Packet Multiple Access II:
Local Area Networks (LANs)

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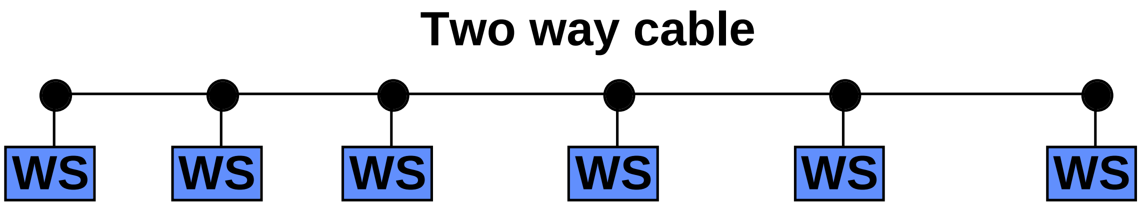
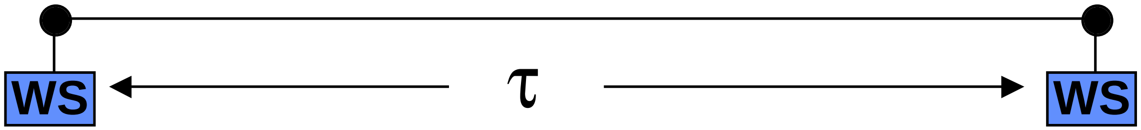
CSMA/CD and Ethernet



- CSMA with Collision Detection (CD) capability
  - Nodes able to detect collisions
  - Upon detection of a collision nodes stop transmission
    - Reduce the amount of time wasted on collisions
- Protocol:
  - All nodes listen to transmissions on the channel
  - When a node has a packet to send:
    - Channel idle => Transmit
    - Channel busy => wait a random delay (binary exponential backoff)
  - If a transmitting node detects a collision it stops transmission
    - Waits a random delay and tries again

Time to detect collisions



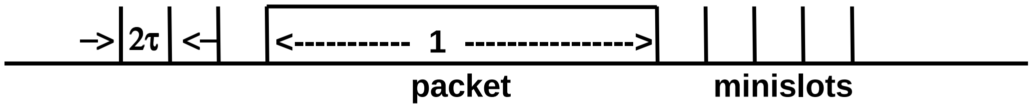
$\tau =$ prop delay

- A collision can occur while the signal propagates between the two nodes
- It would take an additional propagation delay for both users to detect the collision and stop transmitting

- If τ is the maximum propagation delay on the cable then if a collision occurs, it can take up to 2τ seconds for all nodes involved in the collision to detect and stop transmission

Approximate model for CSMA/CD

- Simplified approximation for added insight
- Consider a slotted system with “mini-slots” of duration 2τ



- If a node starts transmission at the beginning of a mini-slot, by the end of the mini-slot either
    - No collision occurred and the rest of the transmission will be uninterrupted
    - A collision occurred, but by the end of the mini-slot the channel would be idle again
- Hence a collision at most affects one mini-slot

Analysis of CSMA/CD

- Assume N users and that each attempts transmission during a free “mini-slot” with probability p
  - P includes new arrivals and retransmissions

$$P(\text{i users attempt}) = \binom{N}{i} P^i (1-P)^{N-i}$$

$$P(\text{exactly 1 attempt}) = P(\text{success}) = NP(1-P)^{N-1}$$

To maximize P(success),

$$\frac{d}{dp}[NP(1-P)^{N-1}] = N(1-P)^{N-1} - N(N-1)P(1-P)^{N-2} = 0$$

$$\Rightarrow P_{opt} = \frac{1}{N}$$

$\Rightarrow$ Average attempt rate of one per slot

$\Rightarrow$ Notice the similarity to slotted Aloha

Analysis of CSMA/CD, continued

$$\text{P(success)} = \text{NP}(1-\text{p})^{\text{N-1}} = (1-\frac{1}{\text{N}})^{\text{N}-1}$$

$$\text{P}_\text{s} = \text{limit } (\text{N} \to \infty) \text{ P(success)} = \frac{1}{\text{e}}$$

Let X = Average number of slots per succesful transmission

$$\text{P}(\text{X} = \text{i}) = (1-\text{P}_\text{s})^{\text{i}-1}\text{P}_\text{s}$$

$$\Rightarrow \text{E[X]} = \frac{1}{\text{P}_\text{s}} = \text{e}$$

- Once a mini-slot has been successfully captured, transmission continues without interruption
- New transmission attempts will begin at the next mini-slot after the end of the current packet transmission

Analysis of CSMA/CD, continued

- **Let S = Average amount of time between successful packet transmissions**

$$S = (e-1)2\tau + D_{Tp} + \tau$$

Ave time until start of next Mini-slot

Idle/collision Mini-slots

Packet transmission time

- **Efficiency = $D_{Tp}/S = D_{Tp} / (D_{Tp} + \tau + 2\tau(e-1))$**

- **Let $\beta = \tau / D_{Tp}$ => Efficiency $\approx 1/(1+4.4\beta) = \lambda < 1/(1+4.4\beta)$**

Notes on CSMA/CD

- Can be viewed as a reservation system where the mini-slots are used for making reservations for data slots

- In this case, Aloha is used for making reservations during the mini-slots

- Once a users captures a mini-slot it continues to transmit without interruptions

- In practice, of course, there are no mini-slots
  - Minimal impact on performance but analysis is more complex

CSMA/CD examples

- Example (Ethernet)
  - Transmission rate = 10 Mbps
  - Packet length = 1000 bits, $D_{Tp} = 10^{-4}$ sec
  - Cable distance = 1 mile, $\tau = 5\times10^{-6}$ sec

  - β = 5x10-2 and E = 80%

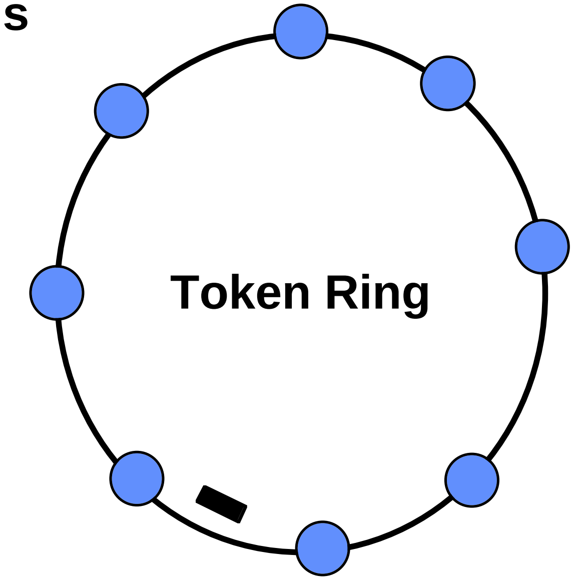
- Example (GEO Satellite) - propagation delay 1/4 second
  - β = 2,500 and E ~ 0%

- CSMA/CD only suitable for short propagation scenarios!

- How is Ethernet extended to 100 Mbps?

- How is Ethernet extended to 1 Gbps?

Token rings



- Token rings were developed by IBM in early 1980's
- Token: a bit sequence
  - Token circulates around the ring
    Busy token: 01111111
    Free token: 01111110
- When a node wants to transmit
  - Wait for free token
  - Remove token from ring (replace with busy token)
  - Transmit message
  - When done transmitting, replace free token on ring

  - Nodes must buffer 1 bit of data so that a free token can be changed to a busy token
- Token ring is basically a polling system
    Token does the polling

Release of token

- Release after transmission
  - Node replaces token on ring as soon as it is done transmitting the packet
  - Next node can use token after short propagation delay

- Release after reception
  - Node releases token only after its own packet has returned to it
    - Serves as a simple acknowledgement mechanism

Throughput analysis (Release after transmission)

- **Suppose each node transmits one packet and then releases the token to the next node**
  - **V_i = propagation and transmission time for token between two nodes (transmission time is usually negligible)**
- **The amount of time to transmit N packets**

$$T_N = N*E[X] + V_1 + V_2 + \ldots + V_N = N*E[X] + N*E[V]$$

$$\lambda < N*E[X]/(N*E[X] + N*E[V]) = 1/(1+E[V]/E[X])$$

- **Compare to CSMA/CD, but notice that V is the delay between two nodes and not the maximum delay on the fiber**

Throughput analysis (release after reception)

- **Nodes release token only after it has returned to it**
- **Again assume each node sends one packet at a time**

- **Total time to send ONE packet**

- $T = E[X] + V_1 + V_2 + \ldots + V_m + V_i$

Time to send token to next node

M nodes on the ring

- $T = E[X] + (m+1)E[V] \Rightarrow$

$$\lambda < E[X]/T = 1/(1+(m+1)E[V]/E[X])$$

Token ring issues

- Fairness: Can a node hold the token for a long time
  - Solution: maximum token hold time

- Token failures: Tokens can be created or destroyed by noise

  - Distributed solution:

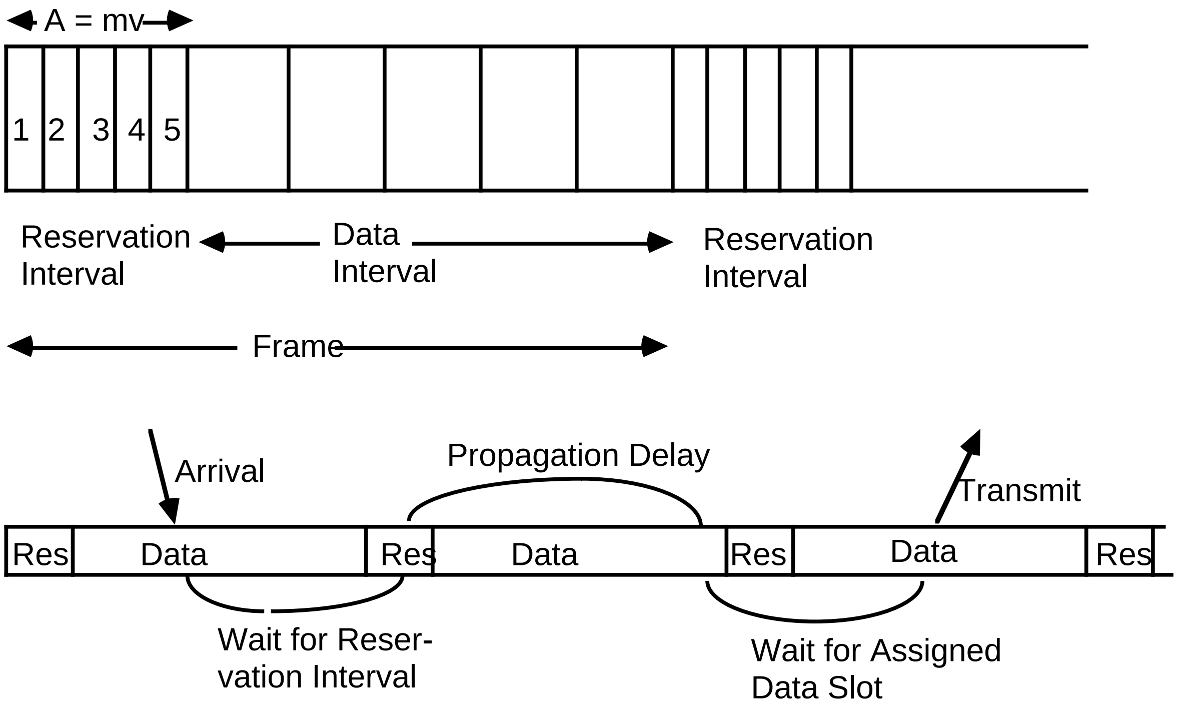
    Nodes are allowed to recognize the loss of a token and create a new token

    Collision occurs when two or more nodes create a new token at the same time => need collision resolution algorithms

- Node failures: Since each node must relay all incoming data, the failure of a single node will disrupt the operation of the ring

- Token ring standard: IEEE 802.5

Large propagation delay (satellite networks)



- **Satellite reservation system**
  - **Use mini-slots to make reservation for longer data slots**
  - **Mini-slot access can be inefficient (Aloha, TDMA, etc.)**
- **To a crude approximation, delay is 3/2 times the propagation delay plus ideal queueing delay.**

Satellite Reservations

- Frame length must exceed round-trip delay
  - Reservation slots during frame j are used to reserve data slots in frame j+1
  - Variable length: serve all requests from frame j in frame j+1
    - Difficult to maintain synchronization
    - Difficult to provide QoS (e.g., support voice traffic)
  - Fixed length: Maintain a virtual queue of requests
- Reservation mechanism
  - Scheduler on board satellite
  - Scheduler on ground
  - Distributed queue algorithm
    - All nodes keep track of reservation requests and use the same algorithm to make reservation
- Control channel access
  - TDMA: Simple but difficult to add more users
  - Aloha: Can support large number of users but collision resolution can be difficult and add enormous delay

Aloha Reservations

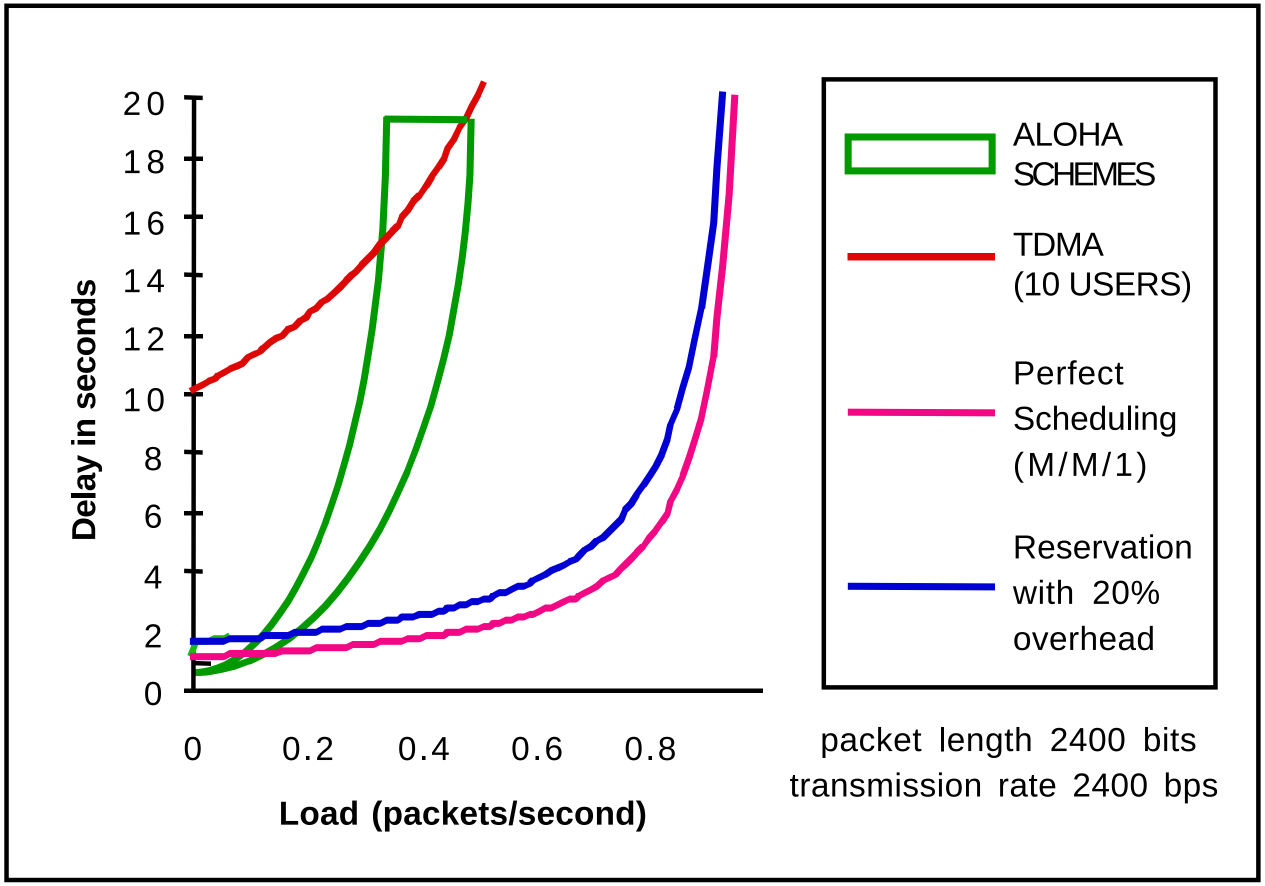
- **Use Aloha to capture a slot**
- **After capturing a slot user keeps the slot until done**
  - **Other users observe the slot busy and don’t attempt**
- **When done other users can go after the slot**
  - **Other users observe the slot idle and attempt using Aloha**
- **Method useful for long data transfers or for mixed voice and data**

Slot	1	2	3	4	5	6	
	15	idle	3	20	■	2	frame 1
	15	7	3	idle	9	2	frame 2
	idle	7	3	■	9	idle	frame 3
	18	7	3	■	9	6	frame 4
	18	7	3	15	9	6	frame 5

Packet multiple access summary

- Latency: Ratio of propagation delay to packet transmission time
  - GEO example: Dp = 0.5 sec, packet length = 1000 bits, R = 1Mbps
    - Latency = 500 => very high
  - LEO example: Dp = 0.1 sec
    - Latency = 100 => still very high
  - Over satellite channels data rate must be very low to be in a low latency environment
- Low latency protocols
  - CSMA/CD, Polling, Token Rings, etc.
  - Throughput ~ $1/(1+a\alpha)$, α = latency, a = constant
- High latency protocols
  - Aloha is insensitive to latency, but generally low throughput
    - Very little delays
  - Reservation system can achieve high throughput
    - Delays for making reservations
  - Protocols can be designed to be a hybrid of Aloha and reservations
    - Aloha at low loads, reservations at high loads

Comparison of MAC protocols



GEO Satellite with 0.5 second round-trip delay