Media Access Control

Media Access Control:

Protocols provide:

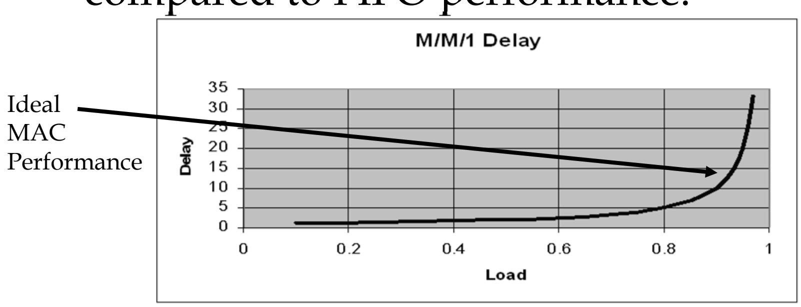
- Direct access to the media
- Distributed control over resource allocation
- Typically broadcast
  (real or virtual)

Media Access Control

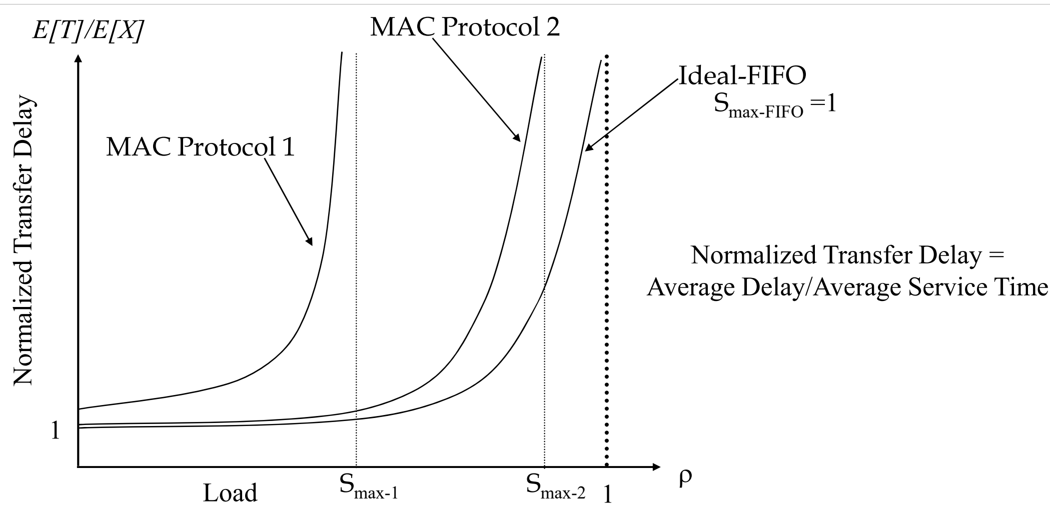
- MAC protocols establish a set of rules that govern who gets to use the shared transmission media.
- Obstacle to perfect channel utilization
  - Finite propagation delay means that each users' **knowledge of the state** of the system is imperfect and thus they can not perfectly schedule transmissions, i.e., some time will be wasted attempting to learn the state of the system and/or learning the fate of transmissions.
  - Lost messages

Media Access Control

- Perfect Knowledge would lead to FIFO performance.
- Performance of MAC protocols will be compared to FIFO performance.



Impact of MAC Overhead



Adapted from: Leon-Garcia & Widjaja: *Communication Networks*

Alternative Media Access Control Strategies

- Static Allocation
  - FDM
  - TDM
- Problems
  - Management; not easy to add users
    - Requires signaling
  - Wasteful in resources for bursty traffic
    (Proved using queueing theory)
- Example
  - A transmission media has a rate of 10 Mb/s and supports 50 users. The system uses static allocation. A user has a 1 Mbyte file to transmit. The file transfer time is:

$$\frac{1x10^{6}\,x8bit}{\frac{10^{7}\,bits/\sec}{50}} = 40\sec$$

Alternative Media Access Control Strategies

- Suppose you *send a message* to all the other 49 users saying, '*I need the whole channel for about 1sec, do not use it, please'*
- As long as the overhead incurred in sending the message is less than 39 sec. the user will get better performance.

Alternative Media Access Control Strategies

- Deterministic
  - Polling
  - Token networks
- Random Access
  - ALOHA
  - Carrier sense multiple access (CSMA)
  - CSMA with collision detection (CSMA/CD)
- Reservation Systems

Alternative Media Access Control Strategies:

Random Access

- Each node sends data with ***limited*** coordination between users:

  No explicit permission to transmit
- Total chaos: Send data as soon as ready
- Limited chaos: Listen before sending data, if the channel is busy do not send.
- Further Limiting chaos: Listen before sending data, continue listening after sending and if collision with another transmission stop sending.

  [Carrier Sense Multiple Access with Collision Detection **CSMA/CD**]

Alternative Media Access Control Strategies:

Random Access

- Advantage: **Simple**
- Disadvantage:
  - No guarantee that you will ever get to send.
  - The MAC protocol technology does not scale

Random Access Protocols:

System Assumptions

- Overlap in time and space of two or more transmissions causes a collision and the destruction of all packets involved.
  [No capture effects]
- One channel
- For analysis no station buffering

Random Access Protocols:

Assumptions

- Time-Alternatives
  - Synchronization between users (Slotted time)
  - No synchronization between users (unslotted time)
- Knowledge of the channel state-Alternatives
  - Carrier sensing (Listen before talk-LBT)
  - Collision detection

Random Access Protocols
Strategies

- ALOHA
  - No coordination between users
  - Send a PDU, start timer, wait for acknowledgment,

    if no acknowledgment (timer fires) then ASSUME collision then **backoff** and try again
- Backoff
  - Select "random" time to attempt another transmission
- Slotted ALOHA
  - Same as ALOHA only time is slotted

Random Access Protocols
Strategies

- *p*-persistent CSMA
  - Listen to channel, on transition from busy to idle transmit with probability *p*
  - After sending the PDU, wait for acknowledgment,

    if no acknowledgment then **backoff** and retransmit
  - Non-persistent, if channel busy then reschedule transmission
  - 1-persistent, Transmit as soon as idle

Random Access Protocols
Strategies

- CSMA/CD
  - 1-persistent but continue to sense the channel, if collision detected then stop transmission.
  - CSMA/CD is used in 10, 100 Mb/s, and 1 Gb/s Ethernet

Limitations on Random Access Protocols

- Distance
  - Time to learn channel state → Propagation time
- Speed
  - Time to learn channel state → Clocking speed

Random Access Protocols
Analysis of ALOHA:

- Goal: Find S_{max}
- Protocol Operation
  - Packet of fixed length L (sec) arrives at station ***i***
    - Station ***i*** transmits immediately
    - Station ***i*** starts an acknowledgment timer
  - If no other station transmits while *i* is transmitting then ***success***
  - Else a collision occurred
  - Station ***i*** learns that a collision occurred if the acknowledgment timer fires before the acknowledgment arrives

Random Access Protocols
Analysis of ALOHA

  - If collision detected then station ***i*** retransmitts at a later time, this time is pseudo-random and is determined by a **backoff** algorithm
- Design Issue:
  - Determine the maximum normalized throughput for an Aloha system

Random Access Protocols
Analysis of ALOHA

Assumptions

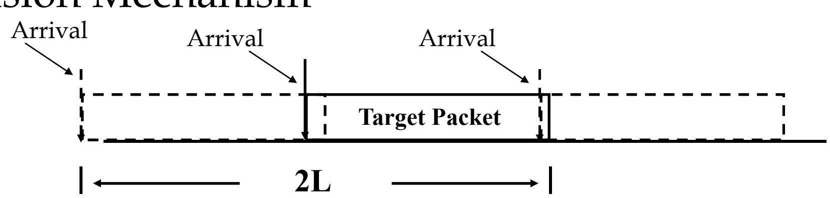
1. λ = Average number of **new** message arrival to the system
2. Λ = Average number arrivals to the system, i.e., new arrivals + retransmissions
3. The total arrival process is Markov, time between arrivals has exponential pdf
4. Fixed Length Packets

$$S = \lambda L \leq 1$$

$$S = \text{throughput}$$

Random Access Protocols
Analysis of ALOHA

Collision Mechanism



Target packet is vulnerable to collision for 2L Sec.

Random Access Protocols:

Analysis of Aloha

Probability of Collision $= 1 - \text{Prob}[\text{no arrivals in 2L sec}]$

$$= 1 - e^{-2L\Lambda}$$

But

$$\overset{\text{New}}{\Lambda = \lambda} + \overset{\text{Retransmitted}}{\Lambda(1 - e^{-2L\Lambda})}$$

Let

$G = \Lambda L =$ Offered load $(S = \lambda L)$

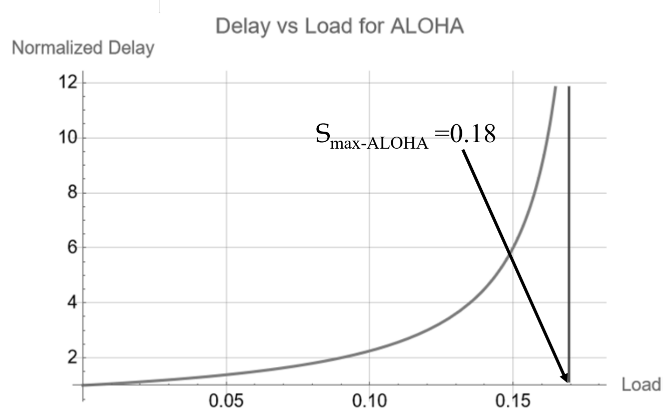
Then

$G = S + G(1 - e^{-2L\Lambda})$ or $S = Ge^{-2L\Lambda}$

Find S_{max}

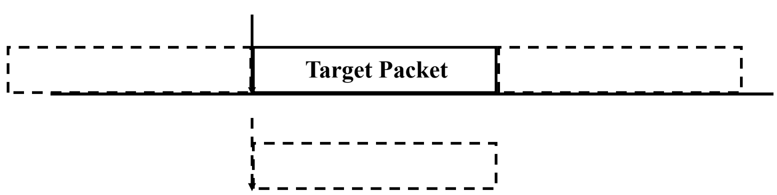
$$\frac{dS}{dG} = 0 \text{ when } G = \frac{1}{2} \text{ or } S_{max} = \frac{1}{2e} = 0.18$$

The Maximum throughpu t for Aloha is 18%



Random Access Protocols

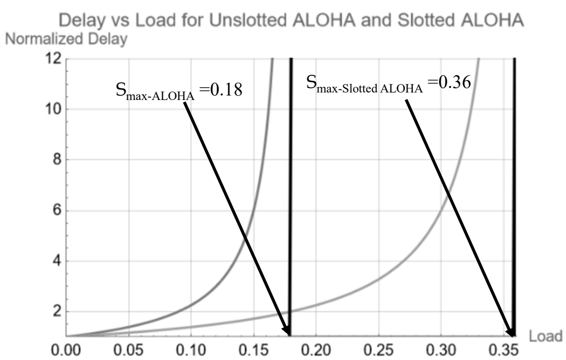
Analysis of Slotted ALOHA



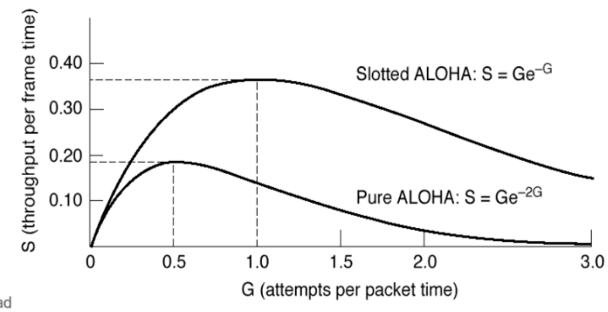
Synchronization reduces the vulnerable period from 2L to L so the maximum throughput is increases to 36%

Random Access Protocols

Performance of Unslotted and Slotted ALOHA



Unslotted ALOHA = Pure ALOHA



From: "Computer Networks, 3rd Edition, A.S. Tanenbaum. Prentice Hall, 1996

Random Access Protocols

CSMA Protocols

- Listen to the channel before transmitting to reduce the vulnerable period
- Let D = maximum distance between nodes (m)
- Let R = the transmission rate (b/s)
- Let c = speed of light = 3×10^8 m/s
- The propagation time = τ (sec) = D/(kc)

  k is a constant for the physical media:

  k = .66 for fiber, k=.88 for coax

  Example: 1 km
  - Free space propagation time = 3.33 us
  - Fiber propagation time = 5.05 us
  - Coax propagation time = 3.79 us

Random Access Protocols
CSMA Protocols

- Assume node A transmits at time t and node B at $t - \varepsilon$,
  where $\varepsilon \rightarrow 0$
  (That is, Node B transmits right before it hears A)
- If after τ=2D/kc sec. no collision occurred, then none will occur and sender will receive ACK
- Define $a = \tau/(L/R)$ = Maximum propagation time/clocking time
  $=(D/kc)/(L/R)$
  $= DR/L(kc)$
- a = **normalized length (size) of the network**
- As a --> 1, CSMA performance approaches ALOHA performance

Random Access Protocols
CSMA Protocols

- Limits on a=*relative size of the network*
  - Want a small to keep vulnerable period short by having:
    - Short bus
    - Lower speeds
    - Long packets

a= DR/L(kc)
where
L= packet length in bits
c= 3×10^8 m/s
k= media prop. constant

Reason for Minimum/Maximum Packet Size in the Internet
- Lower limit (Minimum) packet length to upper bound a
- Maximum packet length to be fair → New Concept

Throughput vs Offered Load

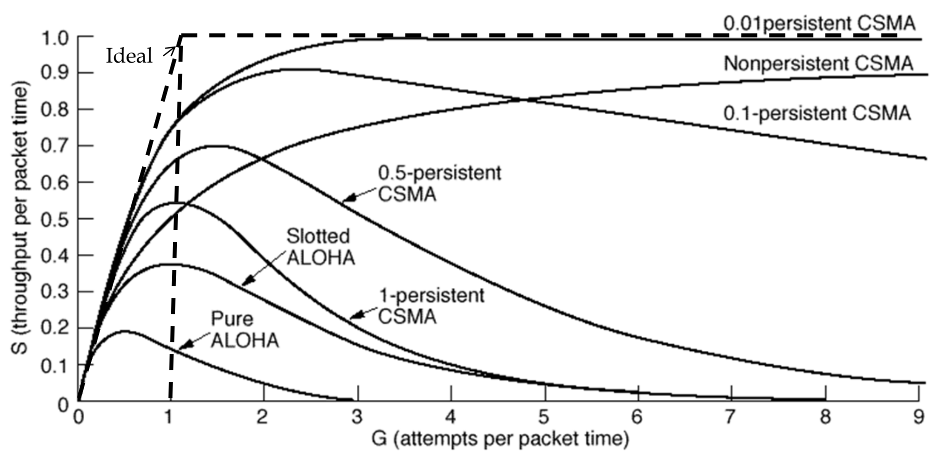
- Aloha $S = Ge^{-2G}$
- Soltted Aloha $S = Ge^{-G}$
- Unslotted Nonpersistent CSMA $S = \frac{Ge^{-aG}}{G(1+2a)+e^{-aG}}$
- Slotted Nonpersistent CSMA

$$S = \frac{aGe^{-aG}}{1-e^{-aG}+a}$$

- For analysis see "Performance Analysis of Local Computer Networks" by Hammond and O'Reilly, 1986

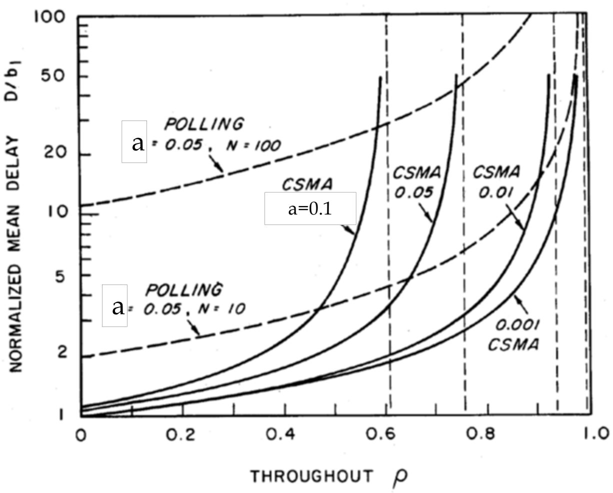
Random Access Protocols

Performance



Modified from: "Computer Networks, 3rd Edition, A.S. Tanenbaum. Prentice Hall, 1996

Polling vs Random Access Performance

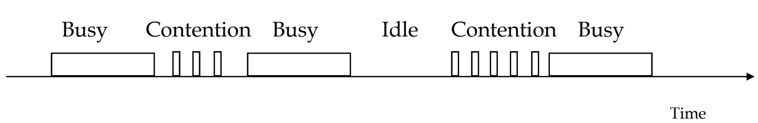


N= # Nodes

From :A Carrier Sense Multiple Access Protocol for Local Networks
Simon S. Lam, Computer Networks 1979

Throughput Analysis for CSMA/CD

- 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

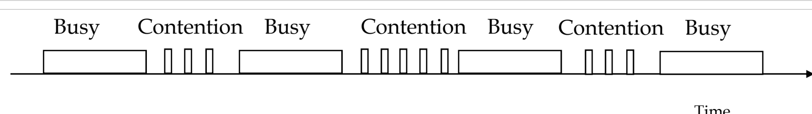
$$P_{success}^{\max} = n\frac{1}{n}(1-\frac{1}{n})^{n-1} = (1-\frac{1}{n})^{n-1} \rightarrow \frac{1}{e}$$

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

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

Note:
2.718 time slots
to resolve contention
applies in other cases

CSMA/CD Throughput



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

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

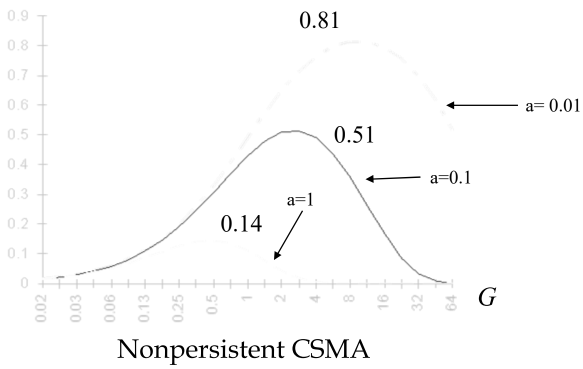
where:

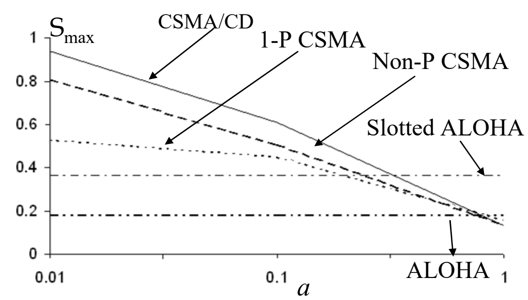
R bits/sec, L bits/frame, X=L/R seconds/frame

a= DR/L(kc) 2e+1 = 6.44

Random Access Protocols

Performance:

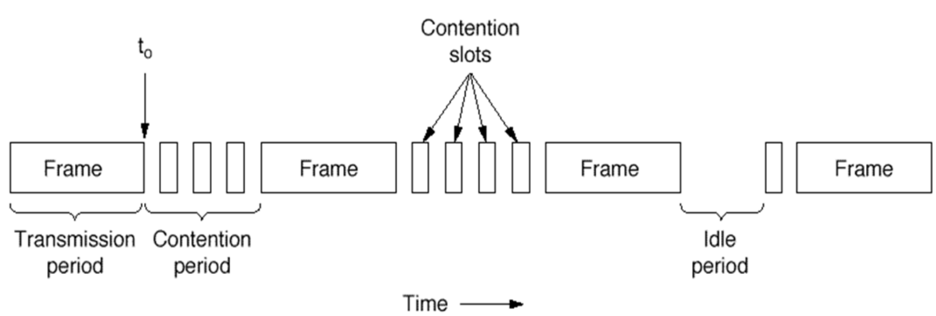




Random Access Protocols

CSMA Protocols: States

- Transmission
- Contention
- Idle

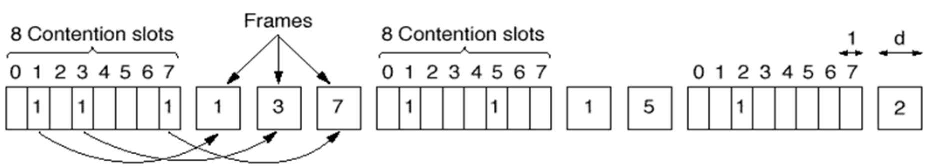


Data Packet Collision Free Protocols Reservations

- Data packet collision free protocols establish rules to determine which stations sends after a successful transmission.
- Assume there are N stations with unique addresses 0 to N-1.
- A contention *interval* is a period after a successful transmission that is divided into N time slots, one for each station.

Data Packet Collision Free Protocols Reservations

- If a station has a PDU to send it sets a bit to 1 in its time slot in the contention interval.
- At the end of the contention interval all nodes know who has data to send and the order in which it will be sent.



From: "Computer Networks, 3rd Edition, A.S. Tanenbaum. Prentice Hall, 1996

Data Packet Collision Free Protocols Reservations

- Problems:
  - Fairness
  - Flexibility
- Many systems use this technique as a basis for their approach to collision free protocols

Random Access and Reservations

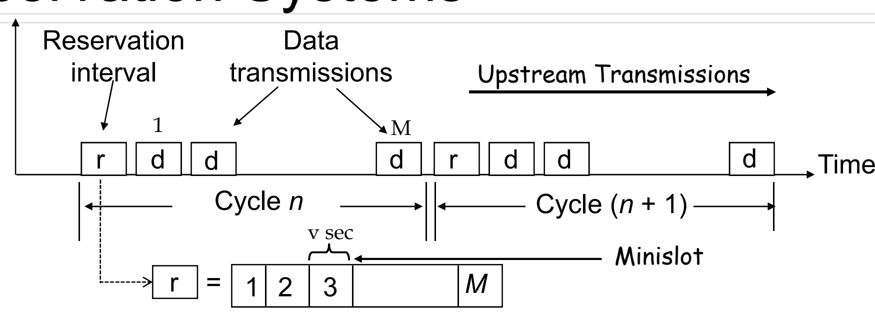
- *Distributed systems*: Stations implement a decentralized algorithm to determine transmission order, e.g., reservation Aloha
- *Centralized systems*: A central controller accepts requests from stations and issues grants to transmit
- The centralized reservation system is used in many access technologies, e.g.,
  - DOCSIS: cable modems
  - Cellular Networks - Long Term Evolution (LTE) & 4G/5G

Adapted from: Leon-Garcia & Widjaja: *Communication Networks*

Reservation System

- System Characteristics
  - Asymmetric
    - Upstream/Uplink
      - Minislots with requests for resources
      - Access Minislots via random access protocol
    - Downstream/Downlink
      - Accepts minislots and includes grants for transmission on the upstream
      - Grants control the flow on the upstream link
      - Order of grants established via a "scheduling" algorithm

Reservation Systems



- Transmissions organized into cycles (or frames, e.g. time/frequency slots, as in OFDMA)
- Cycle: reservation interval + frame transmissions
- Reservation interval has a minislot for ***each*** station to request reservations for frame transmissions; minislot can carry other information, e.g., number of frame to TX, station backlog, channel quality indicator (CQI)

Adapted from: Leon-Garcia & Widjaja: *Communication Networks*

Central controller issues grants to transmit

- Algorithms in the central controller (base station or headend) are used to grant permission to UE to transmit on upstream can be based on:
  - station backlog (queue length),
  - channel quality indicator (CQI)
    - Leads to Opportunistic Scheduling
  - Other…..

Throughput

- Let
  - R = Link rate (b/s)
  - L = packet size (bits) assume fixed length
  - v= minislot size (sec)
  - M = Number of stations
  - X = L/R (sec) = clocking time
- Assume
  - Propagation delay << X=L/R (sec) → Access network
  - Heavy load → stations have packets to send
  - All requests are granted
  - One minislot needed for each packet/station
- Time to transmit M packets = Mv+MX

$$S_{max} = \frac{MX}{M\nu + MX} = \frac{1}{1 + \frac{\nu}{X}}$$

Example:
L=1000 Bytes
R=100Mb/s
v=10us

X= 80us
S_{max} = 87.5%

Adapted from: Leon-Garcia & Widjaja: *Communication Networks*

Throughput

- If *k* frame transmissions can be reserved with ONE reservation message and if there are *M* stations, as many as Mk frames can be transmitted in XM(k+v) seconds

$$S_{\max} = \frac{MkX}{M\text{v} + MkX} = \frac{1}{1 + \frac{\text{v}}{Xk}}$$

Example:
L=1000 Bytes
R=100Mb/s
v=10us
k= 4

X= 80us
S_{max} = ~97%

Throughput: Random access contention for Minislots

- Real systems have too many nodes for each to get a fixed minislot.
- Therefore a random access protocol, typically ALOHA, is used to transmit in a minslot.
  - A station attempts to obtain a grant by transmitting in a minslot in the upstream direction.
  - If successful the station will get the grant on the down stream
  - If unsuccessful, i.e., no grant received, then assume collision, backoff and retry. Here unsuccessful means that the station did not see a grant in corresponding the downstream flow of information.
  - Unsuccessful means collision in the minislot and then backoff and try again

Throughput: Random access contention for Minislots

- Assume slotted Aloha is used for contention for minislots.
- On average, each reservation takes e=2.7 time slots to resolve contention or 2.71 minislot attempts

$$S_{max} = \frac{1}{1 + 2.71v/X}$$

- Effect is just to make the minislots seem longer → reducing S_{max}

Example:
L=1000 Bytes
R=100Mb/s
v=10us

X= 80us
S_{max} = ~75%