LANs
Local Area Networks via the Media Access Control (MAC) Sub Layer
LANs Outline

- Channel Allocation Problem
- Relative Propagation Time
- LAN Utilization Upper Bound
- Multiple Access Protocols
  - TDMA, FDMA
  - Aloha, Slotted Aloha
  - CSMA (non-persistent, 1-persistent, p-persistent), CSMA/CD
- Performance Results
Local Area Networks

- Aloha
- Slotted Aloha
- CSMA
  - non-persistent
  - 1-persistent
  - p-persistent
- CSMA/CD
- Ethernet
- Token Ring
Channel Access Abstraction

Shared Multiple Access Medium

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The history of broadcast networks includes satellite and packet radio networks.

Let us view a satellite as a repeater amplifying and rebroadcasting everything that comes in.

To generalize this problem, consider networks where every frame sent is automatically received by every site (node).
Satellite Channel

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We model this situation as \( n \) independent users (one per node), each wanting to communicate with another user and they have no other form of communication.

The Channel Allocation Problem

To manage a single broadcast channel which must be shared efficiently and fairly among \( n \) uncoordinated users.
Specific LAN Topologies

Ring networks

Multitapped Bus Networks
0. *Listen property* :: (applies to satellites)  
The sender is able to *listen* to sent frame one round-trip after sending it.  
⇒ no need for explicit ACKs.

1. The model consists of *n independent stations*.

2. A *single* channel is available for communications.
3. **Collision Assumption**: If two frames are transmitted simultaneously, they overlap in time and the resulting signal is garbled. *This event is a collision.*

4a. **Continuous Time Assumption**: frame transmissions can begin at any time instant.

4b. **Slotted Time Assumption**: time is divided into discrete intervals *(slots).* Frame transmissions always begin at the start of a time slot.
5a. *Carrier Sense Assumption (CS)* ::

Stations can tell if the channel is busy (in use) before trying to use it. If the channel is busy, no station will attempt to use the channel until it is idle.

5b. *No Carrier Sense Assumption* ::

Stations are unable to sense channel before attempting to send a frame. They just go ahead and transmit a frame.
\( a \) :: Relative Propagation Time

\[
\begin{align*}
\text{length of the data path (in bits)} \\
\frac{a}{\text{length of a standard frame (in bits)}} \\
\text{OR} \\
\text{propagation time (in seconds)} \\
\frac{a}{\text{transmission time (in seconds)}} \\
\text{OR} \\
\text{bandwidth-delay product}^* \\
\frac{a}{\text{average frame size}}
\end{align*}
\]

\* \text{bandwidth-delay product :: the product of the capacity (bit rate) and the delay.}
Figure 15.2 The Effect of $a$ on Utilization for Baseband Bus

(a) Transmission time = 1; propagation time = $a < 1$

(b) Transmission time = 1; propagation time = $a > 1$
Relative Propagation Time

R = capacity (data rate)

d = maximum distance of communications path

v = propagation velocity  (Assume v = 2/3 speed of light
   2 x 10^8 meters/second)

L = frame length

\[ a = \frac{d}{v} = \frac{Rd}{L/R} = \frac{Rd}{vL} \]
Assume a perfect, efficient access that allows one transmission at a time where there are no collisions, no retransmissions, no delays between transmissions and no bits wasted on overhead. {These are best-case assumptions}

\[
\text{Tput Util} = \frac{L}{\text{Capacity propagation time} + \text{transmission time}}
\]
Maximum Utilization for LANs

\[
\text{max. Util} = \frac{L}{d} + \frac{L}{v} = \frac{L}{R_d} + \frac{L}{v} = \frac{1}{a + 1}
\]
Worst Case Collision Scenario

A transmits at $t = 0$

A detects collision at $t = 2\ t_{prop}$

Distance $d$ meters

B transmits before $t = t_{prop}$ and detects collision shortly thereafter

$t_{prop} = d / v$ seconds
LAN Design Performance Issues

For broadcast LANs what are the factors under the designer’s control that affect LAN performance?

- Capacity \{function of media\}
- Propagation delay \{function of media, distance\}
- Bits /frame (frame size)
- MAC protocol
- Offered load – depends on retransmission handling
- Number of stations
- Bit error rate \{function of media\}
Typical frame delay versus Throughput performance

\[ \frac{E[T]}{E[X]} \]

Transfer Delay

Load

\[ \rho_{\text{max}} \]

\[ 1 \]

\[ \rho \]

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Delay-Throughput Performance Dependence on \( a \)

\[
\frac{E[T]}{E[X]} \quad \text{Transfer Delay}
\]

Load

\( \rho'_{\text{max}} \quad \rho_{\text{max}} \quad 1 \)

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Multiple Access Protocols
Multiple Access Links and Protocols

Two types of “links”:

- **point-to-point**
  - PPP for dial-up access
  - point-to-point link between Ethernet switch and host

- **broadcast** (shared wire or medium)
  - old-fashioned Ethernet
  - upstream HFC
  - 802.11 wireless LAN

Shared wire (e.g., cabled Ethernet)

Shared RF (e.g., 802.11 WiFi)

Shared RF (satellite)

Humans at a cocktail party (shared air, acoustical)
Multiple Access Protocols

- single shared broadcast channel
- two or more simultaneous transmissions by nodes: interference
  - collision if node receives two or more signals at the same time

Multiple Access Protocol

- distributed algorithm that determines how nodes share channel, i.e., determine when node can transmit
- communication about channel sharing must use channel itself!
  - no out-of-band channel for coordination
Three broad classes:

- **Channel Partitioning**
  - divide channel into smaller “pieces” (time slots, frequency, code).
  - allocate piece to node for exclusive use.

- **Random Access**
  - channel not divided, allow collisions.
  - “recover” from collisions.

- **“Taking Turns”**
  - nodes take turns, but nodes with more to send can take longer turns.
TDMA: Time Division Multiple Access

- access to channel in "rounds"
- each station gets fixed length slot (length = pkt trans time) in each round
- unused slots go idle
- example: 6-station LAN, 1, 3, 4 have pkt, slots 2, 5, 6 idle
FDMA: Frequency Division Multiple Access

- channel spectrum divided into frequency bands
- each station assigned fixed frequency band
- unused transmission time in frequency bands go idle
- example: 6-station LAN, 1,3,4 have pkt, frequency bands 2,5,6 idle
Random Access Protocols

- When node has packet to send
  - transmit at full channel data rate $R$.
  - no *a priori* coordination among nodes

- two or more transmitting nodes $\rightarrow$ “collision”.

random access MAC protocol specifies:
- how to detect collisions.
- how to recover from collisions (e.g., via delayed retransmissions).

- Examples of random access MAC protocols:
  - slotted ALOHA
  - ALOHA
  - CSMA, CSMA/CD, CSMA/CA
Historic LAN Performance Notation

\[ I :: \text{input load} - \text{the total (normalized) rate of data generated by all } n \text{ stations.} \]

\[ G :: \text{offered load} - \text{the total (normalized) data rate presented to the network including retransmissions.} \]

\[ S :: \text{LAN throughput} - \text{the total (normalized) data rate transferred between stations.} \]

\[ D :: \text{average frame delay} - \text{the time from when a frame is ready for transmission until completion of a successful transmission.} \]
Normalizing Throughput ($S$) 

[assuming one packet = one frame]

Throughput ($S$) is normalized using packets/packet time where

packet time :: the time to transmit a standard fixed-length packet

i.e.,

\[
\text{packet time} = \frac{\text{packet length}}{\text{bit rate}}
\]

NOTE: Since the channel capacity is one packet /packet time, $S$ can be viewed as throughput as a fraction of capacity.

Represented in LG&W by $\rho$ in later graphs.
Historic LAN Performance Notation

retransmissions

D

S

1

2

3

n
Abramson solved the channel allocation problem for ground radio at University of Hawaii in 1970's.

Aloha Transmission Strategy

Stations transmit whenever they have data to send.

- **Collisions** will occur and colliding frames are destroyed.

Aloha Retransmission Strategy

Station waits a *random amount of time* before sending again.
Figure 4-2. Vulnerable period for the shaded frame.
ALOHA

First transmission

\[ t_0 - X \quad t_0 \quad t_0 + X \]

Vulnerable period

Retransmission

\[ t_0 + X + 2t_{prop} \quad t_0 + X + 2t_{prop} + B \]

Time-out

Backoff period

Retransmission if necessary

random backoff period \( B \)
Vulnerable period: $t_0 - X$ to $t_0 + X$  
Two frame transmission times

Assume: Poisson Arrivals with average number of arrivals of $2G$ arrivals/ $2X$

$$S = G e^{-2(1+a)G}$$
Slotted ALOHA (Roberts 1972)

- uses discrete time intervals as *slots* (i.e., *slot = one packet transmission time*) and synchronize the send time (e.g., use “pip” from a satellite).

**Slotted Aloha Strategy**

Station transmits **ONLY** at the beginning of a time slot.

- **Collisions** will occur and colliding frames are destroyed.

**Slotted Aloha Retransmission Strategy**

Station waits a *random amount of time* before sending again.
Slotted ALOHA

- Vulnerable period: $kX$ to $(k+1)X$
- Time-out: $t_0 + X + 2t_{prop}$
- Backoff period: $t_0 + X + 2t_{prop} + B$
- Retransmission if necessary

random backoff period B slots
Vulnerable period :: $t_0 - X$ to $t_0$  one frame transmission time  
Assume: Poisson Arrivals with average number of arrivals of $G$ arrivals/ $X$

$$P_0 = P[k=0, t=1] = e^{-G}$$

$$S = G P_0$$

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

and an adjustment for $a$ yields

$$S = G e^{- (1+a) G}$$
Throughput versus Load

Throughput $S$ for ALOHA and Slotted ALOHA:

- For ALOHA: $Ge^{-2G}$
- For Slotted ALOHA: $Ge^{-G}$

Throughput values:
- ALOHA: 0.184
- Slotted ALOHA: 0.368

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Carrier Sense with Multiple Access (CSMA)
1-persistent CSMA Transmission Strategy

‘the greedy algorithm’

1. Sense the channel.
2. IF the channel is idle, THEN transmit.
3. IF the channel is busy, THEN continue to listen until channel is idle and transmit immediately.
nonpersistent CSMA Transmission Strategy

‘the less-greedy algorithm’

1. Sense the channel.

2. IF the channel is idle, THEN transmit.

3. IF the channel is busy, THEN wait a random amount of time and repeat the algorithm.
'a slotted approximation'

1. Sense the channel.

2. IF the channel is *idle*, THEN with probability $p$ transmit and with probability $(1-p)$ delay one time slot and repeat the algorithm.

3. IF the channel is *busy*, THEN delay one time slot and repeat the algorithm.
Persistent CSMA details

- the time slot is usually set to the maximum propagation delay.
- as $p$ decreases, stations wait longer to transmit but the number of collisions decreases.

Consideration for the choice of $p$:

- $(n \times p)$ must be $< 1$ for stability, where $n$ is maximum number of stations, i.e.,
  
  $p < 1/n$
CSMA Collisions

- In all three strategies a collision is possible.

- CSMA determines collisions by the lack of an ACK which results in a TIMEOUT. {This is extremely expensive with respect to performance.}

- If a collision occurs, THEN wait a random amount of time and retransmit.
Collisions can still occur: propagation delay means two nodes may not hear each other’s transmission.

Collision: entire packet transmission time wasted.

Note: The role of distance & propagation delay in determining collision probability.
Figure 4-4. Comparison of the channel utilization versus load for various random access protocols.
1-Persistent CSMA

Throughput versus Load with varying $a$

$G$

$S$

$a = 0.01$

$a = 0.1$

$a = 1$

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Non-Persistent CSMA

Throughput versus Load with varying $a$

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CSMA/CD (Collision Detection)

CSMA/CD:
- collisions detected within short time.
- colliding transmissions aborted, reducing channel wastage.

Collision Detection:
- easy in wired LANs: measure signal strengths, compare transmitted, received signals
- difficult in wireless LANs: received signal strength overwhelmed by local transmission strength
CSMA/Collision Detection

![Diagram showing CSMA/Collision Detection principle]

- **space**
- **time**
- **collision detect/abort time**

- **A**
- **B**
- **C**
- **D**

- $t_0$
- $t_1$
CSMA/CD

CSMA with Collision Detection

- If a collision is detected during transmission, THEN immediately cease transmitting the frame.

- The first station to detect a collision sends a *jam signal* to all stations to indicate that there has been a collision.

- After receiving a *jam signal*, a station that was attempting to transmit waits a random amount of time before attempting to retransmit.

- The maximum time needed to detect a collision is $2 \times$ propagation delay.
CSMA vs CSMA/CD

- **CSMA** is essentially a historical technology until we include Wireless LANs.

- If propagation time is short compared to transmission time, station can be *listening before sending* with CSMA.

- Collision detection (CD) is accomplished by detecting voltage levels outside acceptable range. Thus attenuation limits distance without a repeater.

- If the collision time is short compared to packet time (i.e., small $a$), performance will increase due to CD.
Probability of 1 successful transmission:

\[ P_{success} = np(1-p)^{n-1} \]

\( P_{success} \) is maximized at \( p = 1/n \):

\[ P_{success}^{\text{max}} = n \left( 1 - \frac{1}{n} \right)^{n-1} \rightarrow \frac{1}{e} \]
Maximum Achievable Throughputs

\[ \rho_{\text{max}} \]

- CSMA/CD
- 1-P CSMA
- Non-P CSMA
- Slotted Aloha
- Aloha

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Frame Delay with varying $a$

![Graph showing the frame delay with varying $a$.](image)

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“Taking Turns” MAC protocols

Channel Partitioning MAC protocols:
- share channel efficiently and fairly at high load.
- inefficient at low load: delay in channel access, 1/N bandwidth allocated even if only 1 active node!

Random Access MAC protocols:
- efficient at low load: single node can fully utilize channel.
- high load: collision overhead

“Taking Turns” protocols:
look for best of both worlds!
Polling:

- master node “invites” slave nodes to transmit in turn
- typically used with “dumb” slave devices
- concerns:
  - polling overhead
  - latency
  - single point of failure (master)
Token passing:

- control token passed from one node to next sequentially.
- token message
- concerns:
  - token overhead
  - latency
  - single point of failure (token)

(data)

(nothing to send)
LANS Summary

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  - Token Passing
- Performance Results