Digital Telephone

- Long before computer communication came into being, telephone companies developed digital communication technology.
- Telephone industries have devised complex long distance digital communication technology.
- Most computer communication rides on the digital communication lines provided by the telephone carriers.
- Key Difference: Synchronous Communication:
  - system designed to move data at a precise rate.

Pulse Code Modulation

- Human voice is digitized and sent as a digital signal.
- How many times it should be sampled?
  - Human voice has frequencies up to 4kHz.
  - Nyquist's theorem suggest that for accurate reproduction it must be sampled two times faster at a rate of 8000 times per second or precisely once in every 125 microsecond.
  - Each sample is sampled at 0-255 levels.
  - A voice channel requires to carry 8x8000 = 64Kbps data.

Digital Circuit & CSU/DSU

- To send computer data over telephone line, the asynchronous data must be converted into the right synchronous telephone standards.
- Data service Unit/Channel Service Unit:
  - CSU handles line diagnostics, termination, control current surge, lightening, etc.
  - It prevent too many 1's!
  - DSU handles the computer side. It can use RS-232 (for less than 56K rate) or some other standard.

DS Telephone Standards

<table>
<thead>
<tr>
<th>Name</th>
<th>Bit Rate (Mbps)</th>
<th>Voice Circuits</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>1.5440</td>
<td>24</td>
<td>North America</td>
</tr>
<tr>
<td>T2</td>
<td>2.0480</td>
<td>30</td>
<td>North America</td>
</tr>
<tr>
<td>E1</td>
<td>2.0480</td>
<td>30</td>
<td>Europe</td>
</tr>
<tr>
<td>E2</td>
<td>2.0480</td>
<td>420</td>
<td>Europe</td>
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<tr>
<td>E3</td>
<td>3.0560</td>
<td>480</td>
<td>Europe</td>
</tr>
</tbody>
</table>

- These are sometime called DS levels. DS refers to Digital Signal Level Standard. T defines the multiplexing mechanism.
Capacity Adjustments

- **Fractional Capacity**
  - Available at rates such as 64Kbps, 128Kbps, 9.6Kbps, 4.8Kbps, etc.
  - These are Time Division Multiplexed on T1.
- **Intermediate Capacity**
  - What if you need 2 T1?
  - Inverse Multiplexer
  - Separate CSU/DSU are required for each line.

Highest Capacity Circuits

<table>
<thead>
<tr>
<th>Standard Name</th>
<th>Optical name</th>
<th>Bit Rate</th>
<th>Voice Circuits</th>
</tr>
</thead>
<tbody>
<tr>
<td>STS-1</td>
<td>OC-1</td>
<td>51.840</td>
<td>810</td>
</tr>
<tr>
<td>STS-3</td>
<td>OC-3</td>
<td>155.520</td>
<td>2430</td>
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<tr>
<td>STS-12</td>
<td>OC-12</td>
<td>622.080</td>
<td>9720</td>
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<td>OC-24</td>
<td>1244.160</td>
<td>19440</td>
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<td>STS-48</td>
<td>OC-48</td>
<td>2488.320</td>
<td>38880</td>
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<tr>
<td>STS-192</td>
<td>OC-192</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Synchronous Transport Protocols (STPs) represent trunk circuits.
- OC is a special version of the standards for fibers.
- OC-3C means single fiber 155 Mbps while OC-3 may require three fibers.

SONET

- **Synchronous Optical Network frames carry these data.**
- The frame size is circuit dependent:
  - STS-1 contains 810 8-bit octates.
  - STS-3 holds 2430 8-bit octates.

- One Frame must be sent in every 125 microsecond.
  - At STS-1 rate, 51.840 Mbps, exactly 6480 bits = 810 octates need to be carried in 125 microsecond.

- Synchronous multiplexing
  - multiplexing without introducing delay.
- SONET is used for Point-to-Point data comm. But it can be used in other ways as well, such as in FDDI ring.

Local Subscribers Line

- Leased lines provides the ability to send data across long distance.
- But, before Internet can be ubiquitous the problem of reaching every house hold have to be solved.
- **Local Loop**;
  - the last mile or a local subscribers carrier line connecting the phone company central office (CO) with the subscriber’s place of business.
- Despite the dial-up modems, progress, the need of bandwidth has grown even faster.
- The voice bandwidth and signal-to-noise ratio dictates the ultimate limit of simple modems.

ISDN

- **Integrated Service Digital Line**
  - One of the first effort to provide large scale digital service.
  - Uses the same twisted-pair copper wire as telephones, no need to special wiring or equipment.
  - Bandwidth 64+64+16+16 = 144 Kbps + (16 signaling).
  - The two Bs can be combined into one
  - Uses TDM over single pair of wire.
- ISDN is an old technology and faces extinction from improved modems and other technologies.
Asymmetric Digital Subscribers Line (ADSL)

- It has more download and smaller upload bandwidth.
  - 6.144 Mbps Down + 576 Kbps Up + 64 Kbps (control Up)
- It keeps the telephone as well.

Other xDSLs

- Symmetric DSL (SDSL)
  - Inverse ADSL is not easy to find so best choice for server farms.
  - Uses a somewhat different encoding technology.
- High rates DSL (HDSL)
  - 1.544 Mbps both directions.
  - Does it by restricting to shorter distances.
  - Requires two pairs of twisted pairs.
  - A one pair variant is HDSL2.
  - It can survive bridge-tap.
- Very High DSL (VDSL)
  - 52 Mbps
  - Requires special concentrator devices to be inserted in between.
  - ADSL G.LITE
    - ITU standard for 1.5 Mbps/512Kbps (December 1999)

How ADSL Works

- Telephone lines are not designed for such high data rate!
- It does everything to evade interference.
  - Combines FDM an Inverse Multiplexing known as Discrete Multi-tone Modulation (DMT).
  - Divides the bandwidth into 286 sub-channels
  - Conceptually a separate modem runs on each of them.
  - Carriers are spaced 4.1325 KHz apart to avoid cross-channel interference.
  - It also does not use frequency from 0-400Hz. To avoid voice.
  - Each modem also tracks the error rate and adjusts the modulation scheme (quantization levels etc) dynamically with the noise in the sub-channels.
  - Does not guarantee a capacity, but is the best effort depending on the cable quality and local interference.
  - Effective rate varies in 32Kbps-6.4mbps DN/32-640 Kbps UP

Cable Modem

- A coax is better carrier than twisted pair.
- CATV available at 80% residential units in USA.
  - Currently 1-450 MHz band is in use can take up to 1 GHz
  - Divided into 6MHz television sub-channels.
  - Amplifies signal in the neighborhood.
  - A very good download broadcast media with high unused capacity.
- Limitations:
  - The FDM does not scale.
  - Capacity is divided by customers.
  - Unidirectional architecture
    - no upstream channel
    - amplifiers in between are unidirectional too.
- Basic Cable Modems use Telephone for upstream traffic
  - Can offer up to 3-10 Mbps download speed

Alternatives

- Satellite
  - Uses Satellite for Downlink and telephone for uplink
- Cellular Like Wireless

Hybrid Fiber Coax (HFC)

- HFC uses a hybrid cable with fiber and coax
  - Fiber carries main data while coax carries individual subscribers data.
  - WiFi requires massive reworking
  - new fiber-coax interface equipment, bi-directional amplifiers
- How it works
  - uses combination of TDM and FDM
  - 1-50 MHz up, 40-450 MHz down (6MHz channels), 450-750 MHz down digital communication.
  - TDM groups customers according to neighborhood.
  - Asymmetric to customers like ADSL.
  - 3-10 Mbps/128 Kbps-10 Mbps upload
<table>
<thead>
<tr>
<th>Company</th>
<th>Type</th>
<th>Pipe Size</th>
<th>Monthly Price</th>
<th>Size</th>
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<tbody>
<tr>
<td>AT&amp;T</td>
<td>DSL</td>
<td>25</td>
<td>$45.95</td>
<td>1.99</td>
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**Source:** PC Magazine, April 1999