18-345 – Fall 08

Lecture 13

Multiple Access Networks

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Reading: Chapter 6

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Datalink Lectures

- Datalink functions
- Framing
- Datalink architectures
- Switching and packet forwarding
- Flow and error control
- Virtual circuits
- Taking turn protocols
- Contention-based access
- LANs, ethernet, and bridging
- Connectivity to the home
- Wireless

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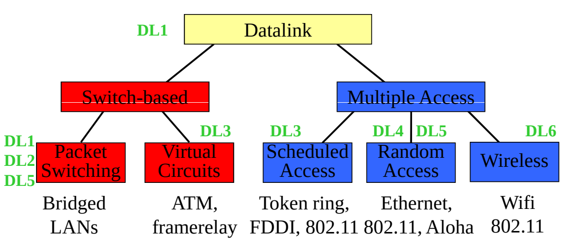
Datalink Classification



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Multiple Access Networks

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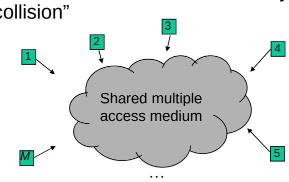
Multiple Access Communications

- Users communicate by broadcasting over a shared communication medium
- Inexpensive: single cable or over the air
- Challenge: How control access to medium?
  - Simultaneous transmissions typically means corrupted packets that cannot be decoded by the receiver – “collision”



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MAC Options

- Static channelization: TDM or FDM
  - E.g. different “up” and “down” frequencies for cellular and satellite
  - Appropriate for constant bit rate channels
- Taking turn protocols: use token or centralized controller to serialize access
  - E.g. token ring, 802.11
- Random access: nodes independently access the medium
  - Need recovery strategy in case of collision

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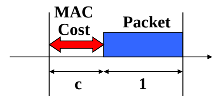
Selecting a MAC Algorithm

- Applications
  - What type of traffic?
  - Voice streams? Steady traffic, low delay/jitter
  - Data? Short messages? Web page downloads?
  - Enterprise or Consumer market? Reliability, cost
- Scale
  - How much traffic can be carried?
  - How many users can be supported?
- Maximum throughput (efficiency)
  - Achievable link utilization for typically traffic loads

Example MAC Efficiencies



$$Efficiency = \frac{1}{1+c}$$

CSMA-CD (Ethernet) protocol:

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

Token-ring network

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

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

MAC Delay Performance

- Frame transfer delay
  - From first bit of frame arrives at source MAC
  - To last bit of frame delivered at destination MAC
- Maximum throughput
  - Actual transfer rate through the shared medium
  - Measured in frames/sec or bits/sec
- Parameters

  R bits/sec & *L* bits/frame

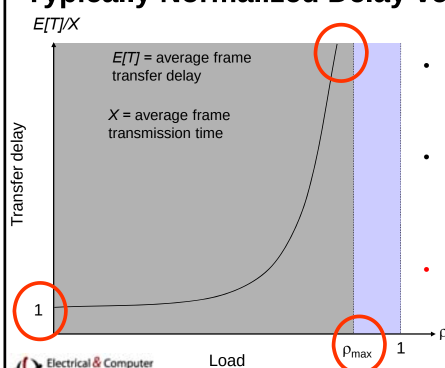
  X=*L*/*R* seconds/frame

  λ frames/second average arrival rate (Poisson)

  Load $\rho = \lambda$ X, rate at which "work" arrives

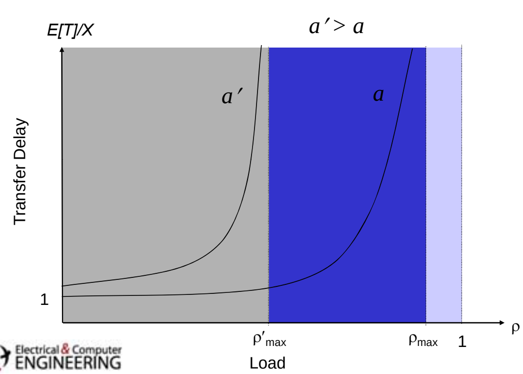
  Maximum throughput (@100% efficiency): *R*/*L* fr/sec

Typically Normalized Delay versus Load



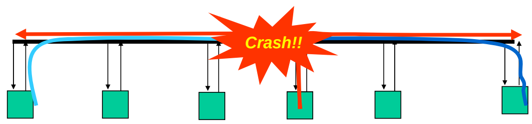
- At low arrival rate, only frame transmission time
- At high arrival rates, increasingly longer waits to access channel
- Max efficiency typically less than 100%

Dependence on "MAC Delay"



Random Access

Random Access: Transmit When Ready



Collisions can occur

Need retransmission strategy to reduce packet error rates

Random Access Techniques

- Completely decentralized
- A user essentially transmits at will, with possibly a few constraints
- Three techniques of interest:
  - Pure ALOHA
  - Slotted ALOHA
  - CSMA/CD (Ethernet)

Poisson Process

- A Poisson process of "rate" $\lambda > 0$ is a counting process a(t) which satisfies the following conditions:
  1. The process has independent increments in disjoint intervals
     - i.e., $a(t_1+\Delta t)-a(t_1)$ is independent of $a(t_2+\delta t)-a(t_2)$ if $[t_1, t_1+\Delta t]$ and $[t_2, t_2+\delta t]$ are disjoint intervals
  2. The increments of the process are stationary.
     - i.e., $a(t_1+\Delta t)-a(t_1)$ does not depend on t_1
  3. The probability of exactly one event occurring in an infinitesimal interval Δt is $P[a(\Delta t)=1] \cong \lambda\Delta t$
  4. The probability that more than one event occurs in any infinitesimal interval Δt is $P[a(\Delta t)>1] \cong 0$
  5. The probability of zero events occurring in Δt is $P[a(\Delta t)=0] \cong 1-\lambda\Delta t$

Informal: memory less

Poisson Distribution

- Above definitions lead to: Probability P(k) that there are exactly k events in interval of length T is then,

$$P(k) = \frac{(\lambda T)^k e^{-\lambda T}}{k!}$$

- We call the above probability the "Poisson distribution"
- Its mean and variance are:

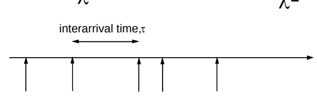
$$E(k) = \lambda T$$
$$\sigma_k^2 = E(k^2) - E^2(k) = \lambda T$$

Inter-arrival Time

- If the arrival process is a Poisson process with rate λ, then the sequence of inter-arrival times are independently and identically distributed **exponential random variables**
  - i.e., with probability density function

$$f_\tau(t) = \lambda e^{-\lambda t} \qquad t \geq 0$$

$$E(\tau) = \int_0^\infty t f_\tau(t)dt = \frac{1}{\lambda} \qquad var(\tau) = \sigma_\tau^2 = \frac{1}{\lambda^2}$$



Exponential Distribution

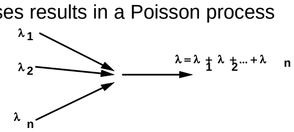
- The exponential random variable satisfies the "memoryless" property:

$$P(\tau > t+h \mid \tau > t) = \frac{P(\tau > t+h, \tau > t)}{P(\tau > t)} = \frac{P(\tau > t+h)}{P(\tau > t)}$$
$$= \frac{e^{-\lambda(t+h)}}{e^{-\lambda t}} = e^{-\lambda h} = P(\tau > h)$$

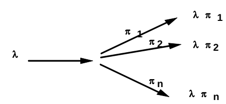
- Knowing how long it has been since the last event (i.e., know *t*) does not give any information about when the next event will occur (i.e., *h*)

Merging and Splitting a Poisson Process

- The merging of several independent Poisson processes results in a Poisson process



- The decomposition of a Poisson stream by random splitting yields independent Poisson streams

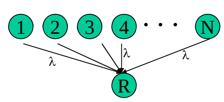


Pure ALOHA

- Developed in University of Hawaii in early 1970's.
- It does not get much simpler:
  1. A user transmits at will
  2. If two or more messages overlap in time, then there is a collision
  3. When a collision occurs, senders are notified
  4. On detecting a collision, colliding stations attempt to retransmit the message in question, but they must stagger their attempts randomly using some "backoff algorithm", to avoid colliding again.
- Although very simple, it is quite wasteful of bandwidth, attaining efficiency of at most 1/(2e) = 0.18

Pure ALOHA: Model

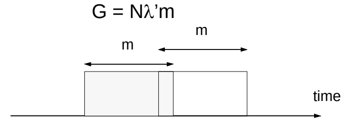
- Let there be N stations contending for use of the channel.
- Each station transmits λ packets/sec on average based on a Poisson arrival process
- All messages transmitted are of the same fixed length, m, in units of time
- Let new traffic intensity be S ≡ Nλm
- Since all new packets eventually get through, 'S' is also the network throughput



Pure Aloha: Vulnerability

- Simplification: assume the retransmitted messages are independent Poisson process as well
- The total rate of packets attempting transmission = newly generated packets + retransmitted ones = λ' > λ
- The total traffic intensity (including retransmissions) is ,

  G = Nλ'm



Collision between two messages

- The "vulnerable period" in which a collision can occur for a given packet is 2 x m sec

Pure Aloha: Analysis

- Calculate "Probability of no collision" two ways:

1. Probability that there is no arrival in interval 2 x m:

   P(no arrival in 2 x m sec) = $e^{-2N\lambda' m} = e^{-2G}$

2. Since all new arrivals eventually get through, we have

   λ/λ' = S/G = Fraction of transmissions that are successful

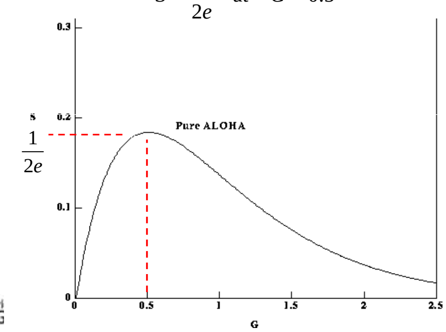
- So, S/G = Probability of no collision = P(no arrival in 2m sec)
- Thus,

  $S/G = e^{-2G}$

  $S = Ge^{-2G}$ → Maximum Throughput of Pure Aloha

Analysis Conclusion

- S is maximum at $S = \frac{1}{2e}$ at $G = 0.5$



Application of Pure ALOHA

- Maximum throughput of ALOHA is only 1/(2e) = 18%
- Maybe be sufficient for some applications, e.g.:
  - Network with line capacity 4800 bps
  - User at a terminal inputs a 60-character message and receives 400-character message in reply (separate return channel)
  - User inputs one message every 2 minutes
  - then, average input rate = 1 character/ 2 seconds
  - or 5 bits/sec if a character is 10 bits long.
  - Thus, 96 interactive users can be accommodated on this channel if only 10% of the line capacity is to be used.
- Pure ALOHA adequate for some lightly loaded channels, e.g. highly bursty interactive traffic

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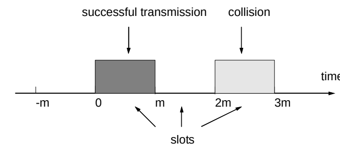
Slotted ALOHA

- Slot the time scale into units of time *m* (equal to message length)
- Modify Aloha by allowing users to attempt transmission at the beginning of each time slot only.
- All users need to be synchronized in time.



Transmission in slotted ALOHA

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Slotted ALOHA Analysis

- Collisions occur if two or more users attempt transmission in the same slot.
- Key point: The "vulnerable period" of the packet of size *m* has been reduced from 2*m* to only *m* !
- Since Poisson arrivals,
  P(successful transmission) = e^{-G} ← Note: Not 2G
- The throughput is then,
  $S = Ge^{-G}$
- The throughput S has maximum value of 1/e = 0.368 at G = 1.

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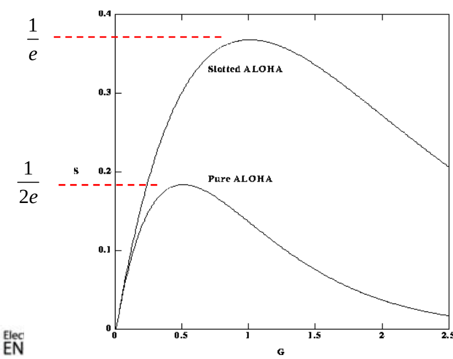
Analysis Results Slotted ALOHA



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CSMA/CD

- CSMA/CD (Carrier Sense Multiple Access Collision Detection)'s basic concepts:
  - All stations listen for transmissions on the line (carrier sensing)
  - Transmit immediately if line is clear
  - Collisions may occur due to the propagation delay between physically-separate stations: stations may simultaneously sense that the channel is idle and start transmitting
  - Once a collision is detected, transmit a jam signal, and then wait for a random delay and attempt retransmission.
- Advantage: The carrier sense feature provides throughput improvement over pure ALOHA
- Advantage: Collision detection provides further improvement in throughput since a long message is aborted rather than transmitted to completion.

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Carrier Sensing in CSMA/CD

- How to handle transmission if line is sensed busy?
  - ***p-persistent scheme***:
    - Transmit with probability p once the channel goes idle
    - Delay the transmission by t_{prop} with the probability (1-p)
  - ***1-persistent scheme***: p = 1
    - E.g. Ethernet
  - ***nonpersistent scheme***:
    - Reschedule transmission for a later time following a prescribed retransmission delay distribution
    - Senses the channel at that time
    - Repeat the process.

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Carrier sensing in CSMA/CD

- All CSMA schemes rely on stations being able to quickly sense the end of a transmission
  - If sensing is not quick, then channel will remain idle while stations wait for line to clear
- How quickly they can sense is directly related to maximum propagation delay in the medium
- For efficient CSMA, the maximum propagation delay t_{prop} must be small compared with the message transmission length (X). i,e,

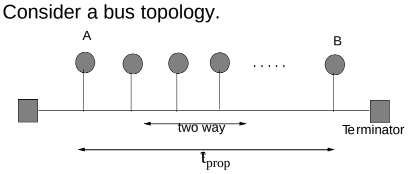
$$a = \frac{t_{prop}}{X} << 1$$

Collision Resolution in CSMA/CD

- Consider 1-persistent CSMA/CD
- What to do in case of collision ?
- Answer: Binary exponential backoff procedure in case of collision:
  - If n successive collisions have occurred (n<16)
    - choose a random number K with equal probability from the set {0,1,2,3,...2^y-1) where y=min(10,n)
    - the node waits for Kx(512 bit-intervals) and retransmits if the channel is idle. e.g., 1 bit-interval = 10^{-7} seconds in 10 Mbps channel
  - If 16 successive collisions occur, the node drops the link and notifies upper layer.

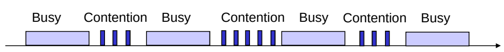
CSMA/CD Analysis Model

- Analysis of maximum throughput
  - Consider a bus topology.

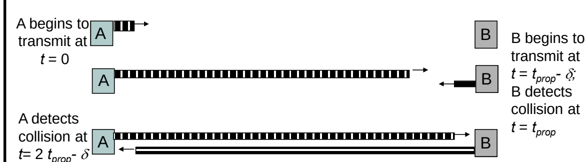


  - Need to find the average time required to launch a successful transmission

CSMA/CD Analysis

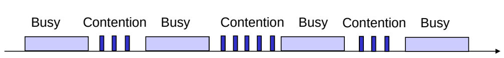


- At maximum throughput, systems alternates between contention periods and frame transmission times
- Essentially, the contention period is like Aloha
- But the "vulnerable period" is round-trip propagation time $2t_{prop}$



It takes station A time $2\ t_{prop}$ to detect collision

CSMA/CD Analysis



- In Aloha, with packet size m and vulnerable period 2m, the maximum efficiency was 1/(2e) and each packet required time 2e x m for transmission
- In CSMA/CD, with vulnerable period $2t_{prop}$, it requires time 2e x t_{prop} for successful resolution of contention
- Requires further time X to transmit packet
- Requires further time t_{prop} for all other stations to detect end of transmission

$$\rho_{\max} = \frac{X}{X + t_{prop} + 2et_{prop}} = \frac{1}{1 + (2e+1)a} = \frac{1}{1 + 6.44a}$$

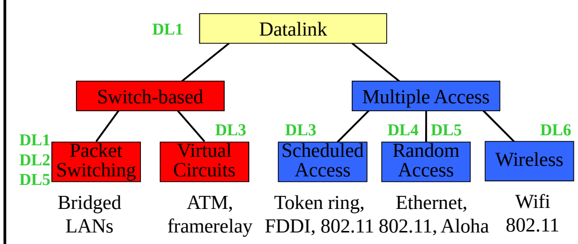
Example

- Find the efficiency of CSMA/CD with 20 Ethernet workstations transmitting 1000 bit messages in 10 Mbps coaxial cabling of 2300 meters long.
- Find the maximum rate of transmission for a workstation in the pure ALOHA and slotted ALOHA with 20 workstations in 10 Mbps coaxial cabling of 2300 meters long.

Comparison of MAC approaches

- Aloha & Slotted Aloha
  - Simple & quick transfer at very low load
  - Accommodates large number of low-traffic bursty users
  - Highly variable delay at moderate loads
  - Efficiency does not depend on a (delay bandwidth product)
- CSMA-CD
  - Quick transfer and high efficiency for low delay-bandwidth product
  - Can accommodate large number of bursty users
  - Variable and unpredictable delay

Datalink Classification



Many techniques also used in higher layers

What is a LAN?

Local area LANs are private networks
- Freedom from regulatory constraints of WANs
- More relaxed security constraints
- Minimal accounting

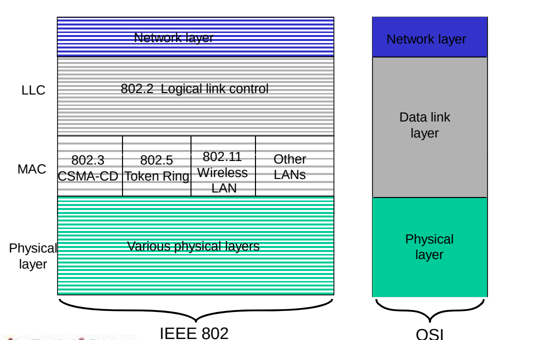
Short distance (~1km) between computers:
- Low cost, high-speed, relatively error-free communication
- Complex error control procedures unnecessary

In local environment, machines may move often:
- Keep track of location a computer at any given time
- Give each machine a unique address
- **Broadcast** all messages to all machines in the LAN

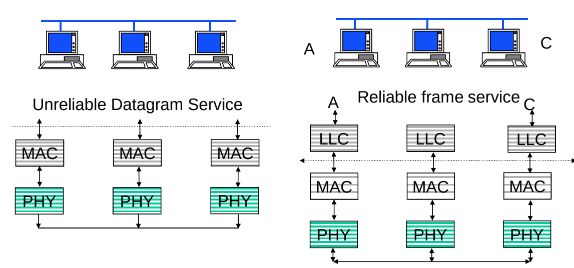
IEEE 802 LAN Family

- The IEEE 802.* set of standards defines a common framing and addressing format for LAN protocols.
  - Simplifies interoperability
  - Addresses are 48 bit strings with no structure
- 802.3 (Ethernet)
- 802.4 (Token bus)
- 802.5 (Token ring)
- 802.6 (Distributed queue dual bus)
- 802.11 (Wireless LAN)
- 802.14 (Cable Modem)
- 802.15 (Wireless Personal Area networks)
- 802.16 (Broadband wireless access)

MAC Sub-layer



Logical Link Control sub-layer

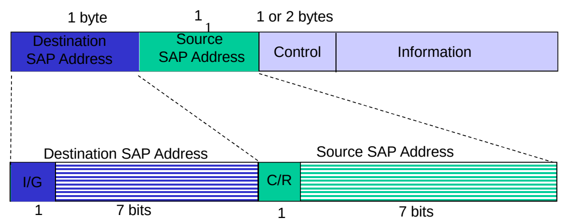


LLC sub-layer services defined by 802

- Type 1: Unacknowledged connectionless service
  - unnumbered frames (HDLC)
- Type 2: Reliable connection-oriented service
  - E.g., asynchronous balanced mode of HDLC
- Type 3: Acknowledged connectionless service

- Additional addressing
  - A workstation has a single MAC physical address
  - Can handle several logical connections (from different upper-layer protocols), distinguished by their SAP (service access points).

LLC PDU Structure



I/G = Individual or group address
C/R = Command or response frame

Encapsulation by MAC frames