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

Monthly Multiplex
Eg. Digital Switch
24 chan PCM

\[ \text{DS1} 1.544 \text{ Mbps} \]

\[ \text{M12 Multiplex} \]
\[ x4 \]

\[ \text{DS2} 6.312 \text{ Mbps} \]

\[ \text{M23 Multiplex} \]
\[ x7 \]

\[ \text{DS3} 44.736 \text{ Mbps} \]

Primary Multiplex
CEPT 1
2.048 Mbps

\[ \text{2nd order Multiplex} \]
\[ x4 \]

\[ 8.448 \text{ Mbps} \]

\[ \text{3rd order Multiplex} \]
\[ x4 \]

\[ 34.368 \text{ Mbps} \]

\[ \text{4th order Multiplex} \]
\[ x4 \]

\[ 139.264 \text{ Mbps} \]

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Figure 4.5
4.2 Figure

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

4.3 Figure

The STS-n signal has a rate equal to n x 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>

**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>

**SONET rates.** The rates of multiplexed STS-1 signals are exact multiples; no additional framing bits are used.
<table>
<thead>
<tr>
<th></th>
<th>SONET</th>
<th>SDH</th>
<th>Data rate (Mbps)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Electrical</td>
<td>Optical</td>
<td>Optical</td>
</tr>
<tr>
<td>STS-1</td>
<td>OC-1</td>
<td>STM-1</td>
<td></td>
</tr>
<tr>
<td>STS-3</td>
<td>OC-3</td>
<td>STM-3</td>
<td></td>
</tr>
<tr>
<td>STS-9</td>
<td>OC-9</td>
<td>STM-3</td>
<td></td>
</tr>
<tr>
<td>STS-12</td>
<td>OC-12</td>
<td>STM-4</td>
<td></td>
</tr>
<tr>
<td>STS-18</td>
<td>OC-18</td>
<td>STM-6</td>
<td></td>
</tr>
<tr>
<td>STS-24</td>
<td>OC-24</td>
<td>STM-8</td>
<td></td>
</tr>
<tr>
<td>STS-36</td>
<td>OC-36</td>
<td>STM-12</td>
<td></td>
</tr>
<tr>
<td>STS-48</td>
<td>OC-48</td>
<td>STM-16</td>
<td></td>
</tr>
<tr>
<td>STS-192</td>
<td>OC-192</td>
<td>STM-64</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 2-37. SONET and SDH Multiplex Rates**

Networks: SONET
Synchronous Multiplexing in SONET

Incoming STS-1 Frames

Synchronized New STS-1 Frames

STS-1  STS-1

Map

STS-1  STS-1

Map

STS-1  STS-1

Map

STS-1  STS-1

Byte Interleave

STS-3
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 ENVELOP · “DATA”) IS NOW N X 87 COLUMNS
- BYTE SEQUENCE IS ROW 1 COLUMN 1 TO ROW 9 COLUMN 90

![Diagram showing byte interleaving process](image-url)
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.
SONET Ring

(a) Dual ring

(b) Loop-around in response to fault
TWO FIBER
BI-DIRECTIONAL
LINE SWITCHING RING

SONET Ring

Networks: SONET
(a) pre-SONET multiplexing

(b) SONET Add-Drop multiplexing

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Figure 4.9
SONET Ring

Regional Ring

Metro Ring

Inter-Office Rings

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SONET Architecture

(a) 

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) 

Networks: SONET

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SONET Architecture

Networks: SONET

The main SONET network elements.

SONET Architecture
Mux = BIM (Byte Interleaved Multiplexer)

Reg = Regenerator

- Boosts power of optical signal
  - Optical signal *converted to* electrical signal.
  - Amplify electrical signal.
  - Amplified electrical signal *converted back to* optical signal.
- **SERVICE ADAPTORS 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 HIERARCHY</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

90 bytes

B B B 87B

3 rows

Information Payload

6 rows

Transport overhead

SPE  Synchronous Payload Envelope

9 Rows

125 µs

Section Overhead

Line Overhead

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Figure 4.15
Figure 2-36. Two Back-to-Back SONET Frames
SPE straddling SONET Frame

frame \( k \)

Pointer

87 columns

Synchronous Payload Envelope

pointer

frame \( k+1 \)

first octet

last octet

first column is path overhead

Networks: SONET
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.