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Consider the following systems:

- There are many people at a table but only one salt shaker.
  - What happens when 2 people reach for the salt at the same time?
  - Fight to the death?

- Two children want to play with the same time?
  - Trust them to work it out?
  - Adult intervention?

- Several people are having a conversation
  - What if two people try to speak at the same time?
2.1 – What do these examples have in common?

The systems issues include:

- *Shared resources* between users
- *Reusable resources* vs. Consumable
- *Mutually Exclusive* access
- Handling *contention*:
  - Centralized approach
  - Decentralized Approach
2.2 – A network view of the situation

Recall the audioconference (conversation) example:

- *Broadcast medium* — When one person (station) speaks all can hear
  - Voices (signals) *collide* if 2 people speak (send) simultaneously
  - Signals that collide are *garbled*

- How should participants decide whose turn it is to speak?
  - Centralized Approach (e.g. use a moderator)
  - Decentralized Approach (e.g. defer upon collision)

- What characterizes a good coordination solution?
  - Maximizes the rate at which messages are exchanged
  - Minimizes the amount of time spent
waiting for a chance to speak

- This is the *multiple access* problem.
- Designing a good solution is hard!
Multiple Access Networks include:

- **Wireless Networks:**
  - Cellular Telephony
  - Wireless Lan
  - Packet Radio (wireless WAN using relay stations).
  - Satellite Communication

- **Shared wire networks:**
  - Ethernet
  - Cable (used by Cable Modems).
Solving the multiple access problem is done by:

1. Choose a “base technology” to isolate traffic from different stations.
   
   (a) Frequency domain (e.g. radio channels)
   
   (b) Time Domain (e.g. TDMA)

2. Determine the allocation of transmission resources among many users.
5 – Design Choices

• Centralized vs. Distributed
  – Is there a master controller?
    * Yes = Centralized
      • Can be easier to get correct
      • Imposes a bottleneck (limiting scalability)
      • Master to slave is *downlink* (cable modem *downstream*)
      • Slave to master is *uplink* (cable modem *upstream*)
    * No = Distributed
      • All stations are peers
      • Sometimes sacrifices efficiency for scalability
      • Can be hard to administer (e.g. spam)

• Circuit Mode vs. Packet Mode transfer
  – Is station traffic at constant rate or bursty?
    * Constant rate stream
• Per packet negotiation is overkill
• Allocate resources to streams not packets!
  – Bursty traffic
    * Avoid wasting resources during idle times
    * Manage at a per packet level
6 – Design Constraints 1 of 3

- Spectrum Scarcity
  - Radio channels allocated by committee (hard to come by!)
  - Few frequencies are available for long distance communication
  - Must not waste bandwidth in a multiple access scheme!

- Properties of Radio Links
  - High error rates
    - Loss due to fading
    - Multipath interference
  - Hidden Terminals — some stations heard only by a subset of (intended) receivers
  - Capture or near-far problem — local signal can be so strong that remote signals (collisions) are undetectable
The parameter $a$, $a = \frac{D}{T}$ where:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D$</td>
<td>maximum propagation delay</td>
</tr>
<tr>
<td>$T$</td>
<td>mean packet transmission time</td>
</tr>
<tr>
<td>$a$</td>
<td>number of packets transmitted before</td>
</tr>
<tr>
<td></td>
<td>The first bit is received by all stations</td>
</tr>
</tbody>
</table>
So what does $a$ mean? Consider a packet collision

- Small $a << 1$ means early detection of collisions
- Large $a$ means late collision detection (avoidance is better!)
9 – Performance Metrics 1 of 2

- **Normalized Throughput** — Fraction of links time devoted to carrying non retransmitted packets
  - **Goodput** — measures fraction of user visible throughput, excludes:
    * protocol overhead
    * collisions
    * retransmissions
  - E.g. Suppose a 10 Mbps link has (max) throughput of 125 byte packets of \( \frac{10^6 \text{ packets}}{\text{sec}} \)
  - But for a particular application/workload combination we get only \( \frac{2.5 \times 10^4 \text{ packets}}{\text{sec}} \)
  - Then goodput = 0.25.

- **Mean Delay** — How long (on average) a station waits before successful packet transmission.
  - Media dependent.
10 – Performance Metrics 2 of 2

- **Stability** — How graceful is performance degradation when load increases.
  - When contention is high, many collisions result in retransmissions (and more collisions).
  - If there are an infinite number of *uncontrolled* workstations, the instability is guaranteed [1, 2].

- **Fairness** — Informally, means *starvation* free.
  - Many formal definitions.
  - max-min fair share (discussed later!)
11 – Base Technologies

• *Base Technology* — isolates data from different stations on a shared medium.
  
  – *Frequency Division Multiple Access* (FDMA)
  
  – *Time Division Multiple Access* (TDMA)
  
  – *Code Division Multiple Access* (CDMA)
12 – FDMA

- FDMA — Assign each broadcasting station its own frequency band.
- Suited to analog links.
- Simple.
- *Guard Bands* separate legitimate broadcast frequency bands.
- Number of frequencies is limited.
  - In wireless networks (e.g. cellular telephones):
    * reduce transmitter power
    * reuse available frequencies in non-adjacent cells
  - e.g. Consider a city with cell phone service.
    * A voice channel takes $30KHz$
      (including a guard band).
    * 833 channels fit in a $25MHz$ band
    * A single (hexagonal) cell can host 118 channels (checkerboarding)
* Partition into $N$ cells, we can now host $118N$ channels (win if $N > 7$).
13 – TDMA

- TDMA — Assign each broadcasting station the same frequency and its own time slot (like TDM).

- Needs time synchronization.

- Benefits
  - Stations can be assigned different bandwidth allocations.
  - Mobiles can use idle time to select the base station.
  - Can turn off power when not transmitting

- Problems
  - Synchronization overhead (guard bits separate time slots).
  - Multipath interference on wireless links is causes serious problems.
14 – CDMA

• CDMA — users separated by time and frequency.

• Has different flavors:
  – *Frequency hopping CDMA* (FH/CDMA) — transmitters change frequency at each time slot
  – *Direct-Sequence CDMA* (DS/CDMA) — Substituted code words for bits (allows for error correction).
    * Each bit of the message is mapped to a *codeword*.
    * Codewords in turn are composed of bits called *chips*.
    * The receiver has a *decorrelator* which maps each codeword back to a bit.
    * Choosing the best codewords is hard (data dependent?).
14.1 – An Analogy

Tanenbaum [3] uses the analogy of a cocktail party.

- **TDM** — When all people in the middle of the room speak, one at a time taking turns speaking.

- **FDM** — When people separate off into clumps, each clump having a conversation.

- **CDMA** — All people are in the middle of the room, but different groups speak in different languages. Conversations in other languages are disregarded as noise.
14.2 – Direct Sequence CDMA 1 of 2

Consider the following approach [3]:

- Suppose the following were true:
  1. Bipolar signals are transmitted
     \((+V = 1, -V = 0)\).
  2. Colliding signals add together (linearly) instead of garbling.
     - (e.g.) 5 stations send a 1 and 2 send 0, so the signals voltage is: \(5V - 2V = 3V\).

- Each station is assigned a unique \(m\) bit code (chip), such that:
  - \(S = [S_1, S_2, \ldots, S_m]\) is a bit vector representing 1 for a particular station.
  - \(\overline{S}\) is the one’s complement of \(S\) representing 0 for that station.
14.3 – Direct Sequence CDMA 2 of 2

Continuing the approach [3]:

- Between any pair of transmitting stations having chips $T, S$:
  - The chip sequences are orthogonal, i.e.,
    $$S \cdot T = 0.$$ 

$$S \cdot T = \frac{1}{m} \sum_{i=1}^{m} S_i T_i = 0 = S \cdot \overline{T} \quad (1)$$

- $S \cdot S = 1$
- $S \cdot \overline{S} = -1$
14.4 – Direct Sequence CDMA Ex 1 of 3

An Example

- Suppose we have inputs $A, B, C, D$ with chip patterns:

<table>
<thead>
<tr>
<th>Input</th>
<th>7</th>
<th>6</th>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A$</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>$B$</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>$C$</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>$D$</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>
4.5 – Direct Sequence CDMA Ex 2 of 3

- If \( V = 1 \) then the bipolar encodings are then:

<table>
<thead>
<tr>
<th>Input</th>
<th>7</th>
<th>6</th>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>( A )</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>+1</td>
<td>+1</td>
<td>-1</td>
<td>+1</td>
<td>+1</td>
</tr>
<tr>
<td>( B )</td>
<td>-1</td>
<td>-1</td>
<td>+1</td>
<td>-1</td>
<td>+1</td>
<td>+1</td>
<td>+1</td>
<td>-1</td>
</tr>
<tr>
<td>( C )</td>
<td>-1</td>
<td>+1</td>
<td>-1</td>
<td>+1</td>
<td>+1</td>
<td>+1</td>
<td>-1</td>
<td>-1</td>
</tr>
<tr>
<td>( D )</td>
<td>-1</td>
<td>+1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>+1</td>
<td>-1</td>
</tr>
</tbody>
</table>

- So then \( B + C \) has the signal:

<table>
<thead>
<tr>
<th>Signal</th>
<th>7</th>
<th>6</th>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>( B )</td>
<td>-1</td>
<td>-1</td>
<td>+1</td>
<td>-1</td>
<td>+1</td>
<td>+1</td>
<td>+1</td>
<td>-1</td>
</tr>
<tr>
<td>( C )</td>
<td>-1</td>
<td>+1</td>
<td>-1</td>
<td>+1</td>
<td>+1</td>
<td>+1</td>
<td>-1</td>
<td>-1</td>
</tr>
<tr>
<td>( B + C )</td>
<td>-2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>+2</td>
<td>+2</td>
<td>0</td>
<td>-2</td>
</tr>
</tbody>
</table>
4.6 – Direct Sequence CDMA 3 of 3

- Here is the trick! Notice that:

\[ C \cdot (B + C) = \frac{1}{8}[2 + 0 + 0 + 0 + 2 + 2 + 0 + 2] = 1 \]  \hspace{1cm} (2)

- And also:

\[ D \cdot (B + C) = \frac{1}{8}[2 + 0 + 0 + 0 - 2 - 2 + 0 + 2] = 0 \]  \hspace{1cm} (3)

and that:

\[ \overline{C} \cdot (B + C) = \frac{1}{8}[-2 + 0 + 0 + 0 - 2 - 2 + 0 - 2] = -1 \]  \hspace{1cm} (4)

- Try this at home: Show that

\[ B \cdot (A + B + \overline{C} + D) = 1 \]  \hspace{1cm} (5)
15 – FDD and TDD

- To convert a half duplex wireless medium to full duplex channel:
  - *Frequency Division Duplex* (FDD) — Uplink and downlink have different frequencies.
  - *Time Division Duplex* (TDD) — Uplink and downlink use different time slots.

- Can be used with FDMA/TDMA and CDMA
  - TDD/CDMA in 2nd generation cordless telephones
  - FDD/TDMA/FDMA in (digital) cellular phones.
16 – Centralized Schemes

- One station is master, all others are slaves.
  - Slave requires masters permission to transmit.

- Appropriate for base station/remote situation
  - Wireless LAN (only base station sees all nodes)
  - Cellular telephony (only base station has high transmit power).
17 – Centralized Access Schemes

- Benefits
  - Easier to get right
  - All coordination logic in the master

- Problems
  - Master provides a single point of failure
  - Master is a bottleneck
  - Slaves vote for new master (reelection protocol)
    * Byzantine Generals Problem?
18 – Circuit Mode

1. Slave stations use a packet mode control channel to request a circuit from the master.

2. Master allocates data transmission resources to the slave.

3. Slave uses the resources until it is done.

4. Data is transferred without contention.

5. Used in Cell Phones
   - EAMPS (Analog FDD/FDMA) — Early US cell phones
   - GSM (Digital FDD/TDMA) — European
   - IS-95 (CDMA) USA.

6. Cellular Digital Packet Data (CPDP) — A packet mode layer on top of circuit mode.
1. Centralized packet mode scheme

2. Polling – master asks slaves if they have data to send
   - *Roll-Call Polling* — Master asks each station in turn. (linear search).
     - Simple
     - But has a high propagation delay penalty

3. *Probing* — Smarter polling scheme! (binary search)
   - Slaves assigned numbers from 0 to \(2^n - 1\).
   - Let \(T\) be the set of slaves wanting to transmit, initially
     \(T = \{0, 1, 2, 3, \ldots, 2^n - 1\}\).
   - Host polls all nodes in \(T\) to see if they have data, either:
     - A Collision occurs, recursively partition the space by a digit in the poll number, checking one half and then the other.
– No collisions occur, unroll the recursion.
20 – Reservation Based Schemes

1. For large values of \( a \) (e.g. satellites):
   - polling is too expensive (large propagation delays).
   - distributed schemes for packet mode are not efficient (because collisions are too expensive)

2. Master coordinates access to link using reservations.

3. Set aside some time slots to carry reservation messages.
   - Reservation messages tend to be small relative to data messages (minislots).
   - Slaves either contend for minislots or use one they own.

4. Master picks the winner in the event of contention, and grants them access.

5. Packet collisions can only occur on minislots, reducing collision overhead.
21 – Distributed Schemes

1. Distributed schemes are hard to get right

2. However, they have advantages
   - increased reliability
   - increased scalability
   - lower message delays
   - higher network utilization

3. Tend to be packet mode
22 – Decentralized Polling

1. Like centralized polling, but no master.

2. Each machine is allocated a time slot to use.
   • Wastes the slot if no input is available.

3. Each machine must be on the same time base.
23 – Decentralized Probing

1. Called *tree based multiple access*

2. All stations in the left subtree place packet on medium.

3. If there is a collision in a subtree between root and root->left_child, partition subtree and try again.

4. On success repeat the process for the right subtree.

5. Works best if $a$ is small.

6. Fails if there are many active stations (especially if in the same subtree).
24 – Carrier Sense Multiple Access (CSMA)

1. *Carrier Sensing* — Check the medium if another station is sending before sending a packet.

2. When can a station send?
   - If the medium is idle send.
   - If a collision occurs detect and resolve

3. Effective if $a$ is small.
25 – Simplest CSMA Scheme

1. Send as soon as medium becomes idle.

2. If the medium is busy two options:
   - **Persistent** – Wait for idle
   - **Non Persistent** — Wait on a timer and try later.

3. Stations waiting to speak will collide.
25.1 – Reducing Collisions

   - Hard to choose $p$.
   - if $p$ is small time is wasted.
   - if $p$ is large more collisions.

2. *exponential backoff* (e.g. ethernet)
   - Upon collision wait wait on a timer and double timeout.
   - Must add a small random increment (why?)
   - Set upper bound on timeout!
   - Adaptive, adjusts to number of stations
   - Don’t need to choose $p$.
   - Need a *collision detect circuit*, CSMA/CD
1. Ethernet is the most common LAN.

2. Ethernet is a wire medium (IEEE 802.3).

3. Uses CSMA/CD and exponential backoff

4. Upon collision places a *jam* signal on wire.
   - Advertises the collision
   - All stations increase their timeout range.

5. Intended for networks with small \( a \), collision loses about 50\( \mu \)sec.

6. Needs a packet long enough (64 bytes) so that a collision is detected before transmission completes.

7. Maximum packet size is 1500 bytes (to prevent hogging).
26.1 – Ethernet 2 of 3

1. Ethernet invented by Metcalf, and originally was 3Mbps on thick coax.

2. Today, most ethernet is 10/100 Mbps and uses either:
   - Thin coax (category 3)
   - Twisted pair (category 5)

3. Encoding is <Speed><Broadband vs. Baseband><Medium>
   - Speed is 3, 10, 100, 1000 Mbps, available, 10 Gbps coming.
   - Baseband for in building, broadband for cable tv
   - Physical Medium
     - 2 — 50 Ohm cable 185m.
     - T — Twisted pair (1 Gbps Max, 100m)
     - 36 — 75 Ohm TV Cable (3600m)
     - Fiber — 1 Gbps (10 Gbps coming)
26.2 – Ethernet Connections

Current trends include.

1. Switched Ethernet (still can have collisions, how?)
   • Instead of sharing a wire, plug all nodes into:
     – Hub — A slow switch, may queue or drop packets. Might broadcast packets.
     – Switch — Typically has bandwidth to handle maximum rate of data transfer from all inputs. Does not broadcast packets.

2. Cable Modems
26.3 – Types of Ethernet

Current Ethernet trends include:

1. Fast Ethernet: IEEE 802.3.U (big winner!)
   - Same as 10BaseT, but has 100 Mbps line spead.
   - Can only span 205 meters (why?)
   - Most NIC are 10/100 Mbps. (autosense)

2. 100 VG Anylan IEEE 802.12
   - Stations make explicit requests to master
   - Master schedules requests (eliminating collisions)
   - Not popular

3. Gigabit Ethernet
   - Switched
   - Fiber and Copper

4. 10 Gigabit Ethernet (in the works)
26.4 – Ethernet Tradeoffs

• Benefits
  – Well understood technology
  – Easy to set up
  – Robust regarding noise

• Problems
  – Heavy loads (> 30% utilization) induce large delays (backoff)
  – Nondeterministic service
  – No prioritization of traffic
  – Expensive to send small packets (e.g. telnet).

• Reasons for Popularity
  – Momentum
  – Problems on shared links only at high load
  – Switching and segmentation of network reduces load.
26.5 – Manchester Encodings

- Suppose we used a unipolar encoding on ethernet?
  - Cannot since there is no way to distinguish between idle and transmitted 0’s

- Solutions, suppose we sent two pulses each bit:
  - Manchester Encoding:
    * 0 send as Low/High
    * 1 sent as High/Low
  - Differential Manchester Encoding (1st bit Manchester?):
    * If next digit is 0 force a transition
    * Otherwise avoid transition
      Show Tanenbaum 4.20 here
26.6 – Ethernet Performance (Theory!)

One treatment partitions time into slots during which there is constant and heavy load [3]

- Consider the following case:
  - $k$ nodes are always ready to transmit
  - Each station transmits during a slot with probability $p$

- Then $k - 1$ stations do not transmit with probability $(1 - p)^{k-1}$.

- And a particular station can have contention free access with probability $p(1 - p)^{k-1}$.

- So the probability that some station acquires the slot is:
  
  $$A = kp(1 - p)^{k-1}$$  

(6)

It can be shown that $A$ is maximized when $p = 1/k$ with $\lim_{k \to \infty} A = \frac{1}{e}$.

- The probability that a contention interval has
exactly \( j \) slots is then

\[
\sum_{j=0}^{\infty} jA(1 - A)^{j-1} = \frac{1}{A}
\]  

(7)

- Since each slot has duration \( 2\tau \), the mean contention interval is then:

\[
w = \frac{2\tau}{A}
\]  

(8)

- If the mean frame take \( P \) seconds to transmit then:

\[
\text{Channel Efficiency} = \frac{P}{P + \frac{2\tau}{A}}
\]  

(9)

If we substitute the notation:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>( B )</td>
<td>Bandwidth of the link</td>
</tr>
<tr>
<td>( c )</td>
<td>signal propagation velocity</td>
</tr>
<tr>
<td>( F )</td>
<td>Frame length</td>
</tr>
<tr>
<td>( L )</td>
<td>Cable length</td>
</tr>
</tbody>
</table>
Then:

\[
\text{Channel Efficiency} = \frac{1}{1 + \frac{2BLe}{cF}} \quad (10)
\]

So high bandwidth long cable connections have lower efficiency!
26.7 – Ethernet Performance (Practice)

We saw a treatment partitions time into slots during which there is constant and heavy load [3]

• But is that realistic?
  – Self similar traffic (Fractals?)

• So What?

• Traditional analysis techniques may not be as accurate as we like!

• So use measurements, and (ideally) try to improve theory!
CSMA with Collision Avoidance (CSMA/CA)

- Used in Wireless lans
- Collisions undetectable (due to Capture, much like NEXT)
- Explicit ACKS required.
- Waiting for ACKS increases cost of collisions
- Uses Collision Avoidance strategy
27.1 – CSMA/CA Algorithm

- Check if medium is busy.
  - If so, wait for medium to become idle

- Wait for interframe spacing
  - High priority stations have small interframe spacing

- Randomly set a contention timer, $T$, $1 \leq T \leq CW$.

- On timeout, send a packet and wait for ACK.

- If no ACK (timeout waiting for ACK), assume packet is lost
  - Double $CW$ and try again.

- If another station transmits while counting down.
  - Freeze $CW$ and unfreeze when packet completes transmission
• CSMA/CA works if all local stations can receive each other’s transmissions.

• But is this realistic?
  – Hidden Terminals — two terminals cannot hear each other but a third (e.g. the base) can
  – Exposed Terminals – some (but not all) terminals cannot hear transmissions from each other.
Hidden Terminals

Exposed Terminals
• Induced CSMA/CA failures
  – Hidden terminals cause collisions because carrier is not detected
  – Exposed terminals cause idling because carrier incorrectly detected.

• *Busy Tone Multiple Access* (BTMA)
  – Assumes transmission is symmetric
  – Incorporates a separate “Busy Tone” channel.
  – Each time a station receives a message, it places a tone on this channel.
  – Any other attempts to talk to that station know it is busy
    * Even if they cannot hear the transmission
  – Avoids Both Problems
31 – Multiple Access Collision Avoidance

- BTMA requires us to partition frequency band
  - But different frequencies have different attenuations
  - Which destroys symmetry, breaking BTMA!

- *Multiple Access Collision Avoidance* (MACA)
  - Use a single band, but send explicit busy messages.
  - Before sending data ask permission by sending a *Request To Send* (RTS) to receiver.
  - An idle receiver responds by sending a *Clear To Send* message
  - If RTS is received by an intended sender, it waits until the other transmission ends.
  - Avoids Both Problems
- Only the owner of the token may transmit
- So every station waits its turn
- Wastes time, if idle stations still get a slot
- So skip over them quickly
- Put stations in a (logical) ring
- When done pass the token to the next station
- Always sends the token in the same direction
- Starvation free!
33 – Token Ring Physical Topology

- Ring
- Star — uses a hub (most common)
- Bus — passes the token on a shared bus
- Dual Ring — In opposite directions (why?)
  e.g. FIDDI
34 – Token Ring Operation

- Normally copies packets from input buffer to output

- If the packet is a token:
  1. Check to see if packets are ready to send
     (a) No — Forward token
     (b) Yes — repeat until done
        i. Sender — Delete token and Send a packet
        ii. Receiver — Copies packet, Sends ACK
        iii. Sender — Receives ACK, deletes packet
           and reinsert token.

- What if token is lost (holder crashes)?
  - Regenerate Token
  - But be careful to remove multiple tokens!
35 – Token Ring Use

- Benefits:
  - Medium access protocol is simple
  - No need for carrier sensing or protocols to handle contention
  - Never any collisions
  - Can prioritize some stations over others

- Problems:
  - Tokens are a point of failure
    * Can get lost or corrupted (trashing network!)
    * Need to protect it (and when needed CAREFULLY regenerate it).
  - All stations must play by the rules
  - Uncooperative stations must be detected and handled (cut off)
  - Stations must monitor network
    * Elect one as monitor.
Most popular token-ring based lan

Uses 100 Mbps dual counter rotating rings

Handles realtime and nonrealtime traffic
  – Token reaches all nodes once every Target Token Rotation Time (TTRT).
  – Station is guaranteed synchronous allocation within every TTRT.

Supports single (cheaper) and dual (expensive) attached stations.
37 – ALOHA

- Invented by Abrahamson at U Hawaii
- Simplest multiple access scheme
- Just send packet
  - Wait for ACK
  - If timed out waiting for ACK, resend (no backoff!)
38 – ALOHA Tradeoffs

- Benefits
  - When $a$ is big, carrier sensing is too expensive
    * Satellites
  - Simple, avoids time synchronization
  - Does not rely on $a$.

- Problems
  - Goodput can be low (depending on mathematical assumptions)
  - Collisions frequent at high loads
  - Collisions can lead to instability
    * Unless backoff is exponential
39 – Slotted ALOHA

- Align slots on boundaries
- Make sure transmissions begin on slot boundaries
- Double’s ALOHA’s capacity by halving the window of vulnerability
- Used in Cell Phone Uplinks
Combines reservation minislots with slotted ALOHA

Contend for mini slots with slotted ALOHA

Stations independently examine reservation requests, and come to the same conclusion

A simple variation

- Partition time into a set of fixed length slots.
- Station winning minislot competition has reserved the slot and keeps it as long as it wants
- Stations losing keep track of idle slots and contend for them.
41 – Reservation ALOHA 2 of 2

• Benefits
  – Works well with large $a$ (WAN)
  – Supports both circuit and packet mode transfers
  – Simple

• Problems
  – No provision for preempting hogs
  – The reservation scheme requires waiting $a$ slots before sending (even if the medium is idle).
    – Variants fix some of these problems.

• Used in upstream (uplink) cable modem traffic.
References

