Simplified Satellite Broadcasting

As an introduction to Local Area Networking, and multiaccess communication, let's take a very simplified look at satellite broadcasting:

- Many users share a single channel.
- Propagation at the speed of light, 300 000 km/sec.
- However, the distance travelled is large (35,880km for conventional TV satellites), resulting in round trip times of ~270msec. (We should contrast this with the proposed 86-satellite Iridium network telephone fleet, in a low 420 nautical mile orbit).
- Bandwidth, typically 3.5Gbps-22Gbps, is currently 100x higher than typical LAN-based networks because it is less limited by the speed of local infrastructure.
- Cost is the same whatever the distance between sender and receiver. Satellite costs have dropped dramatically in the last few years.
- Satellite acts as a repeater of incoming signals, amplifying and re-broadcasting these signals.
- If two stations broadcast simultaneously the satellite will receive and re-broadcast the sum of these two signals, resulting in garbage. Such simultaneous broadcasts are termed collisions.
- A sender can listen to the re-broadcast of their own packets and determine whether a collision has occurred. Notice that there are no acknowledgements.
- Users are uncoordinated and can only communicate via the channel.
Implications for Network Protocols

Therefore, the satellite channel must control its own allocation:

![Satellite Channel Diagram]

The advantages of this "shared medium" approach are:

- No Data Link Layer acknowledgements needed, each sender can verify the correctness of their own messages (because they can hear them).
- No routing problems in the Network Layer subnet (no subnet!).
- No congestion problems or topology optimization.
- Mobile users may be supported.

The disadvantages of this approach are:

- Long propagation delay of ~270msec.
- All users receive all messages, introducing security implications, and there can be no central control of unethical users.

**Question:** How can a single communication channel be efficiently shared between uncoordinated users?
Conventional Channel Allocation

We can employ two common schemes to share the medium:

Polling

Either the satellite or a ground station offers the channel to an individual user for a specified amount of time.

Delays of 270msec make this impractical.

Who should be polled? Should priorities be given to the 100s or 1000s of potential customers?

Frequency and Time Division Multiplexing

There are two significant forms - frequency division multiplexing allocation (FDMA) and time division multiplexing allocation (TDMA).

Using FDMA the channel is divided into N frequency bands (slots) for a maximum of N users. Guard bands are placed between these to limit interference.

Using TDMA the channel is divided into slots based on time intervals, typically 125usec. Each potential user may then use the whole channel for their time quantum (in a manner similar to operating system timesharing).

Both FDMA and TDMA are very inefficient since the actual number of users, M, is generally <<N or>>()N, and traffic is often 'bursty'.

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Pure ALOHA

In 1970 Norman Abramson devised the ALOHA network at the University of Hawaii.

Pure ALOHA uses a contention based protocol:

- Users transmit whenever they wish.
- Users detect their own collisions.
- After a collision, a user ‘backs-off’ for a random time period and then retransmits.

What are our expectations for throughput of this approach?

- Infinite number of users each thinking and sending.
- Generation of packets is a Poisson distribution, with mean $S$. Here, $S =$ number of packets generated per packet time.

If $S > 1$ we have chaos.
If $0 < S < 1$ we get acceptable throughput.

Analysis can show the best possible utilization of 18.38%.

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**Slotted ALOHA (1972)**

The *slotted Aloha* mechanism makes an obvious improvement to improve expected throughput:

- the satellite generates a *timing pulse*.
- users then only transmit when they get this pulse.

This quantization of time reduces the vulnerability period by half (now to a single packet transmission time).

Hence:

\[ S = G \cdot e^{-G} \]

Maximum throughput is now achieved when \( G = 1 \),

\[
giving \ S = \frac{1}{e}
\]

or a **best possible** utilization of 36.79%.

Note that small increases in \( G \) dramatically reduce performance.
Local Area Networks

Let's use an informal definition to characterize our next topic of study, local area networks:

<table>
<thead>
<tr>
<th>Activity</th>
<th>Separation</th>
<th>Bit rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wide area networks, WANs</td>
<td>&gt; 10km</td>
<td>&lt; 10.0 Mbps</td>
</tr>
<tr>
<td>Local area networks, LANs</td>
<td>10 → 0.1km</td>
<td>10.0 → 10,000Mbps</td>
</tr>
<tr>
<td>Multiprocessors</td>
<td>&lt;&lt; 0.1km</td>
<td>&gt; 100Mbps</td>
</tr>
</tbody>
</table>

In particular, for local area networks:

- Machines connect to a (logically) single cable within a 1km radius (often the same building or campus).
- Total data rate > 10Mbps (short round trip time, simple data link layer with, say, a one bit sliding window)
- Single organization ownership (no political domains to traverse).
- Usually use broadcasting (no routing problems, but everyone sees all frames).

One general definition, often cited, is:

"A LAN is a routerless network, using the same protocol stack for each device, and using only a uniform, local, networking media."

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Carrier Sense Networks

- All stations can sense the electrical carrier before sending.
- This is possible because of the use of high speed cables over short distances.

We will be concerned with carrier-sense multiple-access (CSMA) protocols.

Factors Affecting CSMA LANs

1. All frames are of constant (or small, bounded) length.
2. There are no transmission errors, other than those of collisions.
3. There is no capture effect.
4. The random delay after a collision is uniformly distributed and large compared to the frames' transmission time.
5. Frame generation attempts (OLD and NEW) form a Poisson process with mean \( G \) frames per time.
6. A station may not transmit and receive simultaneously.
7. Each station can sense the transmission of other stations.
8. Sensing of the channel state can be performed at the same time as transmitting.
9. The propagation delay is small compared to the frames' transmission time, and identical for all stations.
Persistent CSMA Protocols

Using 1-persistent CSMA protocols, each station first senses the activity on the channel.

If two stations A and B are waiting for C to finish, they just pause for a period, and when they sense that the channel is free, transmit with a probability of 1 (pretty persistent eh?).

This, naturally, results in a good chance of a collision.

The longer a propagation delay on a LAN the more collisions there will be and, hence, the worse will be the performance.

1-persistence is no good for satellite broadcasting because:

each station hears what was happening 270msec ago.

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Non- and p-persistent CSMA Protocols

In non-persistent and p-persistent protocols, each station may again sense a busy channel.

If the channel is found too busy, contending stations 'back-off' for various intervals.

- Non-persistent stations back-off for random intervals.
- p-persistent stations 'jump in' with a probability \( p \) (or back-off for a constant amount of time with a probability \( q = 1 - p \)).

![Graph showing throughput vs. G (attempts per packet time)](image)

Obviously, the lower the value of \( p \), the fewer collision there will be (each station is almost 'chicken' to transmit).

Even though the channel utilization can approach its maximum, each station can be waiting a long time.
IEEE-802.x LAN Standards - The Ethernet System


The 'Ethernet' system is a member of the IEEE-802 family of protocols for local area networks (it is 802.3). 802.3 uses a 1-persistent Carrier-Sense Multiple-Access with Collision Detection (CSMA/CD) method.

See:
- Ethernet: Distributed Packet Switching for Local Computer Networks
- Ethernet Systems on Personal Computers

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Physical Properties

The original 'standard' Ethernet proposal was for a 3Mbps network, connecting up to 256 stations (1975). The IEEE-802.3 standard has since been introduced which at first supported up to 1024 stations at 10Mbps over a total length not exceeding 2.5km.

<table>
<thead>
<tr>
<th>Type</th>
<th>Cable</th>
<th>Max. Segment</th>
<th>Nodes/seg.</th>
<th>Advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>10Base5</td>
<td>Thick coax</td>
<td>500m</td>
<td>100</td>
<td>Used for backbones</td>
</tr>
<tr>
<td>10Base2</td>
<td>Thin coax</td>
<td>185m</td>
<td>30</td>
<td>Cheaper</td>
</tr>
<tr>
<td>10Base-T</td>
<td>Twisted pair</td>
<td>100m</td>
<td>1024</td>
<td>Easy maintenance</td>
</tr>
<tr>
<td>10Base-FX</td>
<td>Fiber optic</td>
<td>2000m</td>
<td>1024</td>
<td>Best between buildings</td>
</tr>
</tbody>
</table>

- Each packet must be at least 64 bytes long to provide some reasonable chance of detecting collisions over long-ish propagation times.
- Due to power losses within the Ethernet cables, each segment cannot exceed 500m, so repeaters were used to connect up to 5 segments in a single LAN.
- Later additions to the 802.3 standard support increasingly faster twisted pair speeds: 100Base-T, 1000Base-T, and recently 10GBase-T.
- Similarly, fiber optic speeds and segment lengths have increased: 10GBase-ER (extended range) allows 40km. 100Gbps is in the works.

More recently, there has been an 'explosion' in wired Ethernet categories:

- Standard: 10Base5, 10Base2, 10BaseT, 10BaseFX
- Fast: 100BaseTX, 100BaseT4, 100BaseFX
- Gigabit: 1000BaseT, 1000BaseLX
- 10-Gigabit: 10000BaseT, 10000BaseLR
Ethernet’s Contention Algorithm

Each station wanting to transmit, listens to the ether and on finding it silent begins transmission.

On detecting a collision a station:

- 'backs-off' for a random period which is a multiple of the 802.3 slot time. (This time is chosen based on the longest allowable path being 2.5km, and is set at 51.2 microseconds).
- After the first collision each station backs-off for 0 or 1 slot times before trying again.
  - If there is a second collision, a station backs-off for 0, 1, 2 or 3 slot times.
  - In general, a station will back-off from 0 to $2^{i-1}$ slot times after the $i^{th}$ collision.
  - This continues for a maximum of 10 collisions (1023 back-offs), after which the station stays at 1023 for 6 more collisions.
- After 16 collisions the station considers the 'ether' severed and reports back to the Networking Layer.

This method, termed binary exponential back-off, ensures a short delay for each station when a small number of stations collide and a reasonable delay when many stations collide.
**Ethernet Addressing Schemes**

Each 802.3 packet contains the source and destination address, each of 6 bytes (48 bits).

<table>
<thead>
<tr>
<th>Preamble</th>
<th>SFD</th>
<th>Destination</th>
<th>Source</th>
<th>Length</th>
<th>Data</th>
<th>CRC</th>
</tr>
</thead>
<tbody>
<tr>
<td>62 bits</td>
<td>2 bits</td>
<td>6 bytes</td>
<td>6 bytes</td>
<td>2 bytes</td>
<td>46 - 1500 bytes</td>
<td>4 bytes</td>
</tr>
</tbody>
</table>

- If all 48 destination bits are set to 1, the packet is a *broadcast* address destined for all stations on a LAN.
- The high-order bit (bit 47) is used to indicate addressing domains, 0 being for individual addresses and 1 being for *multicast* addresses (to deliver packets to a group of stations).
- Bit 46 (high-order less one) indicates whether the address is for the current LAN or for a more global station on another LAN.
- Using $2^{48}$ bits ($7 \times 10^{3}$ stations) each device in the world can have a unique Ethernet card number (assigned by the IEEE).

Of course it is up to the Network Layer to determine how to get to other stations not on your LAN.
Packet Transport Mechanisms

Each station connects to the ether with a transceiver. 'The design of the transceiver must be an exercise in paranoia'. In particular, failures of the transceiver must not pollute the ether, power failure must not 'cloud' the ether and disconnection must not be noticed by other stations.

802.3 uses five significant mechanisms to reduce the probability and cost of losing a packet.

- carrier detection.
  Ethernet uses the carrier sense mechanism of phase encoding which guarantees that there is at least one phase transition on the ether during each bit time.
  The Aloha scheme does not use carrier detection and subsequently suffers a higher collision frequency.
  (Use of deference and acquisition).
- packet error detection (initially 2-byte CCITT-16, now 4-byte CRC-32).
Packet Transport Mechanisms, continued

- interference detection.
  Each transceiver has an interference detector; a station can detect interference because what it is receiving is not what it is transmitting.

  Interference detection has three advantages:
  - A station can detect collisions and re-schedule transmission (no need to wait for a lack of acknowledgement).
  - Interference is detected within the propagation time (with Aloha a whole packet was transmitted and then examined for a collision).
  - The frequency of collisions is immediately used to dynamically change the back-off times.

- truncated packet filtering.
  Interference detection and deference cause most collisions to result in truncated packets of only a few bits. To reduce the overhead of obviously damaged packets, the hardware is able to filter them out.

- collision consensus enforcement.
  Whenever a station detects a collision of its own transmission it deliberately jams the ether to ensure that other colliding stations hear the collision as quickly as possible and then to stop transmitting.
Hubs, Switches, and Collision Domains

A collision now occurs when a device or LAN-segment receives two or more signals simultaneously. Obviously our goal is to reduce collisions by either resolving them quickly, or reducing the likelihood of them occurring at all.

The following diagram highlights the difference between a hub and a switch, when node F is transmitting to node C. The hub will retransmit the frame to all of its outgoing ports, whereas the switch will more 'intelligently' retransmit the signal to the ports known to be wanting the frame:

A collision domain is the set of devices (potentially) receiving a frame collision. Today, it is very difficult to purchase a hub, as switches have become so inexpensive, but hubs can still play a role in Ethernet traffic monitoring.
Interconnecting IEEE-802.x LANs

LANs can be connected by devices named bridges which operate at OSI's layer 2 (the Data Link Layer) - in contrast to repeaters which are only layer 1 devices.

Because bridges are at the Data Link Layer, they can deliver any Network Layer traffic equally well, including Internet IP packets, Novell's IPX, and genuine OSI packets.

There are many reasons why a single organization has many LANs, in need of connection:

- Different departments will employ different LAN technologies without regard to other departments,
- The single organization may be spread over distances in excess of what a single LAN can support,
- It is necessary to isolate LAN traffic to balance or filter traffic between certain source/destination pairs,
- Multiple LANs can provide increased reliability (as we'll see, bridges are discerning in what they copy between different LANs), and
- Multiple LANs can provide increased security. As all stations on IEEE-802 LANs see all traffic, we need to isolate sensitive traffic.
IEEE-802.3 Bridges

The primary benefits to installing bridges include a simple 'load-balancing' scheme and increased reliability.

Bridging becomes difficult when connecting different types of LAN.

1. The most obvious problem is differing bit rates (we typically have 4Mbps, 10Mbps, 16Mbps and, now, 100Mbps and 1000Mbps).

A bridge must have sufficient buffer space to allow a backlog of frames between LANs. Moreover, when transmitting from a fast LAN to a slow one, the bridge introduces (buffering) delays which confuse (naive) timeout schemes.
Bridging Different Types of LANs, continued

2. Data Link frame reformatting is another problem. The 3 primary IEEE-802 frame formats are very similar, and a bridge can modify most fields.

However, consider a token-ring connected to an Ethernet. The token-ring frames have a priority, which is lost once they enter the Ethernet LAN.

Similarly, Ethernet frames need a default priority to enter a token-ring. (Even worse, consider a token-ring connected to an Ethernet, connected to another token-ring).
Bridging Different Types of LANs, continued

3. A further significant problem is frame sizes - 
4. 802.3 Ethernet is limited to 1500 bytes of data, 
5. 802.4 token-bus to 8191 bytes, and 
6. 802.5 token-ring is unlimited!

Clearly fragmentation to the rescue, but the Data Link Layer is neither responsible for fragmentation, nor can protocols manage partial frames. [Devices which can support these bridging functions are Network Layer devices named brouters].

A Summary of 802.x to 802.y Bridging

<table>
<thead>
<tr>
<th>Source LAN</th>
<th>Destination LAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>802.3</td>
<td>802.3 (CSMA/CD)</td>
</tr>
<tr>
<td>802.4</td>
<td>1, 4</td>
</tr>
<tr>
<td>802.5</td>
<td>1, 5, 6, 7, 10</td>
</tr>
</tbody>
</table>

Actions:
1. Reformat the frame and compute new checksum
2. Reverse the bit order,
3. Copy the priority, meaningful or not,
4. Generate a fictitious priority,
5. Discard priority,
6. Drain the ring (somehow),
7. Set A and C bits (by lying),
8. Worry about congestion (fast LAN to slow LAN),
9. Worry about token handoff ACK being delayed or impossible,
10. Panic if frame is too long for destination LAN

Parameters assumed:

<table>
<thead>
<tr>
<th>Source LAN</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>802.3</td>
<td>1500-byte frames, 10 Mbps (minus collisions)</td>
</tr>
<tr>
<td>802.4</td>
<td>8191-byte frames 10 Mbps</td>
</tr>
<tr>
<td>802.5</td>
<td>5000-byte frames 4 Mbps</td>
</tr>
</tbody>
</table>