Synchronous Optical Networks
SONET
Telephone Networks
{Brief History}

- Digital carrier systems
  - The hierarchy of digital signals that the telephone network uses.
  - Trunks and access links organized in DS (digital signal) hierarchy
  - Problem: rates are not multiples of each other.
- In the 1980’s Bellcore developed the Synchronous Optical Network (SONET) standard.
- Previous efforts include: ISDN and BISDN.
North American Digital Hierarchy

- **Primary Multiplex**
  - Eg. Digital Switch
  - 24 chan PCM

- M12 Multiplex
  - DS1 1.544 Mbps
  - M13 Multiplex
  - x4

- **DS2 6.312 Mbps**

- M23 Multiplex
  - DS3 44.736 Mbps

- **DS3 44.736 Mbps**

European Digital Hierarchy

- **Primary Multiplex**
  - Eg. Digital Switch
  - 30 chan PCM

- CEPT 1 2.048 Mbps

- **2nd order Multiplex**
  - x4

- **3rd order Multiplex**
  - 8.448 Mbps
  - x4

- **4th order Multiplex**
  - 34.368 Mbps
  - x4

- CEPT 4 139.264 Mbps

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Figure 4.5
4.2

SONET sources are synchronized to a common master clock. Different streams are multiplexed by byte interleaving.

4.3

The STS-n signal has a rate equal to n × 51.84 Mbps. In Europe the hierarchy starts at 155.52 Mbps. All the standards become compatible at speeds of 155 Mbps.
SONET

SONET:: encodes bit streams into optical signals propagated over optical fiber. SONET defines a technology for carrying many signals of different capacities through a synchronous, flexible, optical hierarchy.

- A bit-way implementation providing end-to-end transport of bit streams.
- All clocks in the network are locked to a common master clock so that simple TDM can be used.
- Multiplexing done by byte interleaving.
- SONET is backward compatible to DS-1 and E-1 and forward compatible to ATM cells.
- Demultiplexing is easy.
SONET

- Transmission links of the telephone network have been changing to **SONET** where rates are arranged in **STS** (Synchronous Transfer Signal) hierarchy.
- The hierarchy is called **SDH** (Synchronous Digital Hierarchy) defined by CCITT.
- It is an ITU standard.
<table>
<thead>
<tr>
<th>Medium</th>
<th>Signal</th>
<th>Voice circuits</th>
<th>North America</th>
<th>Japan</th>
<th>Europe</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-1 paired cable</td>
<td>DS-1</td>
<td>24</td>
<td>1.5</td>
<td>1.5</td>
<td>2.0</td>
</tr>
<tr>
<td>T-1C paired cable</td>
<td>DS-1C</td>
<td>48</td>
<td>3.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T-2 paired cable</td>
<td>DS-2</td>
<td>96</td>
<td>6.3</td>
<td>6.3</td>
<td>8.4</td>
</tr>
<tr>
<td>T-3 coax, radio, fiber</td>
<td>DS-3</td>
<td>672</td>
<td>45.0</td>
<td>34.0</td>
<td>32.0</td>
</tr>
<tr>
<td>Coax, waveguide, radio, fiber</td>
<td>DS-4</td>
<td>4032</td>
<td>274.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1.2 **TABLE**

Digital carrier systems. This is the hierarchy of digital signals that the telephone network uses. Note that the bit rate of a DS-1 signal is greater than 24 times the rate of a voice signal (64 Kbps) because of the additional framing bits required.

<table>
<thead>
<tr>
<th>Carrier</th>
<th>Signal</th>
<th>Rate in Mbps</th>
</tr>
</thead>
<tbody>
<tr>
<td>OC-1</td>
<td>STS-1</td>
<td>51.840</td>
</tr>
<tr>
<td>OC-3</td>
<td>STS-3</td>
<td>155.520</td>
</tr>
<tr>
<td>OC-9</td>
<td>STS-9</td>
<td>466.560</td>
</tr>
<tr>
<td>OC-12</td>
<td>STS-12</td>
<td>622.080</td>
</tr>
<tr>
<td>OC-18</td>
<td>STS-18</td>
<td>933.120</td>
</tr>
<tr>
<td>OC-24</td>
<td>STS-24</td>
<td>1244.160</td>
</tr>
<tr>
<td>OC-36</td>
<td>STS-36</td>
<td>1866.240</td>
</tr>
<tr>
<td>OC-48</td>
<td>STS-48</td>
<td>2488.320</td>
</tr>
</tbody>
</table>

1.3 **TABLE**

SONET rates. The rates of multiplexed STS-1 signals are exact multiples; no additional framing bits are used.
**Figure 2-37. SONET and SDH Multiplex Rates**

<table>
<thead>
<tr>
<th>Electrical</th>
<th>Optical</th>
<th>Optical</th>
<th>Gross</th>
<th>SPE</th>
<th>User</th>
</tr>
</thead>
<tbody>
<tr>
<td>STS-1</td>
<td>OC-1</td>
<td>STM-1</td>
<td>51.84</td>
<td>50.112</td>
<td>49.536</td>
</tr>
<tr>
<td>STS-3</td>
<td>OC-3</td>
<td>STM-3</td>
<td>155.52</td>
<td>150.336</td>
<td>148.608</td>
</tr>
<tr>
<td>STS-9</td>
<td>OC-9</td>
<td>STM-3</td>
<td>466.56</td>
<td>451.008</td>
<td>445.824</td>
</tr>
<tr>
<td>STS-12</td>
<td>OC-12</td>
<td>STM-4</td>
<td>622.08</td>
<td>601.344</td>
<td>594.432</td>
</tr>
<tr>
<td>STS-18</td>
<td>OC-18</td>
<td>STM-6</td>
<td>933.12</td>
<td>902.016</td>
<td>891.648</td>
</tr>
<tr>
<td>STS-24</td>
<td>OC-24</td>
<td>STM-8</td>
<td>1244.16</td>
<td>1202.688</td>
<td>1188.864</td>
</tr>
<tr>
<td>STS-36</td>
<td>OC-36</td>
<td>STM-12</td>
<td>1866.24</td>
<td>1804.032</td>
<td>1783.296</td>
</tr>
<tr>
<td>STS-48</td>
<td>OC-48</td>
<td>STM-16</td>
<td>2488.32</td>
<td>2405.376</td>
<td>2377.728</td>
</tr>
<tr>
<td>STS-192</td>
<td>OC-192</td>
<td>STM-64</td>
<td>9953.28</td>
<td>9621.504</td>
<td>9510.912</td>
</tr>
</tbody>
</table>

Networks: SONET
Synchronous Multiplexing in SONET

Incoming STS-1 Frames  

Map  

Map  

Map  

Map

STS-1  STS-1  

STS-1  STS-1  

STS-1  STS-1

Synchronized New STS-1 Frames

Byte Interleave

STS-1  STS-1  

STS-1  STS-1  

STS-1  STS-1

STS-3

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Figure 4.17
**INTERLEAVING**

**STS-1** signals are **BYTE INTERLEAVED** to create a **STS-N** signal by combining each byte in the various data streams in a way such that each byte is in a uniquely specified location facilitating demultiplexing.

**FIRST ALIGN STS-1 FRAMES**
- Next byte interleave to form STS-N signal
- The transport overhead is now 3 x N
- The SPE (synchronous payload envelope - "data") is now N x 87 columns
- Byte sequence is row 1 column 1 to row 9 column 90
SONET Architecture

• **SONET** topology can be a mesh, but most often it is a dual ring.

• Standard component of **SONET ring** is an **ADM** (Add/Drop Multiplexer)
  – Drop one incoming multiplexed stream and replace it with another stream.
  – Used to make up bi-directional line switching rings.
(a) Dual ring  (b) Loop-around in response to fault
TWO FIBER
BI-DIRECTIONAL
LINE SWITCHING RING

SONET Ring

Networks: SONET
Figure 4.9

(a) pre-SONET multiplexing

(b) SONET Add-Drop multiplexing
SONET Ring

Regional Ring

Metro Ring

Inter-Office Rings

Networks: SONET
Gigabit ATM Applications Over 10 Gb/s SONET Ring

Washington U. St Louis 1995
SONET Architecture

STE: Section Terminating Equipment, e.g. a repeater
LTE: Line Terminating Equipment, e.g. a STS-1 to STS-3 multiplexer
PTE: Path Terminating Equipment, e.g. an STS-1 multiplexer

(b)
The main SONET network elements.

**SONET Architecture**
Mux

= BIM (Byte Interleaved Multiplexer)

Reg

= Regenerator

• Boosts power of optical signal
  • Optical signal is converted to electrical signal.
  • Amplify electrical signal.
  • Amplified electrical signal converted back to optical signal.
- **Service Adapters** map various services (voice, data, video...) into the payload envelope of virtual tributaries or STS-1.

- STS-1 signals are multiplexed into STS-N (byte interleave synchronous multiplexer)
MULTIPLEXING LOWER THAN STS-1 DATA RATES INTO BASIC SONET STS-1

- VIRTUAL TRIBUTARY (VT) DEFINED FOR Sub-STS-1 SIGNALS
- GIVEN EACH SPE-1 COLUMN HAS CAPACITY OF 9 rows x 8 bits x 8000 SPE/sec = .576 Mb/s
- VT-6 TRIBUTARY REQUIRES 6.912 / .576 = 12 COLUMNS

<table>
<thead>
<tr>
<th>SONET HEIRARCHY</th>
<th>Digital Signals</th>
<th>SPE frame columns</th>
</tr>
</thead>
<tbody>
<tr>
<td>28 X DS1</td>
<td>DS3 (44.736 Mb/s)</td>
<td></td>
</tr>
<tr>
<td>VT-6 (6.912 Mb/s)</td>
<td>DS2 (6.312 Mb/s)</td>
<td>12</td>
</tr>
<tr>
<td>VT-3 (3.456 Mb/s)</td>
<td>DS1C (3.152 Mb/s)</td>
<td>6</td>
</tr>
<tr>
<td>VT-2 (2.304 Mb/s)</td>
<td>CEPT-1 (2.048 Mb/s)</td>
<td>4</td>
</tr>
<tr>
<td>VT-1.5 (1.728 Mb/s)</td>
<td>DS1 (1.544 Mb/s)</td>
<td>3</td>
</tr>
<tr>
<td>24 TDM/PCM CHANNEL</td>
<td>T1 (1.544 Mb/s)</td>
<td></td>
</tr>
<tr>
<td>1 TDM/PCM CHANNEL</td>
<td>DS0 (64 Kb/s)</td>
<td></td>
</tr>
</tbody>
</table>

- VIRTUAL TRIBUTARY GROUPS ARE DEFINED TO CONTAIN COMBINATIONS OF VARIOUS VTs SUCH THAT THE TOTAL IS 12 COLUMNS.
  1 X VT-6   = 12
  2 X VT-3   = 12
  3 X VT-2   = 12
  4 X VT-1.5 = 12

- SEVEN (87/12 col/VT-12) ARE MAPPED INTO 1 STE-1 WITH 1 COLUMN LEFT FOR PATH OVERHEAD AND 2 COLUMNS ARE STUFFED.
SONET Frame

- **Section Overhead**: 3 rows
- **Line Overhead**: 6 rows
- **Transport overhead**: 9 rows

**90 bytes**

**125 µs**

**SPE** Synchronous Payload Envelope

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Figure 2-36. Two Back-to-Back SONET Frames
SPE straddling SONET Frame

Figure 4.16

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ATM Cells in an STS-3 Frame

An STS-3 frame accommodates 44 ATM cells. No framing bits are provided to delimit the cell boundary.