Frame Transmission

**Link Bandwidth**: Number of bits per second that can be transmitted on a link

- 10 Mbps \( \rightarrow \) 1 bit is injected onto the medium every 0.1 usec \((0.1 \times 10^{-6} \text{ sec})\)

**Frame Latency (Delay) On a Link (1)**

- **Frame Latency** = \( \frac{D}{c'} + \frac{L}{R} = \frac{D}{(2/3)c} + \frac{L}{R} \)
  - Propagation time + Transmission time
  - Time between first bit placed on the "wire" until last bit leaves the "wire" at the receiver
- Propagation time over the distance \( D \) in copper wire
  - Electrons travel over copper wire at about 2/3 the speed of light \((c) \rightarrow c' = (2/3)c\)
  - \( c' \), the speed of an electron over a copper wire is approximately 200 m/usec
- Same approximation for optical fiber cable
- Transmission time of a frame that is \( L \) bits long over a link with rate (bandwidth) \( R \) bps

**Frame Latency (Delay) on a Link (2)**

- Propagation time
- Transmission time
- Receiver
**Space-Time Diagram**

- **Transmission Time:** Time required to put all bits of a frame onto a link
- **Propagation Time:** Time that a single bit takes to travel from the transmitter to the receiver
  - One-way propagation time

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**Frame Latency Example**

**Given**
- Bandwidth of \( R = 10 \text{ Mb/s} \)
- Frame (Packet) size of \( L = 1,500 \text{ bytes} \)
- Distance of \( D = 2,500 \text{ meters} \)
- Sending and receiving overhead = 0 usec
- Assume no signal attenuation

**What is the interbit time?**
- \( 1/R = 0.1 \text{ usec} \)

**What is the total latency of the frame from sender to receiver?**
- \( \frac{2,500}{200} \text{ usec} + 12,000 \times 0.1 \text{ usec} = 12.5 + 1,200 \text{ usec} = 1.2125 \text{ msec} \)
- The transmission time dominates the propagation time!

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**Multiple Hops**

- **Total Propagation Time**
  - Depends on total distance \( D(1) + D(2) \)

- **Total Transmission Time**
  - Depends on number of transmission interfaces (\#Hops) because of store-and-forward mechanism

- **Queueing Time**
  - Due to link usage by other packets

**General Multihop Latency (Delay)**
- Delay due to Hop \( i = \frac{3D(i)}{(2c)} + \frac{L}{R(i)} + Q(i) \)
- Total Delay = \( \sum_{i=1}^{H} \left[ \frac{3D(i)}{(2c)} + \frac{L}{R(i)} + Q(i) \right] \)

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**Round-Trip Time (RTT)**

- **1-Way Propagation Time**
  - Time that a single bit takes to travel from the transmitter A to the receiver B

- **2-Way Propagation Time**
  - \( = 2 \times (1\text{-Way Propagation Time}) \)
### Bandwidth-Delay Product

The bandwidth-delay product (Bandwidth x Delay)

- The volume (e.g., #bytes) that can be transmitted before the first Ack arrives at the transmitter
- For single hop: Delay = RTT
- For multihop: Delay includes queueing time

Pipelining leads to bandwidth x delay performance

### Some Bandwidth-Delay Products

<table>
<thead>
<tr>
<th>Network</th>
<th>Bandwidth (Kbps)</th>
<th>RTT (ms)</th>
<th>Bandwidth-Delay (bytes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 Mbps Ethernet</td>
<td>10</td>
<td>2</td>
<td>2,500</td>
</tr>
<tr>
<td>T1 (transcontinental)</td>
<td>1,544</td>
<td>60</td>
<td>11,580</td>
</tr>
<tr>
<td>T1 (satellite)</td>
<td>1,544</td>
<td>500</td>
<td>96,500</td>
</tr>
<tr>
<td>T3 (transcontinental)</td>
<td>45,000</td>
<td>60</td>
<td>337,500</td>
</tr>
<tr>
<td>Gigabit (transcontinental)</td>
<td>1,000,000</td>
<td>60</td>
<td>7,500,000</td>
</tr>
</tbody>
</table>

### Effective End-to-End Throughput

- Effective Throughput
  - \( \text{Effective Throughput} = \frac{\text{Transfer Size}}{\text{Transfer Time}} \)
- Transfer Size
  - Size of file, message, packet, frame, …, transfer unit
- Transfer Time
  - Total time involved in a successful transfer
  - May include time to:
    - Setup transfer; Retransmit damaged or lost transfer units
- Example
  - Request 1 MB file across 1 Gbps network, RTT=100 msec
  - Throughput = \( \frac{1 \text{ MB}}{100 \text{ msec} + 1 \text{ MB}/1 \text{ Gbps}} = 8.4 \text{ MB}/(108.4 \text{ msec}) = 77.5 \text{ Mbps} \)

### The LAN Parameter 'a'

- \( a = \frac{\text{Max propagation delay}}{\text{Time to transmit average size packet}} \)
  - The number of packets that a transmitting station can place on the medium before the farthest station receives the first bit
- Small \( a \) (wired/wireless LANs can have \( a = 0.01 \))
  - Propagation delay is a small fraction of the packet transmission time
  - Every station receives at least part of the packet before source finishes transmission
- Large \( a \) (satellite links can have \( a = 100 \))
  - Source may transmit many packets before receiver sees the first bit
Assignment

- Begin reading
  - Donahoo and Calvert, Chapters 1-3, and 5