Synchronous Optical Networks (SONET)
SONET Outline

- Brief History
- SONET Overview
- SONET Rates
- SONET Ring Architecture
  - Add/Drop Multiplexor (ADM)
  - Section, Line and Path
  - Virtual Tributaries
  - Synchronous Payload Envelope (SPE)
- Connection to ATM
• 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**
- x4

**M23 Multiplex**
- x7

**European Digital Hierarchy**

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

**2nd order Multiplex**
- x4

**3rd order Multiplex**
- x4

**4th order Multiplex**
- x4

**CEPT 1**
- 2.048 Mbps

**CEPT 2**
- 8.448 Mbps

**CEPT 3**
- 34.368 Mbps

**CEPT 4**
- 139.264 Mbps

Leon-Garcia & Widjaja: *Communication Networks*
SONET sources are synchronized to a common master clock. Different streams are multiplexed by byte interleaving.

The STS-n signal has a rate equal to $n \times 51.84$ Mbps. In Europe the hierarchy starts at 155.52 Mbps. All the standards become compatible at speeds of 155 Mbps.
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 1.2

**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>Medium</th>
<th>Signal</th>
<th>Voice circuits</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-1 paired cable</td>
<td>DS-1</td>
<td>24</td>
</tr>
<tr>
<td>T-1C paired cable</td>
<td>DS-1C</td>
<td>48</td>
</tr>
<tr>
<td>T-2 paired cable</td>
<td>DS-2</td>
<td>96</td>
</tr>
<tr>
<td>T-3 coax, radio, fiber</td>
<td>DS-3</td>
<td>672</td>
</tr>
<tr>
<td>Coax, waveguide, radio, fiber</td>
<td>DS-4</td>
<td>4032</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Medium</th>
<th>Signal</th>
<th>Voice circuits</th>
</tr>
</thead>
<tbody>
<tr>
<td>North America</td>
<td>Japan</td>
<td>Europe</td>
</tr>
<tr>
<td>1.5</td>
<td>1.5</td>
<td>2.0</td>
</tr>
<tr>
<td>3.1</td>
<td>6.3</td>
<td>8.4</td>
</tr>
<tr>
<td>6.3</td>
<td>34.0</td>
<td>32.0</td>
</tr>
<tr>
<td>45.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>274.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 1.3

**SONET rates.** The rates of multiplexed STS-1 signals are exact multiples; no additional framing bits are used.

<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

<table>
<thead>
<tr>
<th>SONET</th>
<th>SDH</th>
<th>Data rate (Mbps)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Gross</td>
</tr>
<tr>
<td>Electrical</td>
<td>Optical</td>
<td>Optical</td>
</tr>
<tr>
<td>STS-1</td>
<td>OC-1</td>
<td>Optical</td>
</tr>
<tr>
<td>STS-3</td>
<td>OC-3</td>
<td>STM-1</td>
</tr>
<tr>
<td>STS-9</td>
<td>OC-9</td>
<td>STM-3</td>
</tr>
<tr>
<td>STS-12</td>
<td>OC-12</td>
<td>STM-4</td>
</tr>
<tr>
<td>STS-18</td>
<td>OC-18</td>
<td>STM-6</td>
</tr>
<tr>
<td>STS-24</td>
<td>OC-24</td>
<td>STM-8</td>
</tr>
<tr>
<td>STS-36</td>
<td>OC-36</td>
<td>STM-12</td>
</tr>
<tr>
<td>STS-48</td>
<td>OC-48</td>
<td>STM-16</td>
</tr>
<tr>
<td>STS-192</td>
<td>OC-192</td>
<td>STM-64</td>
</tr>
</tbody>
</table>

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

Low-Speed Mapping Function

Medium-Speed Mapping Function

High-Speed Mapping Function

DS1
DS2
CEPT-1
DS3
CEPT-4
ATM

51.84 Mbps

Medium-Speed Mapping Function

High-Speed Mapping Function

SONET Multiplexing

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SONET Synchronous Multiplexing

Map

Map

Map

Incoming STS-1 Frames

Synchronized New STS-1 Frames

Byte Interleave

STS-3
ST3-1 SIGNALS ARE \textit{BYTE INTERLEAVED} TO CREATE A \textit{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
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
SONET Ring

Changed from FDDI
(a) pre-SONET multiplexing

MUX → DEMUX → MUX → DEMUX

remove tributary → insert tributary

(b) SONET Add-Drop multiplexing

MUX → ADM → DEMUX

remove tributary → insert tributary

Leon-Garcia & Widjaja: Communication Networks
Gigabit ATM Over 10 Gb/s SONET Ring

Washington U. St Louis 1995
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) Leon-Garcia & Widjaja: Communication Networks
The main SONET elements
BIM = 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 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).
SONET Frame

Info: Payload

90 bytes

9 Rows

125 µs

Section Overhead

3 rows

Line Overhead

6 rows

Transport overhead

B  B  B

87B

Information Payload

SPE  Synchronous Payload Envelope

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

- Frame $k$
- Frame $k+1$

First column is path overhead

First octet

87 columns

9 rows

Synchronous Payload Envelope

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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.

ATM Cell Format

<table>
<thead>
<tr>
<th>Header</th>
<th>Payload</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 Bytes</td>
<td>48 Bytes</td>
</tr>
</tbody>
</table>
SONET Summary

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