Fundamentals of Telecommunications

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Overview

- Single phone conversation: m-Law and A-Law
- Multiplexing: T1 Framing, Signaling, Frame Formats
- Digital TDM Hierarchy
- Echo Cancellation
- Signaling: Functions, modes
Time Division Multiplexing

- Voice signal has a bandwidth of 4 kHz
  (300 Hz to 3300 Hz is transmitted on phone systems)

- Nyquist sampling theorem:
  Sample at twice the highest signal frequency
  ⇒ Sample at 8 kHz ⇒ Sample every 125 µsec

- 256 levels ⇒ 8 bits per sample × 8000 samples/sec
  = 64 kbps
Analog voice to Digital Signal
⇒ Pulse code modulation (PCM)

Difference between actual and transmitted level
⇒ Quantizing noise. More perceptible at low levels.
⇒ Expand the number of levels at low amplitudes
Compress at high amplitudes = Companding
In North America: $\mu$-Law
\[ y = \frac{\ln (1+\mu x)}{\ln (1+\mu)}, \quad \mu = 255 \]

In Europe: A-Law
\[ y = \frac{1+ \ln Ax}{1+ \ln A}, \quad A = 87.6 \]

Linear for small values of $x$ ($x \leq 1/\mu$ or $x \leq 1/A$) and logarithmic for larger values.
Echo Cancellation

Problem: Full duplex transmission over a single pair

Solution 1: FDM for the two directions. ⇒ Only half of the bandwidth for each direction

Solution 2: Use digital signal ⇒ Some part of the signal returns (echo). Near-end and far-end echoes

Echo Cancellation: Reflections from various distances along the path are estimated and subtracted from the received signal ⇒ 144 kbps up to 4 km
300 bps over Single Pair

- 300 bps modems (Bell 108 specification)
- Use frequency shift keying
  - 0 \rightarrow 1070 \text{ Hz}, 1 \rightarrow 1270 \text{ Hz in one direction}
  - 0 \rightarrow 2025 \text{ Hz}, 1 \rightarrow 2225 \text{ Hz in the other direction}
Local Loop

- Distribution network uses a star topology
  ⇒ Hierarchical System: Subscribers are connected to local exchanges (or end offices), which are connected via trunks to other tandem or toll switching centers.

- Feeder cables connect central office to remote nodes. Can be replaced via fiber. May multiplex using TDM or WDM

```
  Central Office  →  Bundles of TP  →  Individual TP
                   |                  |
                   v                  
             Remote Node
```

The Ohio State University

Raj Jain
Multiplexing

- Multiple conversations $\Rightarrow$ Multiple frequency bands
  
  Frequency division multiplexing (FDM)

  Useful for analog signals.

- In 1962, telephone carrier cable between Bell System offices could carry approx 1.5 Mbps over a mile
  
  $= \text{Distance between manholes in large cities}$

  $= \text{Distance between amplifiers}$

- $1500/64 \approx 24$ $\Rightarrow$ Can multiplex approx.
  
  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:
  - Framing bit
  - T1 Frame = 193 bits/125 µs
- Simple Framing: Add 101010 (1 bit per frame)
- Any other sequence ⇒ Resynchronize
T1 Signaling

- On-hook/off-hook or destination address = Signaling
- Initially, manual through operators
  Later through switches
- In T1-frames, initially, the 8th bit of every 6th frame
  in each channel was used for signaling
- 8th bit is not reliable
  ⇒ Use only 7 bits per frame ⇒ 56 kbps
- In the newer PRI (primary rate interface) format used
  with ISDN, the signaling information of 23 channels
  is combined into a separate 24th channel.
  Each user gets full 64 kbps.
## D4 and ESF Frame Formats

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<th>Frame #</th>
<th>193&lt;sup&gt;rd&lt;/sup&gt; bit</th>
<th>Use</th>
<th>193rdbit</th>
<th>Use</th>
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<td>X</td>
<td>FDL</td>
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</table>

### Superframe

- D4 Format superframe = 12 Frames
- ESF format extended superframe = 24 Frames

- FT = Terminal Framing Bit
- FS = Multiframe Alignment
- FDL = Datalink bit (M bit)
- CRC = Cyclic Redundancy Check bit
- X = Data dependent

193 bits
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, ...
European System: E1

- European counter part of American T1
- Designed by Conference of Post and Telecommunications (CEPT)
- 32 bytes per 125 µs frame = 2.048 Mb/s
  - 30 channels are used for data
  - One channel for synchronization
  - One channel for signalling
### Digital TDM Hierarchy

<table>
<thead>
<tr>
<th></th>
<th>North America</th>
<th>Europe</th>
<th>Japan</th>
</tr>
</thead>
<tbody>
<tr>
<td>DS0</td>
<td>64 kbps</td>
<td>64 kbps</td>
<td>64 kbps</td>
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<tr>
<td>DS1</td>
<td>1.544 Mbps</td>
<td>E1 2.048 Mbps</td>
<td>J1 1.544 Mbps</td>
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<tr>
<td>DS2</td>
<td>6.313 Mbps</td>
<td>E2 8.448 Mbps</td>
<td>J2 6.312 Mbps</td>
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<tr>
<td>DS3</td>
<td>44.736 Mbps</td>
<td>E3 34.368 Mbps</td>
<td>J3 32.064 Mbps</td>
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<tr>
<td>DS4</td>
<td>274.176 Mbps</td>
<td>E4 139.264 Mbps</td>
<td>J4 97.728 Mbps</td>
</tr>
<tr>
<td>DS1C</td>
<td>3.152 Mbps</td>
<td>E5 565.148 Mbps</td>
<td>J5 397.200 Mbps</td>
</tr>
</tbody>
</table>
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 Fns

- **Supervisory**: To obtain resources to establish/hold/release a connection.
- **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.
Signaling Channel

- In-band signaling $\Rightarrow$ Signaling over the same channel as payload
- Out-of-band signaling $\Rightarrow$ Separate channels for signaling (but may be same physical circuits)
- Common Channel Signaling (CCS) $\Rightarrow$ Separate circuits for signaling $\Rightarrow$ Allows several new functions, such as 800
Signaling Modes

- Associated Mode: CCS follows the same path as payload
- Nonassociated Mode: CCS uses a separate network
Summary

- 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.
- Signaling: In band vs Common Channel, associated vs non-associated.
Homework

- Read Sections 2.1.2, 6.1.3-6.3.1 of McDyson’s book
- Submit answer to the following:
  What is the percentage of overhead in DS-1 transmission format (percentage of bits that are not user data)?
- Due: Next Week