SC/CSE 3213 Winter 2014

L17: Medium Access Control

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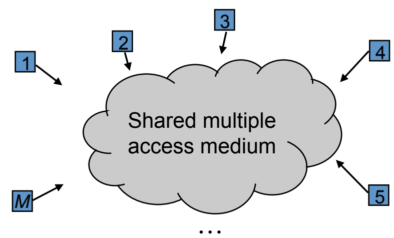
Outline

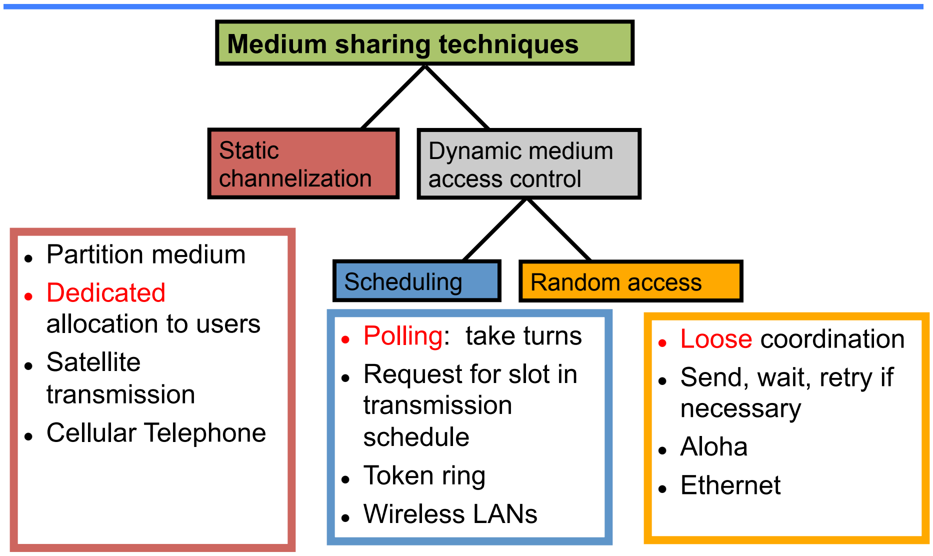
- Multiple access communications
  - Taxonomy
  - Examples
- Simple efficiency calculations
- Random access: ALOHA
- Carrier sensing
- Collision detection

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?*

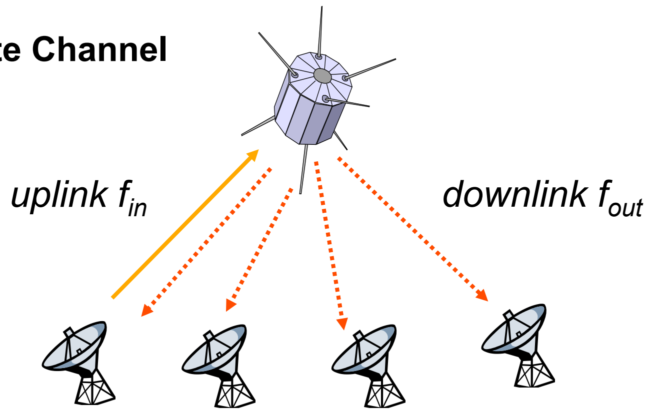


Approaches to Media Sharing



Channelization: Satellite

Satellite Channel

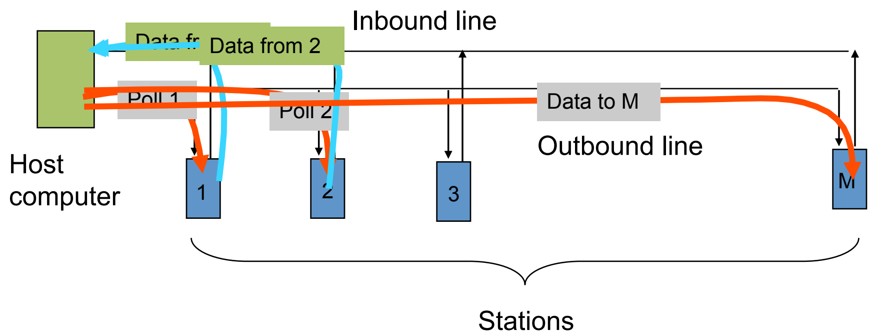


Channelization: Cellular

uplink f_1 ; downlink f_2

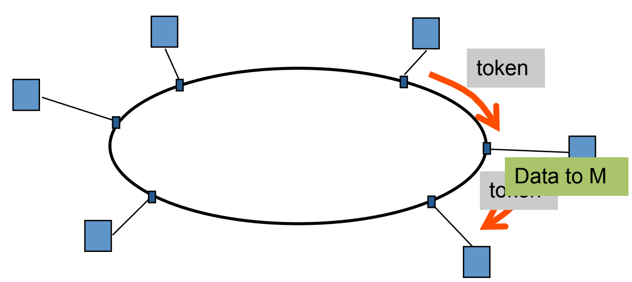
uplink f_3 ; downlink f_4

Scheduling: Polling



Scheduling: Token-Passing

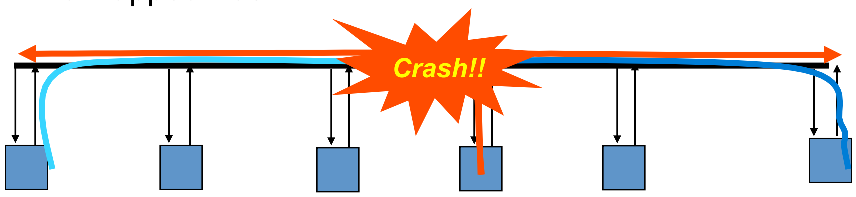
Ring networks



Station that holds token transmits into ring

Random Access

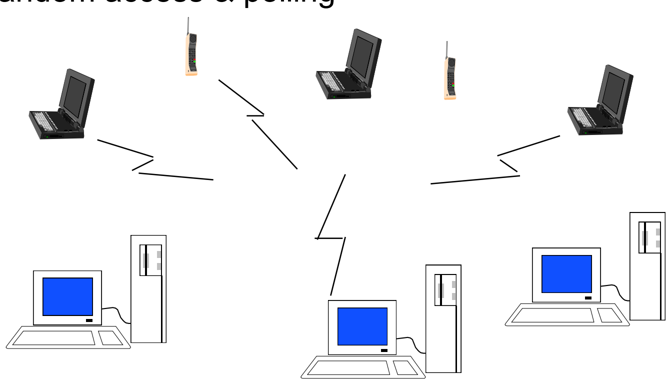
- Multitapped Bus



- Transmit when read
- Transmissions can occur
- Need retransmission strategy

Wireless LAN

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

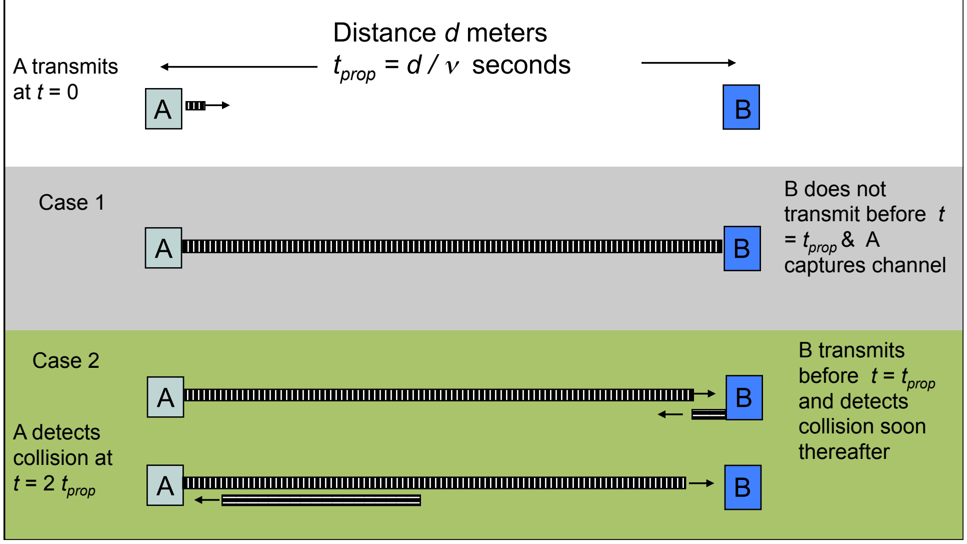


Delay-Bandwidth Product

- *Delay-bandwidth* product key parameter
  - Coordination in sharing medium involves using bandwidth (explicitly or implicitly)
  - Difficulty of coordination commensurate with delay-bandwidth product
- Simple **two-station example**
  - Station with frame to send listens to medium and transmits if medium found idle
  - Station monitors medium to detect collision
  - If collision occurs, station that began transmitting earlier retransmits (propagation time is known)

Two-Station MAC Example

- Two stations are trying to share a common medium



Efficiency of Two-Station Example

- Each frame transmission requires $2t_{prop}$ of quiet time
  - Station B needs to be quiet t_{prop} before *AND* after Station A's transmit
  - R transmission bit rate
  - L bits/frame

$$\textit{Efficiency} = \rho_{\max} = \frac{L}{L + 2t_{prop}R} = \frac{1}{1 + 2t_{prop}R/L} = \frac{1}{1+2a}$$

$$\textit{MaxThroughput} = R_{eff} = \frac{L}{L/R + 2t_{prop}} = \frac{1}{1+2a} R \text{ bits/second}$$

Normalized Delay-Bandwidth Product

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

← Propagation delay (t_{prop})
← Time to transmit a frame (L/R)

Typical MAC Efficiencies

Two-Station Example:

$$\textit{Efficiency} = \frac{1}{1+2a}$$

CSMA-CD (Ethernet) protocol:

$$\textit{Efficiency} = \frac{1}{1+6.44a}$$

Token-ring network:

$$\textit{Efficiency} = \frac{1}{1+a'}$$

a' = latency of the ring (bits)/average frame length

- If $a << 1$, then efficiency close to 100%
- As a approaches 1, the efficiency becomes low

Typical Delay-Bandwidth Products

Distance	10 Mbps	100 Mbps	1 Gbps	Network Type
1 m	3.33 x10^{-6}	3.33 x10^{-5}	3.33 x 10^{-4}	Desk area network
100 m	3.33 x 10^{-4}	3.33 x 10^{-3}	3.33 x 10^{-2}	Local area network
10 km	3.33 x 10^{-2}	3.33 x 10^{-1}	3.33 x 10^{+0}	Metropolitan area network
1,000 km	3.33 x 10^{+1}	3.33 x 10^{+2}	3.33 x 10^{+3}	Wide area network
100,000 km	3.33 x 10^{+3}	3.33 x 10^{+4}	3.33 x 10^{+5}	Global area network

- Max size Ethernet frame: 1,500 bytes = 12,000 bits
- Long and/or fat pipes give large a

MAC Delay Performance

- Frame transfer delay
  - **From**: First bit of frame arrives at source MAC
  - **To**: Last bit of frame delivered at destination MAC
- Throughput
  - Rate at which signals successfully transmitted over medium
  - Measured in frames/sec or bits/sec
- Parameters

  λ throughput (avg. number of successful frames/second)

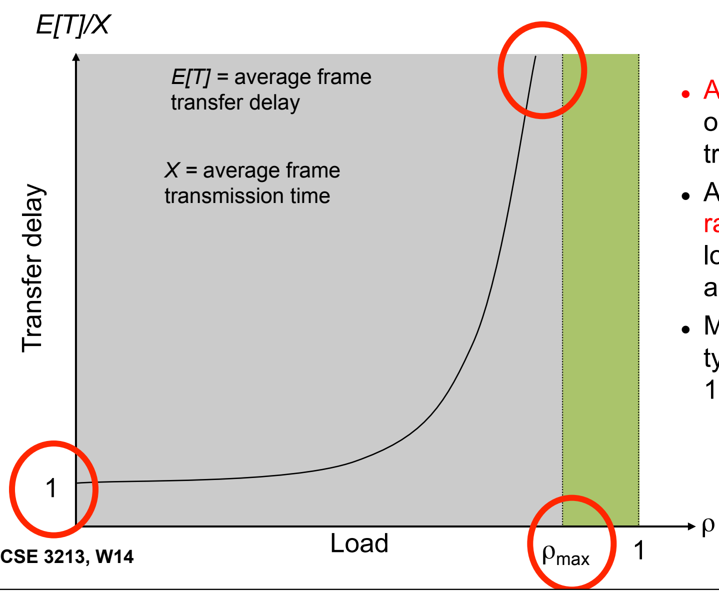
  R bits/sec & L bits/frame

  $X=L/R$ seconds/frame (avg. time span of frame)

  Load: $\rho = \lambda X$, (*normalized throughput*) (can't exceed 1)

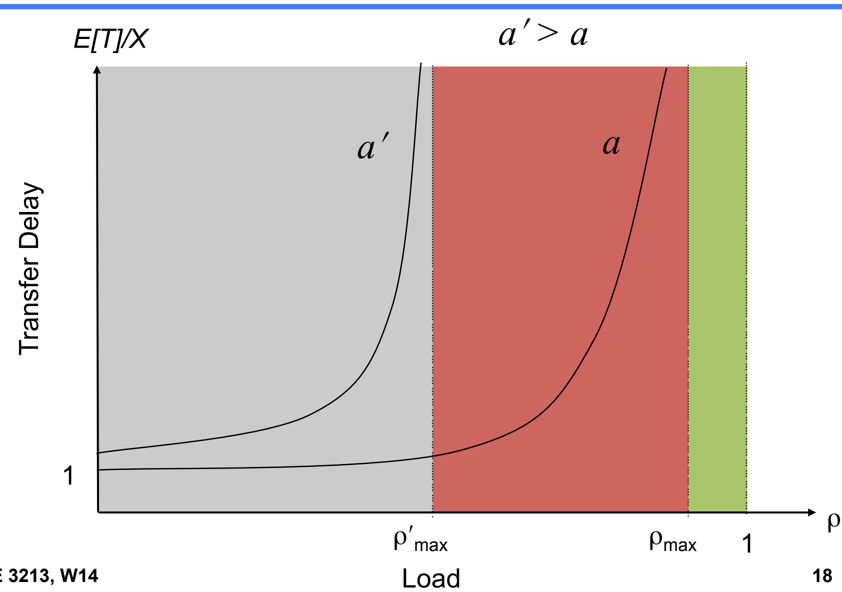
  Maximum throughput (@100% efficiency): R/L fr/sec

Normalized Delay vs Load



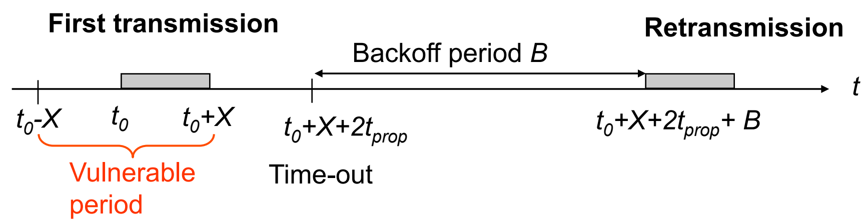
- At low arrival rate, only frame transmission time
- At high arrival rates, increasingly longer waits to access channel
- Max efficiency typically less than 100%

Dependence on $Rt_{prop}/L = a$



ALOHA

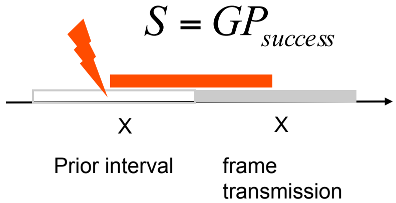
- Wireless link to provide data transfer between main campus & remote campuses of University of Hawaii
- Simplest solution: just do it
  - A station transmits whenever it has data to transmit
  - If more than one frames are transmitted, they interfere with each other (collide) and are lost
  - If ACK not received within timeout, then a station picks random backoff time (to avoid repeated collision)
  - Station retransmits frame after backoff time



ALOHA Model

- Definitions
  - *X*: *avg. frame transmission time* (seconds)
  - *G*: "*total load*" ("offered load"), rate at which NEW & RETRANSMITTED frames pumped into channel (frames/X seconds)
  - *S*: "*throughput*"/"*carried load*", rate at which NEW info get successfully through channel (frames/X seconds)
  - $P_{success}$: probability a frame transmission is successful

$$S = GP_{success}$$



- Transmission successful if:
  - No OTHER transmission occurs during vulnerable period
  - vulnerable period is t_0-*X* TO t_0+*X*

Abramson's Assumption

- <u>*What is probability of no arrivals in vulnerable period?*</u>
- Abramson assumption: Effect of backoff algorithm is that frame arrivals are equally likely to occur at any time interval
- $G = \lambda \bullet X$:avg. # arrivals per X seconds
- Divide X into n intervals of duration $\Delta = X/n$
- p = probability of arrival in Δ interval, then

$G = n \bullet p$ (since there are n intervals in X seconds)

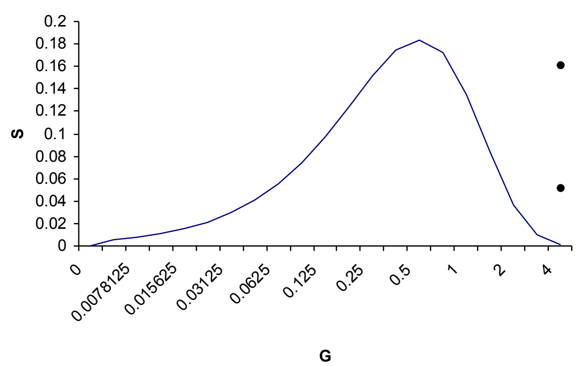
$$P_{success} = P[0 \text{ arrivals in 2X seconds}] =$$

$$= P[0 \text{ arrivals in 2n intervals}]$$

$$= (1-p)^{2n} = (1-\frac{G}{n})^{2n} \rightarrow e^{-2G} \text{ as n} \rightarrow \infty$$

Throughput of ALOHA

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



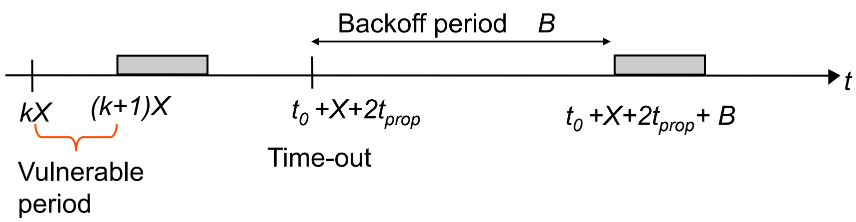
- Max carried load is ρ_{max}= 1/2*e (18.4%)*
  - *18.4% of new frames launched per X get through network*
- Bimodal behaviour

  Small G, S≈G

  Large G, S↓0
- Collisions can snowball and drop throughput to zero

Slotted ALOHA

- Time is slotted in X second slots
- Stations synchronized to frame times
- Stations transmit frames in first slot after frame arrival in data link transmit queue
- Backoff intervals in multiples of slots



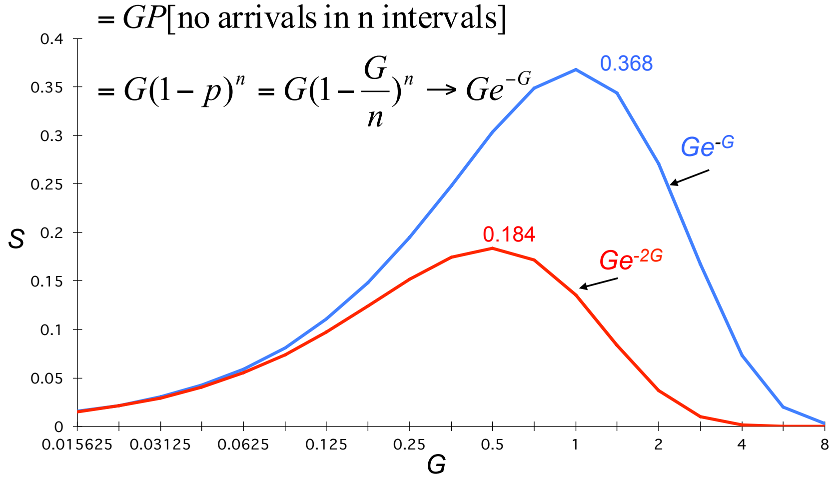
Only frames that arrive during prior X seconds collide

Throughput of Slotted ALOHA

$$S = GP_{success} = GP[\text{no arrivals in X seconds}]$$

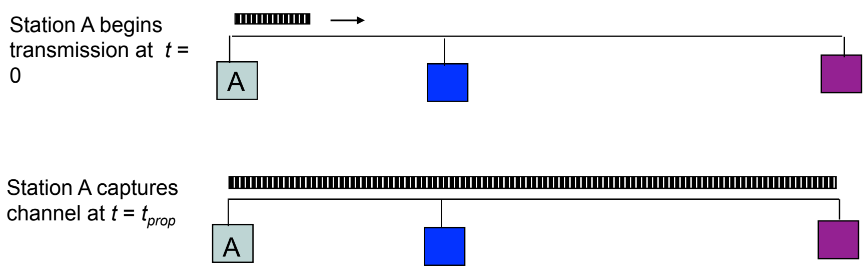
$$= GP[\text{no arrivals in n intervals}]$$

$$= G(1-p)^n = G(1-\frac{G}{n})^n \rightarrow Ge^{-G}$$



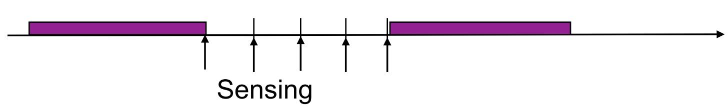
Carrier Sensing Multiple Access (CSMA)

- A station senses the channel before it starts transmission
  - If busy, either wait or schedule backoff (different options)
  - If idle, start transmission
  - Vulnerable period is reduced to t_{prop} (due to *channel capture* effect)
  - If t_{prop} >X, no gain compared to ALOHA or slotted ALOHA

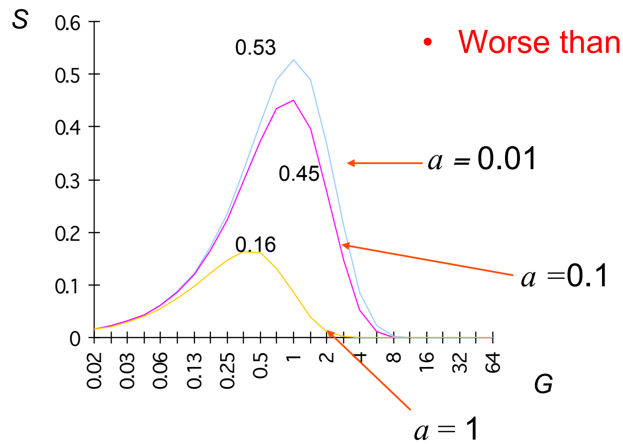


CSMA Options

- 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

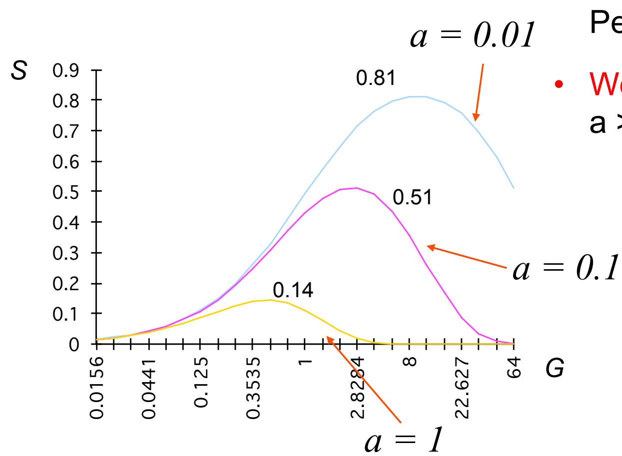


1-Persistent CSMA Throughput



- Better than ALOHA & slotted ALOHA for small a
- Worse than ALOHA for a > 1

Non-Persistent CSMA Throughput

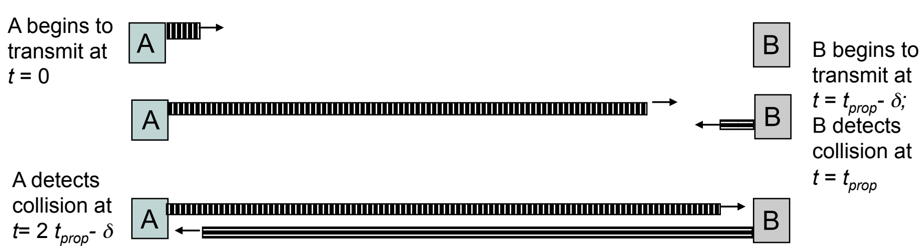


- Higher maximum throughput than 1-Persistent for small a
- Worse than ALOHA for a > 1

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

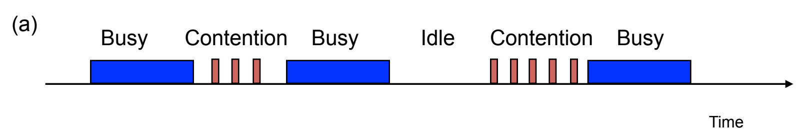
CSMA-CD Reaction Time



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), channel is busy and 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:

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

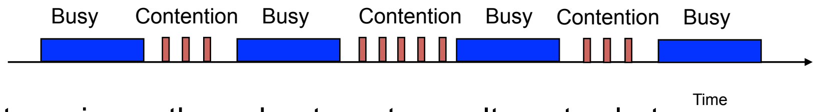
- Taking derivative of $P_{success}$ we find max occurs at p=1/n

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

- 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

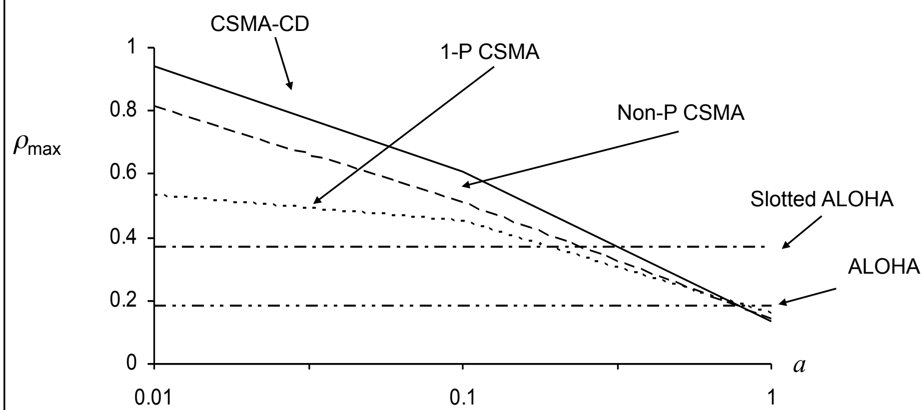
  d meters is diameter of system

  $2e+1 = 6.44$

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,…, 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