Lectures 12: CSMA, CSMA/CD and Ethernet

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Carrier Sense Multiple Access (CSMA)

- **In certain situations nodes can hear each other by listening to the channel - "Carrier Sensing"**
- **CSMA: Polite version of Aloha**
  - **Nodes listen to the channel before they start transmission**

    Channel idle => Transmit

    Channel busy => Wait (join backlog)

  - **When do backlogged nodes transmit?**

    When channel becomes idle backlogged nodes attempt transmission with probability $q_r = 1$

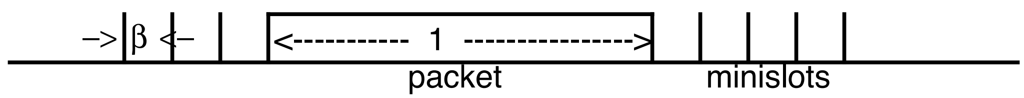
    Persistent protocol, $q_r = 1$

    Non-persistent protocol, $q_r < 1$

CSMA

- Let τ = the maximum propagation delay on the channel
  – When a node starts/stops transmitting, it will take this long for all nodes to detect channel busy/idle

- For initial understanding, view the system as slotted with "mini-slots" of duration equal to the maximum propagation delay
  – Normalize the mini-slot duration to $\beta = \tau/D_{tp}$ and packet duration = 1



- Actual systems are not slotted, but this hypothetical system simplifies the analysis and understanding of CSMA

Rules for slotted CSMA

- When a new packet arrives
  - If current mini-slot is idle, start transmitting in the next mini-slot
  - If current mini-slot is busy, node joins backlog
  - If a collision occurs, nodes involved in collision become backlogged

- Backlogged nodes attempt transmission after an idle mini-slot with probability $q_r < 1$ (non-persistent)
  - Transmission attempts only follow an idle mini-slot
  - Each"busy-period" (success or collision) is followed by an idle slot before a new transmission can begin

- Time can be divided into epochs:
  - A successful packet followed by an idle mini-slot (duration = β+1)
  - A collision followed by an idle mini-slot (duration = β+1)
  - An idle mini-slot (duration = β)

Analysis of CSMA

- **Let the state of the system be the number of backlogged nodes**
- **Let the state transition times be the end of idle slots**
  - **Let T(n) = average amount of time between state transitions when the system is in state n**

$$T(n) = \beta + (1 - e^{-\lambda\beta} (1-q_r)^n)$$

When qr is small $(1-q_r)^n \sim e^{-q_r n} \Rightarrow T(n) = \beta + (1 - e^{-\lambda\beta - nq_r})$

- **At the beginning of each epoch, each backlogged node transmits with probability** q_r
- **New arrivals during the previous idle slot are also transmitted**
- **With backlog n, the number of packets that attempt transmission at the beginning of an epoch is approximately Poisson with rate**

$$g(n) = \lambda\beta + nq_r$$

Analysis of CSMA

- **The probability of success (per epoch) is**

  $$P_s = g(n)\, e^{-g(n)}$$

- **The expected duration of an epoch is approximately**

  $$T(n) \sim \beta + (1 - e^{-g(n)})$$

- **Thus the success rate per unit time is**

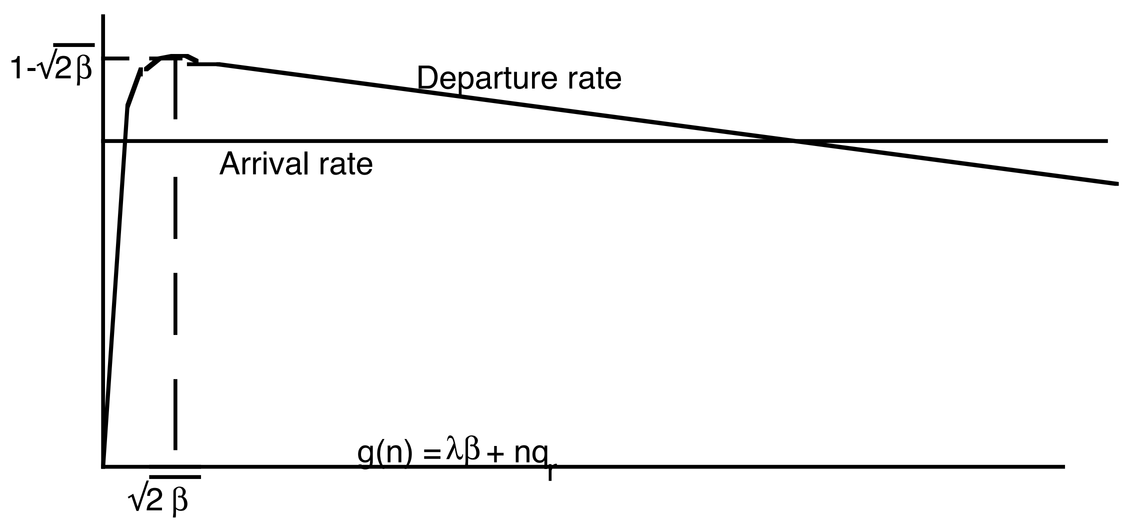
$$\lambda < departure\ rate = \frac{g(n)e^{-g(n)}}{\beta + 1 - e^{-g(n)}}$$

Maximum Throughput for CSMA

- **The optimal value of g(n) can again be obtained:**

$$g(n) \approx \sqrt{2\beta} \qquad \lambda < \frac{1}{1+\sqrt{2\beta}}$$

- **Tradeoff between idle slots and time wasted on collisions**
- **High throughput when β is small**
- **Stability issues similar to Aloha (less critical)**



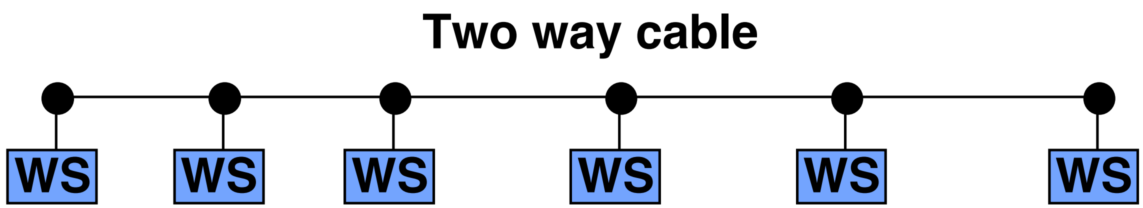
Unslotted CSMA

- **Slotted CSMA is not practical**
  - **Difficult to maintain synchronization**
  - **Mini-slots are useful for understanding but not critical to the performance of CSMA**

- **Unslotted CSMA will have slightly lower throughput due to increased probability of collision**

- **Unslotted CSMA has a smaller effective value of β than slotted CSMA**
  - **Essentially β becomes average instead of maximum propagation delay**

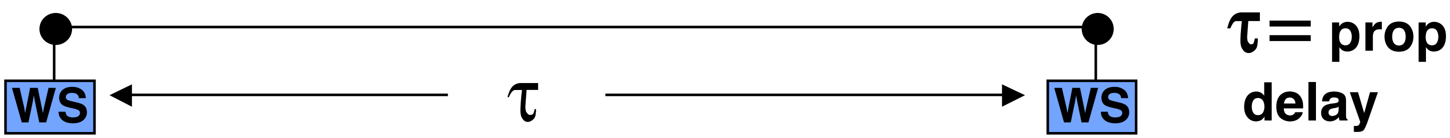
CSMA/CD and Ethernet



- 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 $\Rightarrow$ Transmit
    - Channel busy $\Rightarrow$ wait a random delay (binary exponential back-off)
  - If a transmitting node detects a collision it stops transmission
    - Waits a random delay and tries again

Time to detect collisions



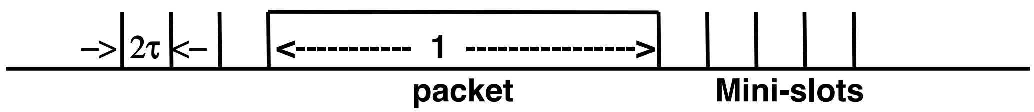
- A collision can occur while the signal propagates between the two nodes

- 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

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

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

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

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

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

Let X = Average number of slots per succesful 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 $\approx 1/(1+4.4\beta) = \lambda < 1/(1+4.4\beta)$**

- **Compare to CSMA without CD where** $\lambda < \dfrac{1}{1+\sqrt{2\beta}}$

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, $\tau = 5x10^{-6}$ sec

  $\Rightarrow \beta$ = 5x10-2 and E = 80%

- **Example (GEO Satellite) - propagation delay 1/4 second**

  $\Rightarrow \beta$ = 2,500 and E ~ 0%

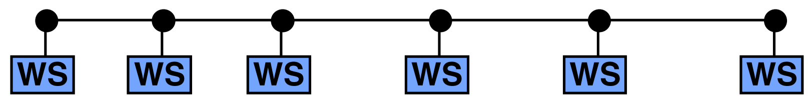
- **CSMA/CD only suitable for short propagation scenarios!**

- **How is Ethernet extended to 100 Mbps?**

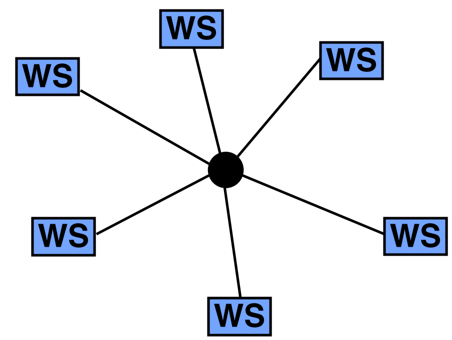
- **How is Ethernet extended to 1 Gbps?**

Migration to switched LANs

- **Traditional Ethernet**
  - Nodes connected with coax
    - Long “runs” of wire everywhere
  - CSMA/CD protocol



- **“Hub” Ethernet**
  - Nodes connected to hub
    - Hub acts as a broadcast repeater
    - Shorted cable “runs”, Useful for 100 Mbps
  - CSMA/CD protocol
  - Easy to add/remove users
  - Easy to localize faults
  - Cheap cabling (twisted pair, 10baseT)



- **Switched Ethernet**
  - No CSMA/CD
    - Easy to increase data rate (e.g., Gbit Ethernet)
  - Nodes transmit when they want
  - Switch queues the packets and transmits to destination
  - Typical switch capacity of 20-40 ports
  - Each node can now transmit at the full rate of 10/100/Gbps
  - Modularity: Switches can be connected to each other using high rate ports