Fundamentals of Telecommunications

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- Time Division Multiplexing T1, T3, DS1, E1
- T1 Framing
- Echo Cancellation
- Signaling
Time Division Multiplexing

- Voice signal has a bandwidth of 4 kHz
- Nyquist sampling theorem:
  Sample at twice the highest signal frequency
  \[ \Rightarrow \text{Sample at } 8 \text{ kHz} \Rightarrow \text{Sample every } 125 \ \mu\text{sec} \]
- 256 levels \[\Rightarrow\] 8 bits per sample \( \times \) 8000 samples/sec = 64 kbps
- In 1962, telephone carrier (cable) between Bell System offices could carry approximately 1.5 Mbps over a mile = Distance between manholes in large cities = Distance between amplifiers
- \(1500/64 \approx 24\Rightarrow\) Can multiplex approximately 24 voice channels on that carrier \[\Rightarrow\] Telecommunication-1 carrier or T1 carrier. Named after the ANSI committee.
T1 Frame

- T1 = 24 voice channels = Digital Service 1 = DS1
- Used time-division multiplexing:

  ![T1 Frame Diagram]

  T1 Frame = 193 bits/125 μs

- Framing: Add 101010 (1 bit per frame)

  Frame 1  Frame 0  Frame 1  Frame 0  Frame 1

- Any other sequence ⇒ Resynchronize
T1 Signaling

- Initially, 8th bit of every channel was used for signaling
- Now, every 6th frame, the 8th bit of each channel is used for signaling
- Net rate = $(8 \times 5 + 7)/(125 \times 6) = 62.66$ kbps
- For digital data service, 24th channel is used for sync byte which allows faster and more reliable frame resynchronization. 8th bit in each of the 23 channels indicates whether the data is user’s or system control
- 8th bit is not reliable
  ⇒ Use only 7 bits per frame ⇒ 56 kbps
- For mixture of voice and data, all 24 channels can be used. No sync bytes.
Subrate Multiplexing

- Used for data rates lower than 56 kbps.
- One bit of the 7 bits is used to indicate data rate.
- 6 bits per channel = 48 kbps
  - Five 9.6 kbps subchannels
  - Ten 4.8 kbps subchannels
  - Twenty 2.4 kbps subchannels
- Five subchannels ⇒ Subchannel 1 uses frames 1, 6, 11, ...
# Digital TDM Hierarchy

<table>
<thead>
<tr>
<th></th>
<th>North America</th>
<th>European</th>
<th>Japan</th>
</tr>
</thead>
<tbody>
<tr>
<td>DS0</td>
<td>64 kbps</td>
<td>64 kbps</td>
<td>64 kbps</td>
</tr>
<tr>
<td>DS1</td>
<td>1.544 Mbps</td>
<td>E1 2.048 Mbps</td>
<td>1.544 Mbps</td>
</tr>
<tr>
<td>DS2</td>
<td>6.313 Mbps</td>
<td>E2 8.448 Mbps</td>
<td>6.312 Mbps</td>
</tr>
<tr>
<td>DS3</td>
<td>44.736 Mbps</td>
<td>E3 34.368 Mbps</td>
<td>32.064 Mbps</td>
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<tr>
<td>DS4</td>
<td>274.176 Mbps</td>
<td>E4 139.264 Mbps</td>
<td>97.728 Mbps</td>
</tr>
<tr>
<td>DS1C</td>
<td>3.152 Mbps</td>
<td>E5 565.148 Mbps</td>
<td>397.200 Mbps</td>
</tr>
</tbody>
</table>
300 bps over Single Pair

- 300 bps modems (Bell 108 specification)
- Use frequency shift keying
  - $0 \Rightarrow 1070$ Hz, $1 \Rightarrow 1270$ Hz in one direction
  - $0 \Rightarrow 2025$ Hz, $1 \Rightarrow 2225$ Hz in the other direction
Echo Cancellation

- Problem: Full duplex transmission over a single pair
- Solution 1: Use different frequencies for the two directions. Only half of the bandwidth available for each direction
- Solution 2: Use digital signal \(\Rightarrow\) Some part of the signal returns (echo). Near-end and far-end echoes

Echo Cancellation: Estimate echo and subtract from received signal. Transmitted signal is known. Reflections from various distances along the path are estimated and subtracted from the received signal \(\Rightarrow 144\) kbps up to 4 km
Time-Compression Multiplexing

- Half-duplex transmission
- Central office and subscriber take turns for transmitting
- Some time is allowed for propagation delay and for the line to turn around
- Wire rate is more than twice the signal rate
Optical Fiber in the Local Loop

- Distribution network uses a star topology
- Feeder cables connect central office to remote nodes
- Initially, feeder cables can be replaced via fiber. May multiplex using TDM or WDM
- Active star Remote node ⇒ It multiplexes/demultiplexes.
- Passive star remote node ⇒ Subscriber equipment multiplexes/demultiplexes

![Diagram of optical fiber in the local loop](image)
Circuit Switching

- Three Phases: Circuit setup, Signal Transfer, Circuit Disconnect
- Hierarchical System: Subscribers are connected to local exchanges (or end offices), which are connected via trunks to other tandem or toll switching centers.
- Routing can be static or adaptive. Load independent or load dependent.
Signaling

- Signal = Control
- Signaling in telephone networks
  = Control messages in computer networks
- Examples:
  - Connection setup request
    = Off-hook signal from telephone to switch
  - Connection setup acknowledge = Dial tone
  - Destination address = Pulse or tone dialing
  - Destination busy = Busy tone
  - Destination Available = Ringing tone
Other Signaling Functions

- Transmission of dialed number between switches
- Transmission of information between switches indicating that a call cannot be completed
- Transmission of billing information
- Transmission of information for diagnosing and isolating failures
- Control of satellite channels
Types of Signaling Functions

- **Supervisory**: To obtain resources to establish/hold/release a connection. Includes information sent back to the subscriber's switch about the status of the call.

- **Address**: Identify destination. Subscriber to switch. Between switches.

- **Call information**: Provide call status to the calling subscriber

- **Network Management**: Operation, troubleshooting, and maintenance of the network. Not directly involved in call establishment/termination.

- Signaling between a subscriber and the network is different (simple) from that inside the network.
In-band signaling ⇒ Signaling over the same channel as payload

Out-of-band signaling ⇒ Separate channels for signaling (but may be same physical circuits)

Common Channel Signaling (CCS)
⇒ Separate circuits for signaling
⇒ Allows several new functions, such as 800

--- Payload --- Signaling
Signaling Modes

- Associated Mode: CCS follows the same path as payload
- Nonassociated Mode: CCS uses a separate network
- T1, DS1, DS3, ...
- T1 Frames consist of 193 bits per 125 µs.
- Echo cancellation is required if sharing the same wire-pair for both directions.
- Optical fiber can be used to replace feeder cable.
- Signaling: In band vs Common Channel, associated vs non-associated.
Homework

- Read chapter 2 and sections 3.1-3.5 of Stallings (ISDN and Broadband ISDN)
- Submit answer to exercise 2.7