} = \frac{1}{1+(2e+1)Rd/\nu L}$$

- where:

  R bits/sec, *L* bits/frame, X=*L/R* seconds/frame

  $a = t_{prop}/X$

  ν meters/sec. speed of light in medium

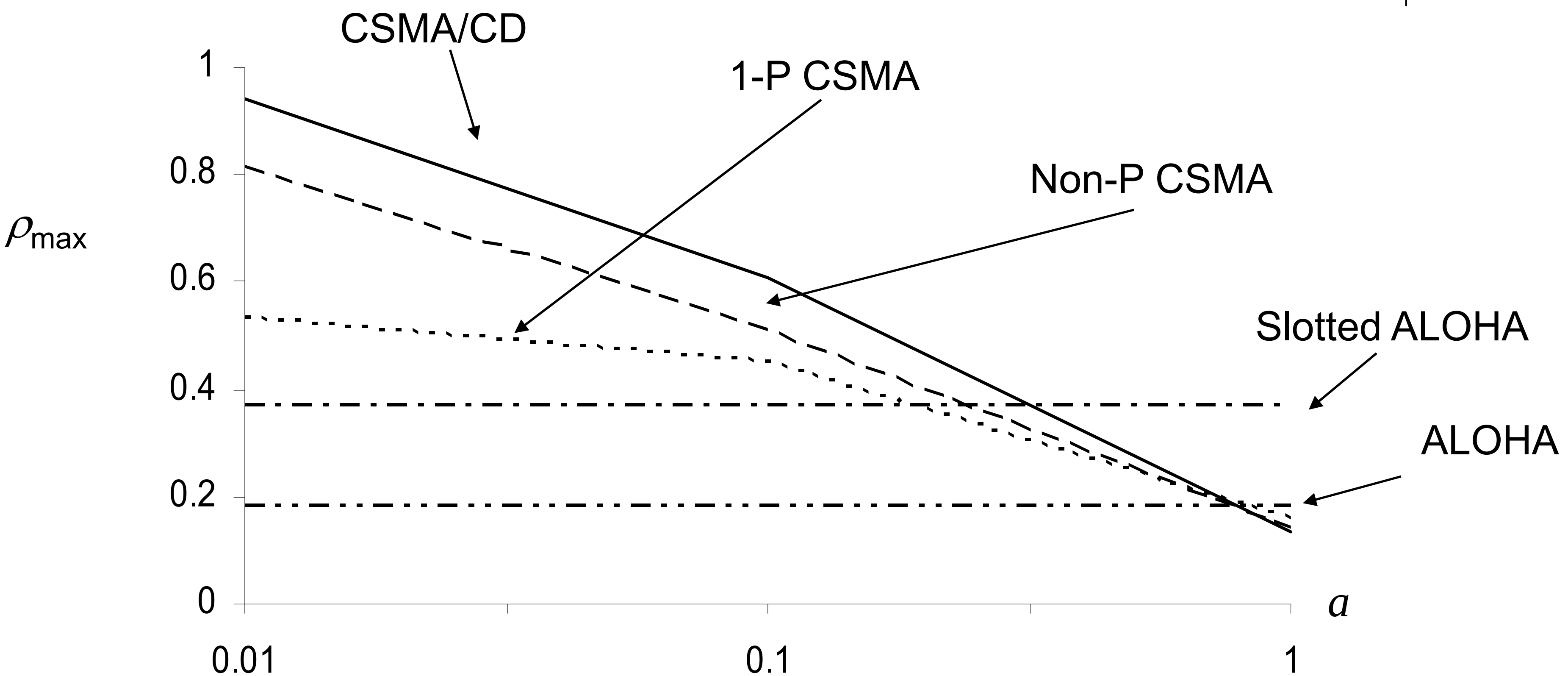
  d meters is diameter of system

  $2e+1 = 6.44$

CSMA-CD Application: Ethernet

- First Ethernet LAN standard used CSMA-CD
  - 1-persistent Carrier Sensing
  - R = 10 Mbps
  - t_{prop} = 51.2 microseconds
    - 512 bits = 64 byte slot
    - accommodates 2.5 km + 4 repeaters
  - Truncated Binary Exponential Backoff
    - After nth collision, select backoff from $\{0, 1,\ldots, 2^k – 1\}$, where k=min(n, 10)

Throughput for Random Access MACs



- For small a: CSMA-CD has best throughput
- For larger a: Aloha & slotted Aloha better throughput