

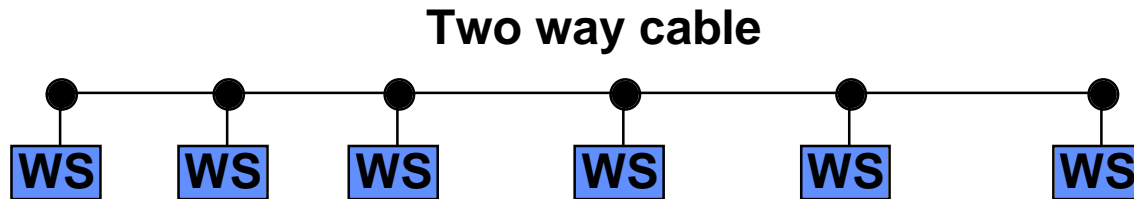


Packet Multiple Access II: Local Area Networks (LANs)

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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

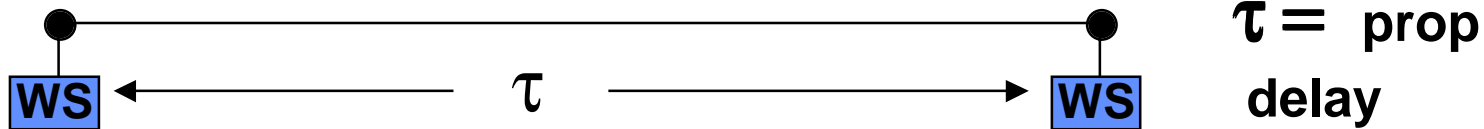
- **Protocol:**
 - All nodes listen to transmissions on the channel

 - 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



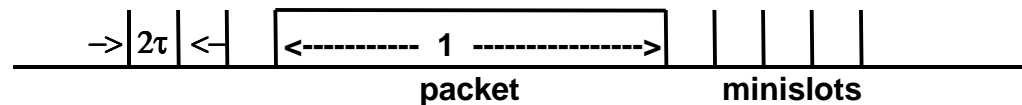
- A collision can occur while the signal propagates between the two nodes
- It would take an additional propagation delay for both users to detect the collision and stop transmitting
- If τ is the maximum propagation delay on the cable then if a collision occurs, it can take up to 2τ seconds for all 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

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

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

To maximize $P(\text{success})$,

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

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

\Rightarrow Average attempt rate of one per slot

\Rightarrow Notice the similarity to slotted Aloha



Analysis of CSMA/CD, continued



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

$$P_s = \lim_{N \rightarrow \infty} P(\text{success}) = \frac{1}{e}$$

Let X = Average number of slots per successful transmission

$$P(X = i) = (1 - P_s)^{i-1} P_s$$

$$\Rightarrow E[X] = \frac{1}{P_s} = e$$

- 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

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

Idle/collision Mini-slots Packet transmission time Ave time until start of next Mini-slot

- Efficiency = $D_{Tp}/S = D_{Tp} / (D_{Tp} + \tau + 2\tau(e-1))$
- Let $\beta = \tau / D_{Tp} \Rightarrow$ 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, $\tau = 5 \times 10^{-6}$ sec
 - $\beta = 5 \times 10^{-2}$ and $E = 80\%$
- **Example (GEO Satellite) - propagation delay 1/4 second**
 - $\beta = 2,500$ and $E \sim 0\%$
- **CSMA/CD only suitable for short propagation scenarios!**
- **How is Ethernet extended to 100 Mbps?**
- **How is Ethernet extended to 1 Gbps?**

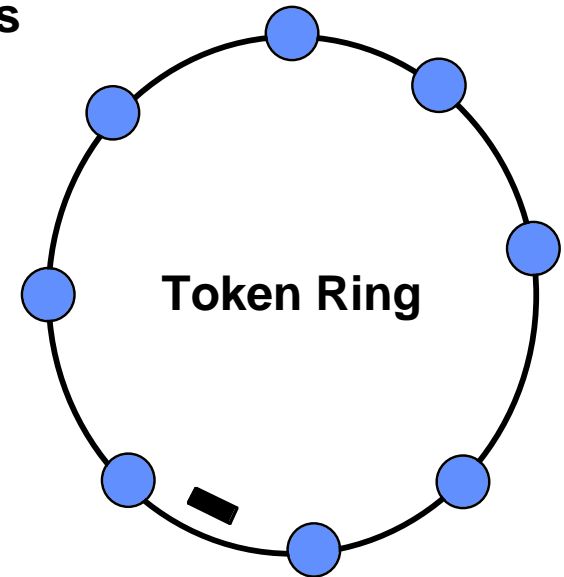


Token rings



- **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

$$T_N = N \cdot E[X] + V_1 + V_2 + \dots + V_N = N \cdot E[X] + N \cdot E[V]$$

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

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

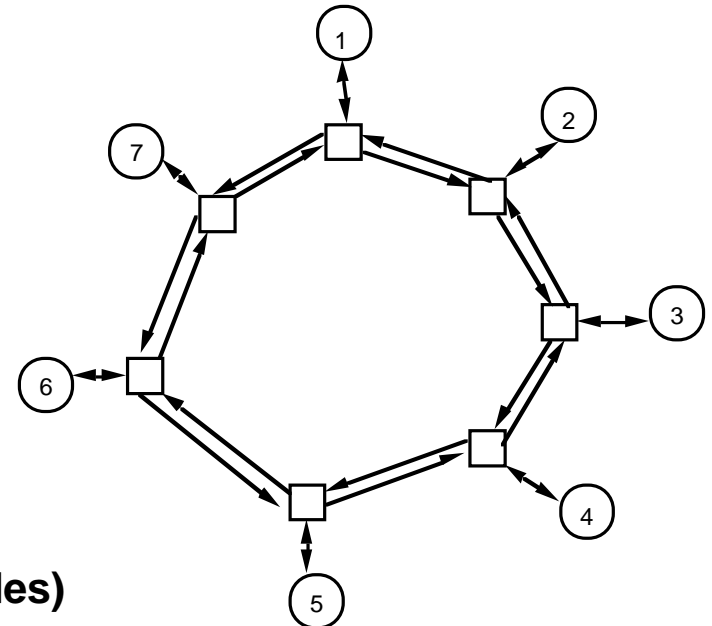
- **Fairness: Can a node hold the token for a long time**
 - **Solution: maximum token hold time**
- **Token failures: Tokens can be created or destroyed by noise**
 - **Distributed solution:**
 - Nodes are allowed to recognize the loss of a token and create a new token**
 - Collision occurs when two 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**



FDDI

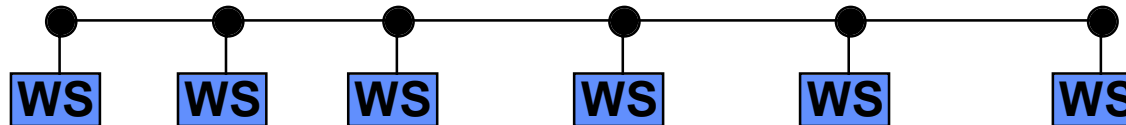


- **Fiber distributed data interface (FDDI) is a 100 Mbps Fiber Optic Token Ring local area network standard**
- **FDDI uses two counter-rotating rings**
 - **Single faults can be isolated by switching from one ring to the other on each side of fault.**
- **Token release after transmission**
- **Limit on token hold time**
- **Upper-bound on time between token visits at a node**
 - **Support for guaranteed delays**
 - **Imposes a limit on the size of a ring (distance between nodes, number of nodes)**
- **FDDI designed to be a metro or campus area network technology**





TOKEN BUSES



- **Special control packet serves as a token**
- **Nodes must have token to transmit**
- **Token is passed from node to node in some order**
 - Conceptually, a token bus is the same as a token ring
 - When one node finishes transmission, it sends an idle token to the next node (by addressing the control packet properly)
 - Similar to a polling system
- **Issues**
 - Efficiency lower than token rings due to longer transmission delay for the packets and longer propagation delays
 - Need protocol for joining and leaving the bus



IMPLICIT TOKENS

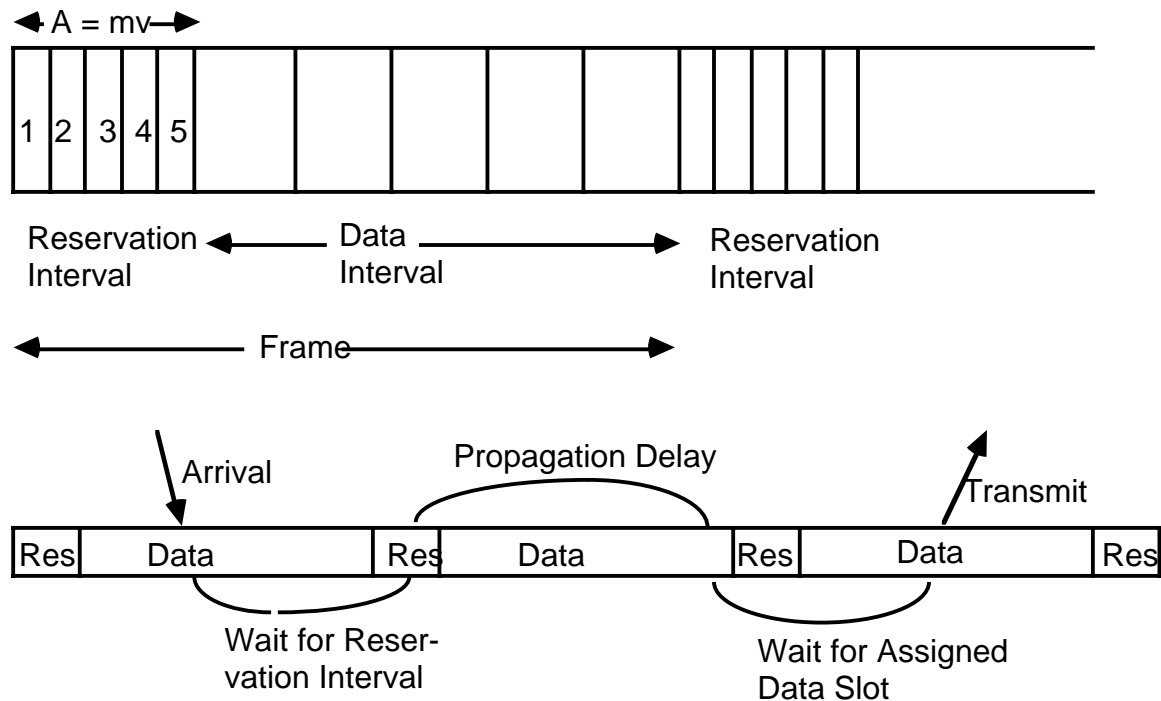


- **The idle tokens on a token bus can be replaced with silence**
- **The next node starts to transmit a packet after hearing the bus become silent**
- **If the next node has no packet, successive nodes start with successively greater delay**
- **If the bus propagation delay is much smaller than the time to transmit a token, this can reduce delay**

- **This scheme is used for wireless LANs (IEEE 802.11) and it goes by the name of CSMA/CA (collision avoidance)**



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



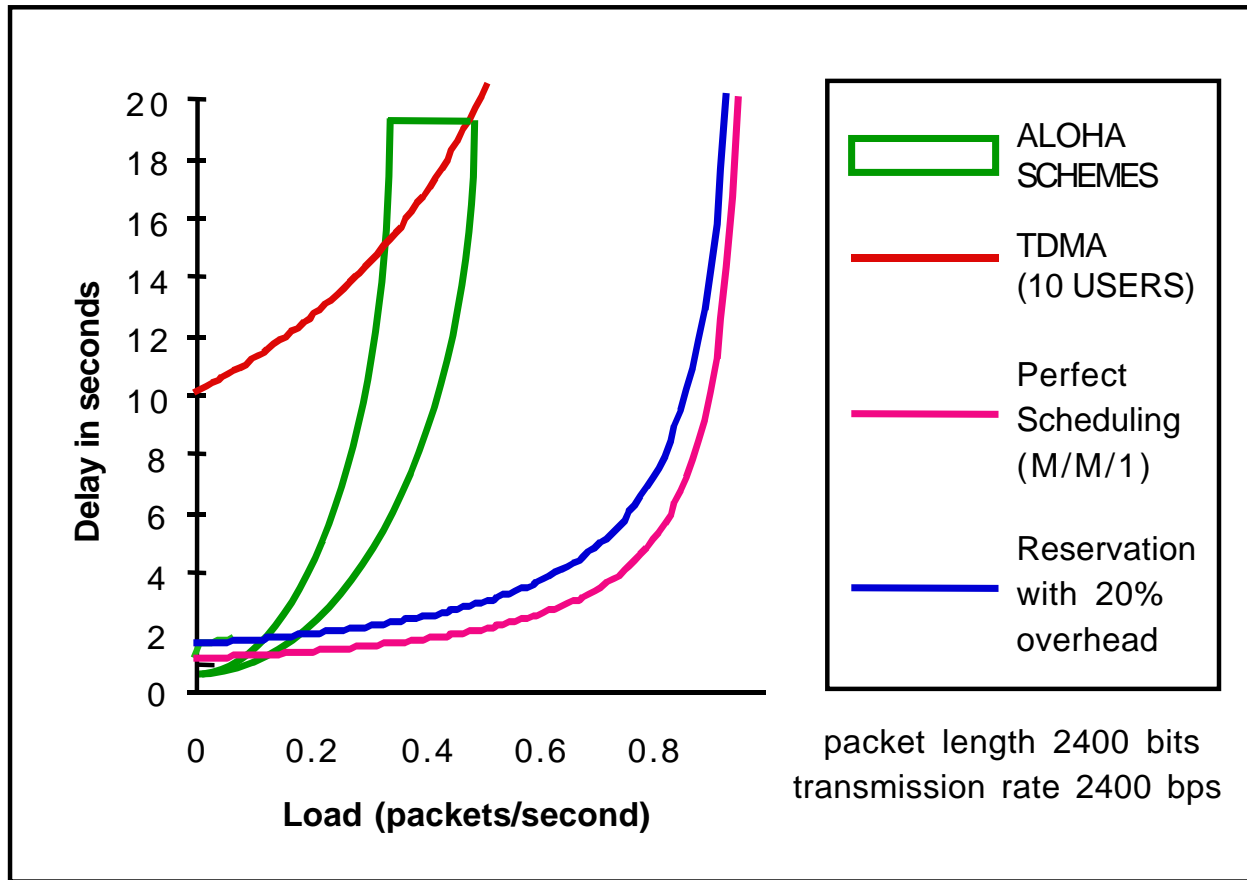
Packet multiple access summary



- **Latency: Ratio of propagation delay to packet transmission time**
 - GEO example: $D_p = 0.5$ sec, packet length = 1000 bits, $R = 1$ Mbps
Latency = 500 \Rightarrow very high
 - LEO example: $D_p = 0.1$ sec
Latency = 100 \Rightarrow 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 $\sim 1/(1+a\alpha)$, 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