DATA LINK COMMUNICATION:
TECHNOLOGY AND ACCESS CONTROL

Point-to-point communication

Already seen digital/analog transmission of digital data including coding and error detection.

Reliable transmission

Principal methodology: ARQ (Automatic Repeat reQuest) or PAR (Positive Acknowledgment with Retransmission) or backward error correction (BEC).
Three components:

- acknowledgment (ACK)
- timeout
- retransmit
Stop-and-wait

Assumption: Frame is “lost” due to corruption; discarded by NIC after error detection.
Issue of RTT (Round-Trip Time) and timer management:

- what is proper value of timer?
- RTT estimation
- easier for single link than *path* in an internetwork
- largely independent of queueing effect

More serious problem: Not keeping the pipe full.

\[ \rightarrow \text{ bandwidth-delay product} \]

Literally, volume of data in on the link.

To achieve high utilization, want to keep volume of traffic flowing close to the bandwidth limit.
Example: Link BW 1.5 Mbps, 45 ms RTT; bandwidth-delay product = 1.5 Mbps × 45 ms = 67.5 kb ≈ 8 kB.

If frame size 1 kB, then (effective) throughput is $1024 \times 8/0.045 = 182$ kbps; utilization is only $0.125$.

Solution: Other things being equal, must increase frame size.

- straightforward increase of frame size is problematic; why?
- send blocks of data, i.e., sequence of frames
- creates management problem
Sliding window protocol

- **SWS**: Send Window Size
- **RWS**: Receiver Window Size
- **LAR**: Last ACK Received
- **LFS**: Last Frame Sent
- **NFE**: Next Frame Expected
- **LFA**: Last Frame Acceptable
Assign sequence number (SeqNum) to individual frames.

Maintain invariants:

- \( \text{LFS} - \text{LAR} + 1 \leq \text{SWS} \)
- \( \text{LFA} - \text{NFE} + 1 \leq \text{RWS} \)

Sender: Update LAR, send more frames, then update LFS.

Receiver: Cumulative ACK; let SeqNumToAck denote the largest sequence number not yet acknowledged.

- \( \text{NFE} \leftarrow \text{SeqNumToAck} + 1 \)
- \( \text{LFA} \leftarrow \text{SeqNumToAck} + \text{RWS} \)
ACK variants:

- piggyback
- negative ACKs
- selective ACKs

Sequence number wrap-around problem:

\[ SWS < \frac{(\text{MaxSeqNum} + 1)}{2}. \]

\[ \Rightarrow \text{similar to stop-and-wait (binary)} \]
Further optimization/control variables in end-to-end case?

Why can packets still be lost given that link layer achieves reliability?

Link-based flow/congestion control revival (H. T. Kung). Achieve flow control/multiplexing (buffer sharing)/reliability at link level.
Multi-access communication

Ethernet and CSMA/CD

→ copper, optical fiber

Types:

- 10Base2 (ThinNet): coax, segment length 200 m, 30 nodes/segment
- 10Base5 (ThickNet): coax, segment length 500 m, 100 nodes/segment
- 10Base-T: twisted pair, segment length 100 m, 1024 nodes/segment
- 10Base-F: fiber, segment length 2000 m, 1024 nodes/segment
- 100Base-T (Fast Ethernet): category 5 UTP, fiber (also 100VG-AnyLAN)
- Gigabit Ethernet: fiber, category 5 UTP
Connectivity example:

- $10\text{Base-2, 10Base5}$
- bus/star configuration
- multihomed/singlehomed
- unique Ethernet address per NIC
Segments can be hooked up by repeaters, bridges, gateways, (hub) switches.

- maximum of 2 (4 for IEEE 802.3) repeaters between two hosts; 1500 m
- for Fast Ethernet, 2 repeater hops

High-bandwidth Ethernets have \textit{shorter} network diameter.

- about 2500 m for 10 Mbps Ethernet
- about 200 m for 100 Mbps Ethernet
- even shorter for 1 Gbps Ethernet
DIX Ethernet frame:

```
8 6 6 2 46 - 1500 4 1
```

- preamble
- source address
- dest. address
- body
- CRC
- type
- postamble

IEEE 802.3 Ethernet frame:

```
8 6 6 2 46 - 1500 4 1
```

- preamble
- source address
- dest. address
- body
- CRC
- length
- postamble

LLC header

⇒ IEEE 802.2 LLC (Logical Link Control)
Encoding: Manchester

Addressing:

- 48 bit unique address
- point-to-point
- broadcast (all 1’s)

Receiver: Ethernet adaptor accepts frames with relevant address.

- accepts only own frame address
- accepts all frames (promiscuous mode)
MAC (Medium Access Control): CSMA/CD

- **CS (Carrier Sense):** Can detect if some other node is using the link.

- **MA (Multiple Access):** Many nodes are allowed to simultaneously access the link.

- **CD (Collision Detection):** Can detect if simultaneous access has occurred (corrupted signal).
Ethernet is 1-\textit{persistent} MA scheme; more generally, $p$-persistent where $0 < p \leq 1$.

Worst-case collision scenario:

- sender (worst case) needs to wait $2\tau$ sec before detecting collision
- for 2500 m length, 51.2 $\mu$s round-trip time ($2\tau$)
- enforce 51.2 $\mu$s slot (jam) time
- at 10 Mbps, 512 bits; i.e., minimum frame size
Hence, upon collision detection:

- Make sure to transmit at least 512 bits
  \[ \rightarrow 2 \times \text{bandwidth-delay product} \]
  \[ \rightarrow 6 + 6 + 2 + 46 + 4 = 64 \text{ B} = 512 \text{ bits} \]
- exponential backoff; wait for \( 0 \leq X \leq 51.2 \mu s \) before next attempt
- on \( i \)'th collision, wait for \( 0 \leq X \leq (2^i - 1)51.2 \mu s \) before next attempt, \( i \leq 16 \)
- \( X = 0 \mu s, 51.2 \mu s, 2 \times 51.2 \mu s, 3 \times 51.2 \mu s, \ldots \)
  \[ \rightarrow \text{distributed bus arbitration mechanism} \]