Multiplexing

- Sharing of high capacity transmission medium between several transmissions
- Various approaches, including FDM & TDM

(a) Frequency-division multiplexing

(b) Time-division multiplexing
1. FDM
- Number of low BW analog signals simultaneously transmitted on high BW link
- Each signal is “shifted” in frequency by modulating a carrier signal
- Shifted signals can be sent simultaneously since they do not overlap in frequency
- At receiver, filters separate “shifted” signals; demodulation recovers signals
- TV, radio are examples of FDM

```
\[ m_1(t) \rightarrow \text{Subcarrier} \ f_{sc1} \rightarrow S_{sc1}(t) \]
\[ m_2(t) \rightarrow \text{Subcarrier} \ f_{sc2} \rightarrow S_{sc2}(t) \]
\[ \vdots \]
\[ m_N(t) \rightarrow \text{Subcarrier} \ f_{scN} \rightarrow S_{scN}(t) \]
\[ \sum m_c(t) \rightarrow \text{Transmitter} \ f_c \rightarrow s(t) \]
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```
\[ M_c(f) \]
\[ f \]
\[ f_{sc1}, f_{sc2}, \ldots, f_{scN} \]
\[ B_{sc1}, B_{sc2}, \ldots, B_{scN} \]

\[ s(t) \rightarrow \text{Receiver} \rightarrow \text{Bandpass filter, } f_{sc1} \rightarrow \text{Demodulator, } f_{sc1} \rightarrow m_1(t) \]
\[ \vdots \]
\[ \text{Bandpass filter, } f_{scN} \rightarrow \text{Demodulator, } f_{scN} \rightarrow m_N(t) \]
```
• Analog Carrier Systems
  – Designed to transmit voiceband signals over high-capacity transmission links, based on FDM
  – A standardized FDM hierarchy

North American and int’l FDM carrier standards
2. Synchronous TDM

- High data rate of digital transmission medium used to simultaneously transmit a number of lower data rate digital signals
- Sources are scanned in round-robin fashion; each source has fixed slot for transmission
- At destination, the received stream is distributed to the corresponding receivers
• Pulse stuffing
  – Used when data rate of sources are not related by a simple rational number.
  – e.g.
  • One source at 8 kbps and another at 7.2 kbps. The slower is “pulse stuffed” with extra dummy pulses to send out on link at same rate. Since 8/7.2 = 10/9, every nine real samples, one dummy bit is sent out for the slower channel. Reverse at receiver: every 10th pulse is thrown away.
• Digital Carrier Systems
  – designed to transmit voice signals over high-capacity transmission links, based on synchronous TDM
  – DS-1: basic frame format of the TDM hierarchy (in North America)

**DS-1 frame format**

![Diagram of DS-1 frame format]

Notes:
1. Bit 193 is a framing bit, used for synchronization.
2. Voice channels:
   - 8-bit PCM used on five of six frames.
   - 7-bit PCM used on every sixth frame. Bit 8 of each channel is a signaling bit.
3. Data channels:
   - Channel 24 used for signaling only in some schemes.

★ Framing bit for frame synchronization and alignment. Every 12 frames form a multiframe. The F bits in the odd numbered frames have the pattern 101010 and are used for frame sync. F bits in the even numbered frames have a pattern of 001110, and are used for multiframe synchronization.

⚠ When T1 system is used for entirely for data, only 23 channels are used for data. The 24th one is used for a special synchronization pattern, to allow faster and more reliable reframing (recovery) following a framing error.
### TDM carrier standards

<table>
<thead>
<tr>
<th>Carrier system</th>
<th>Frame format</th>
<th>Number of voice channels</th>
<th>Data rate (Mbps)</th>
<th>Level number</th>
<th>Number of voice channels</th>
<th>Data rate (Mbps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-1</td>
<td>DS-1</td>
<td>24</td>
<td>1.544</td>
<td>1</td>
<td>30</td>
<td>2.048</td>
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<tr>
<td>T-1C</td>
<td>DS-1C</td>
<td>48</td>
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<td>120</td>
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<td>DS-2</td>
<td>96</td>
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<td>DS-3</td>
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<td>1920</td>
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<td>DS-4</td>
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<td>7680</td>
<td>565.148</td>
</tr>
</tbody>
</table>

### Multiplexing T1 streams onto higher carriers

[Diagram showing multiplexing of T1 streams into higher carriers]
3. Statistical TDM

- With synchronous TDM, channel capacity wasted when sources transmit intermittently (Due to fixed assignment of channel)
- Statistical TDM (also known as asynchronous TDM and intelligent TDM) does not use fixed assignment; a source gets a time slice only if it is active.