SONET

CME 451

Introduction

- Synchronous optical network (SONET).
  - ANSI in 1980s
  - European and Japanese: synchronous digital hierarchy (SDH).
- Based on time-domain multiplexing (TDM)
- Specifications: bit rates, frame formats
- OAM&P: Operations, administration, maintenance and provisioning
  - Fast restoration time, within 50 ms.
- Layer 1 Networking Protocol
  - on top of Layer 0, e.g., WDM (invisible to SONET).

Introduction

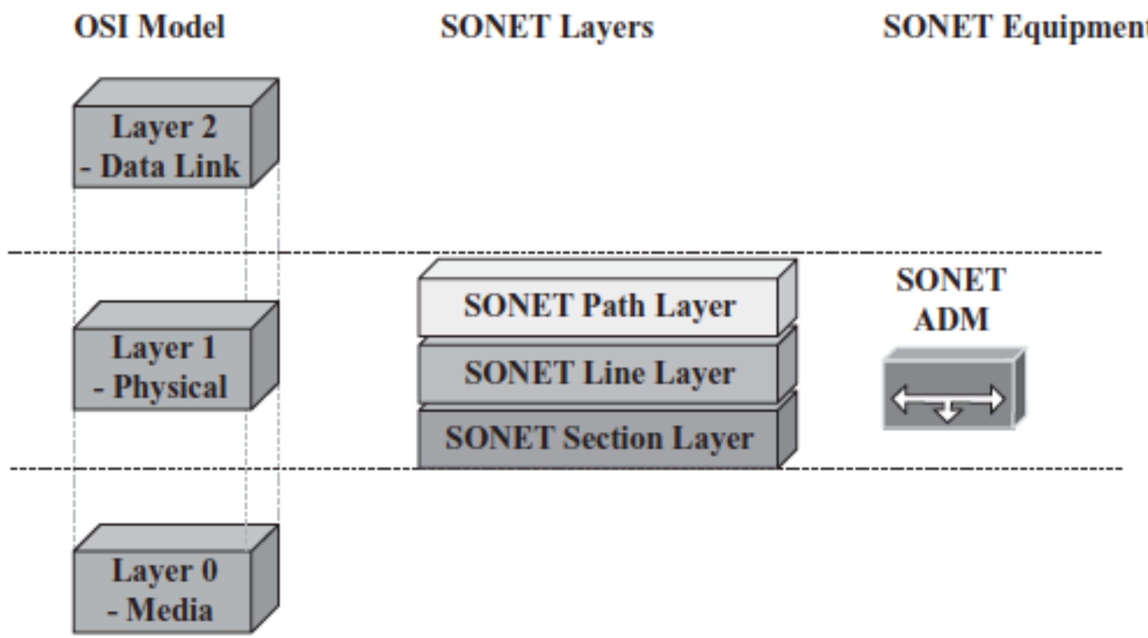


FIGURE 4.1 OSI model, SONET Layers, and examples of networking equipment.

SONET Rates

- Optical or electrical line signals
  - Synchronous transport signal (STS):
    - Electrical, shorter distances over copper wires.
  - Optical carrier (OC):
    - Longer distances, optical fibers

TABLE 4.1 SONET and SDH Bandwidth Rates

Bandwidth	SONET	SDH	Optical Carrier	Number of Voice Channels
51.84 Mb/s	STS-1	—	OC-1	672
155.52 Mb/s	STS-3	STM-1	OC-3	2,016
622.08 Mb/s	STS-12	STM-4	OC-12	8,064
2.488 Gb/s	STS-48	STM-16	OC-48	32,256
9.953 Gb/s	STS-192	STM-64	OC-192	129,024
39.813 Gb/s	STS-768	STM-256	OC-768	516,096

SONET Network Architectures

- Add-drop multiplexer (ADM) as SONET workhorse
  - most versatile equipment
  - Creating SONET rings and point-to-point connections

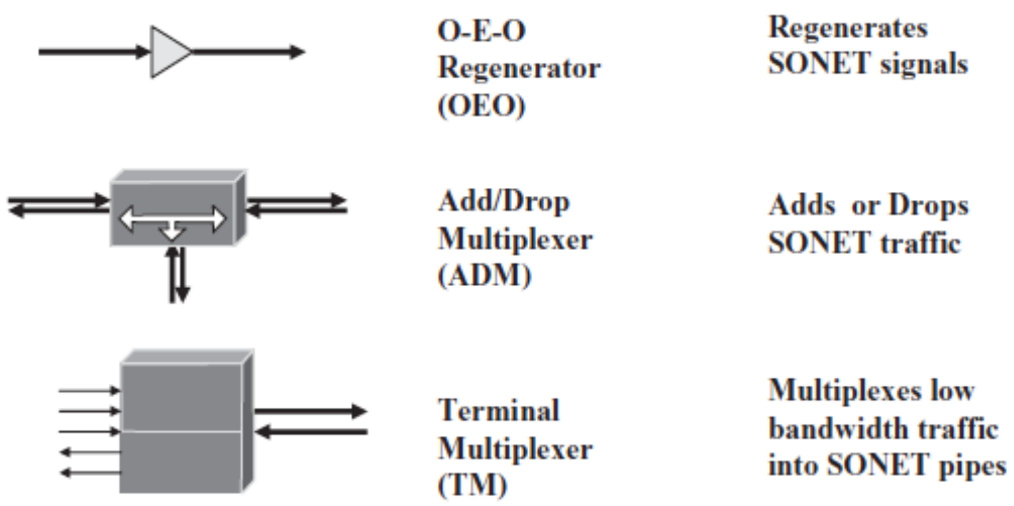


FIGURE 4.2 SONET networking equipment.

SONET Networks

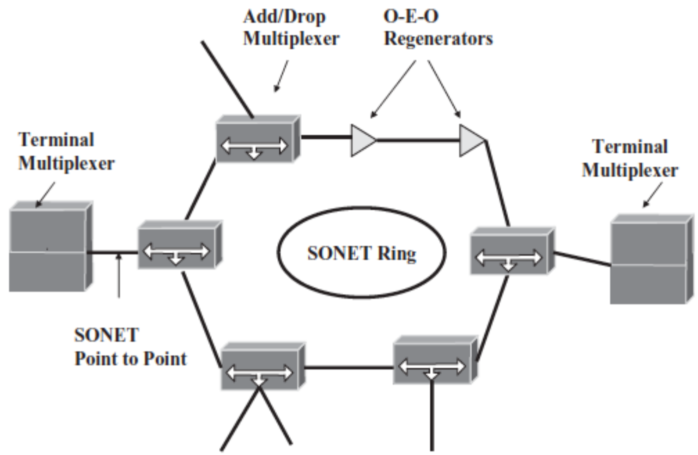


FIGURE 4.3 SONET transport network.

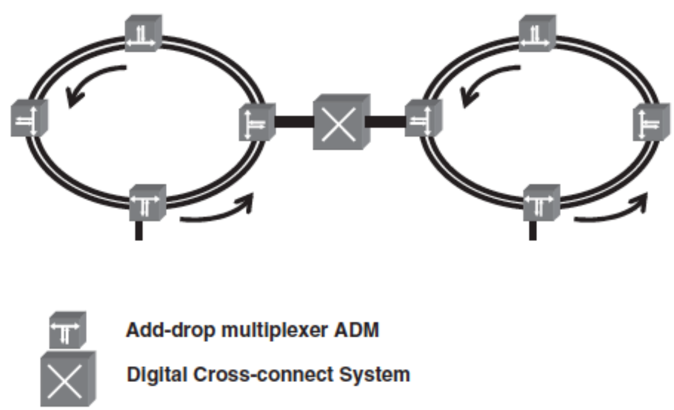


FIGURE 4.4 SONET digital cross-connect connecting two ADM rings.

SONET Networks

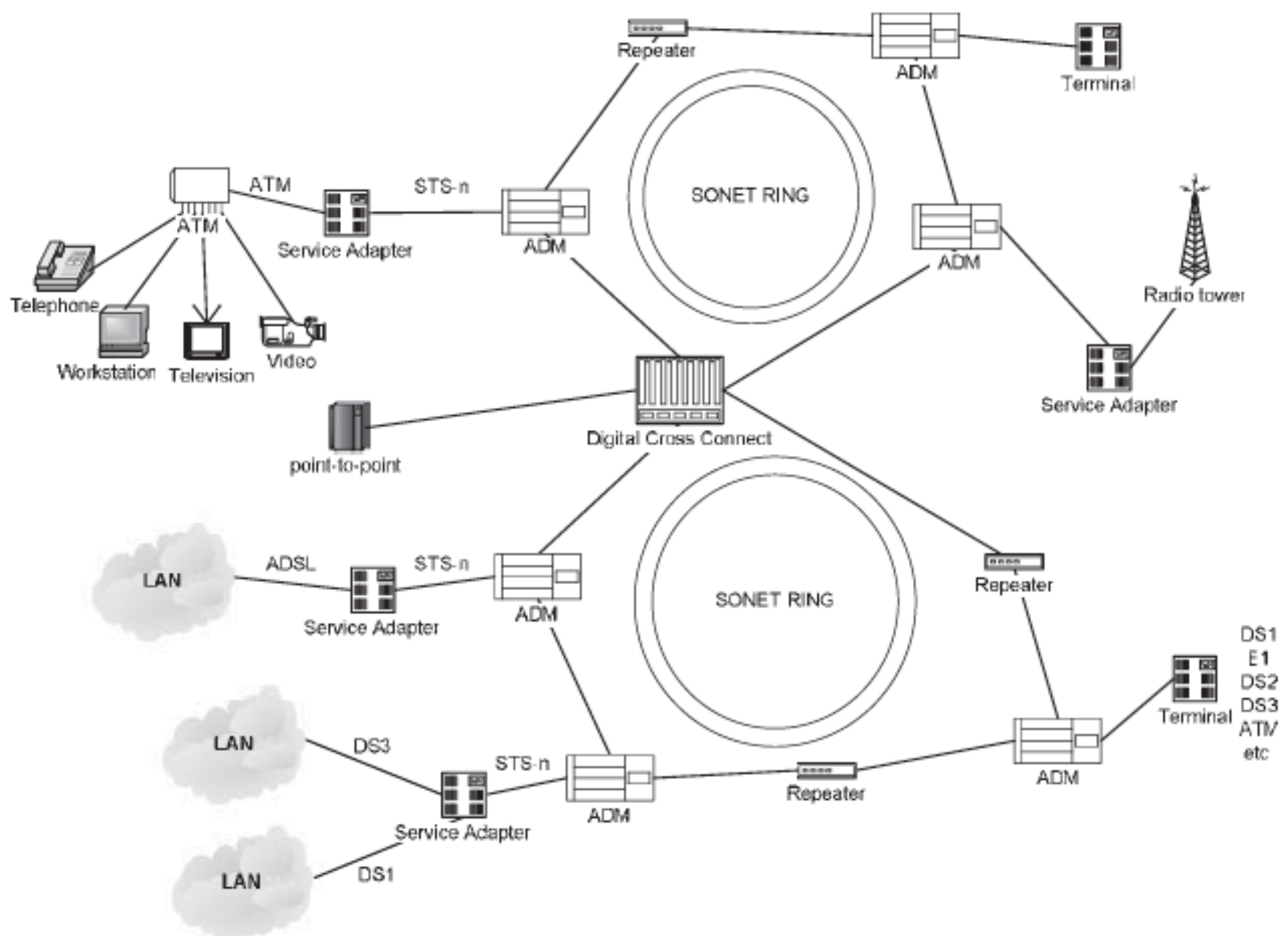


FIGURE 4.5 Example of a SONET network.

SONET Networks

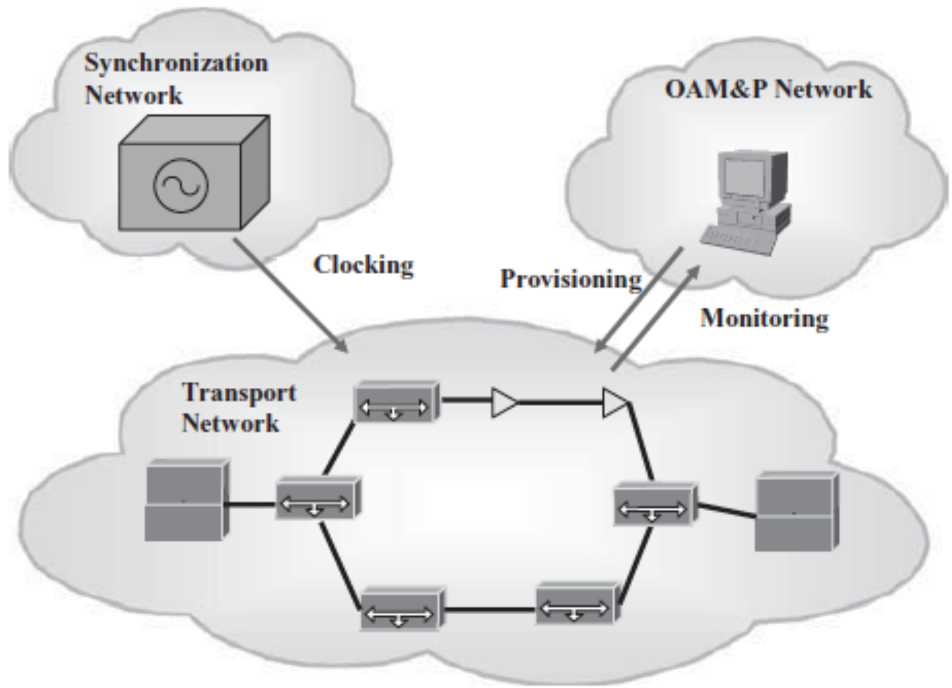


FIGURE 4.6 SONET network overview.

SONET Terminology

- section << line << path

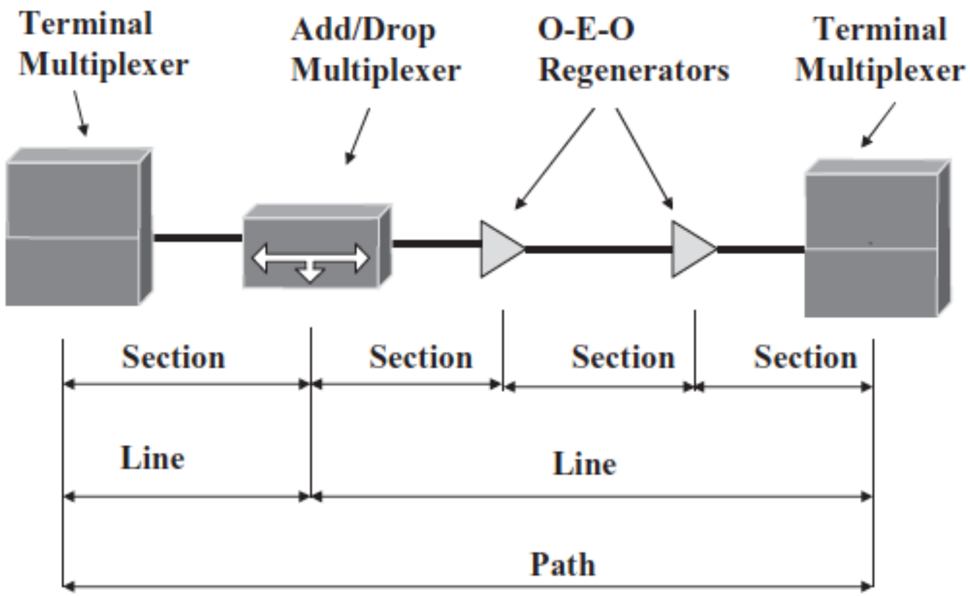
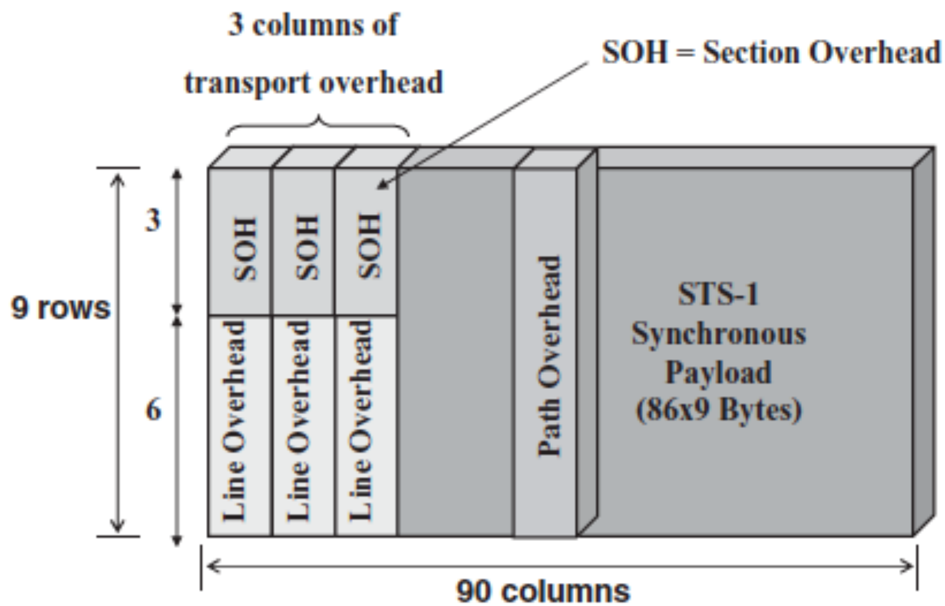


FIGURE 4.7 SONET network segment terminology.

SONET Framing

- Byte-interleaved multiplexing scheme
  - Simplifies multiplexing
  - End-to-end network management
- STS-1: building block for STS-N family
  - 51.84 Mb/s (see Table 4.1)
  - Frame length = 125 us (8000 frames per sec)
  - Visualized as row-column format
    - Transmission order: row by row, top to bottom, left to right.
  - Two main areas:
    - transport overhead: info for transporting;
    - synchronous payload: actual data.

STS-1 Frame



STS-1 = 90 Bytes x 9 = 810 Bytes = 6,480 bits
6,480 bits x 8 kHz = 51.84 Mb/s

FIGURE 4.8 STS-1 frame format.

SONET Framing

- A1 & A2 for frame boundary and frame error detection

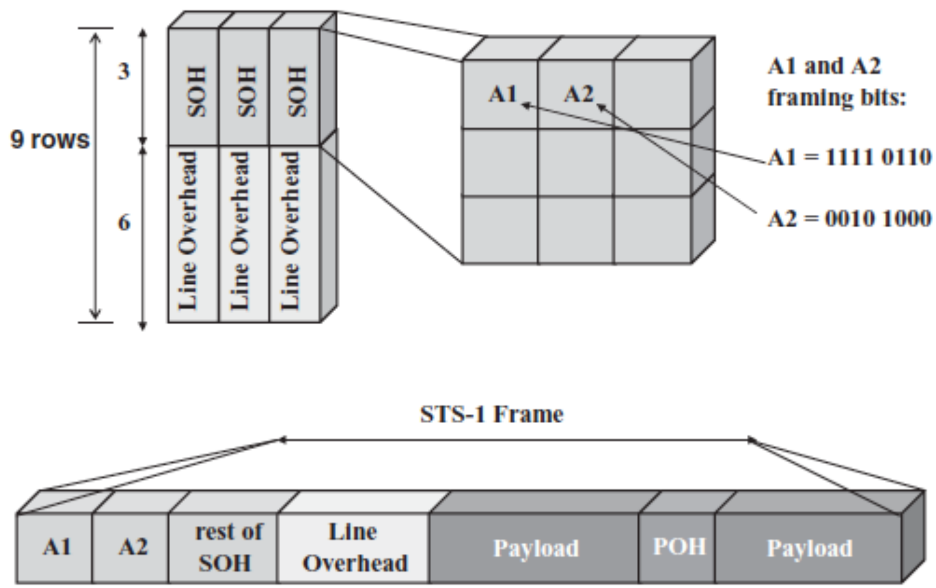
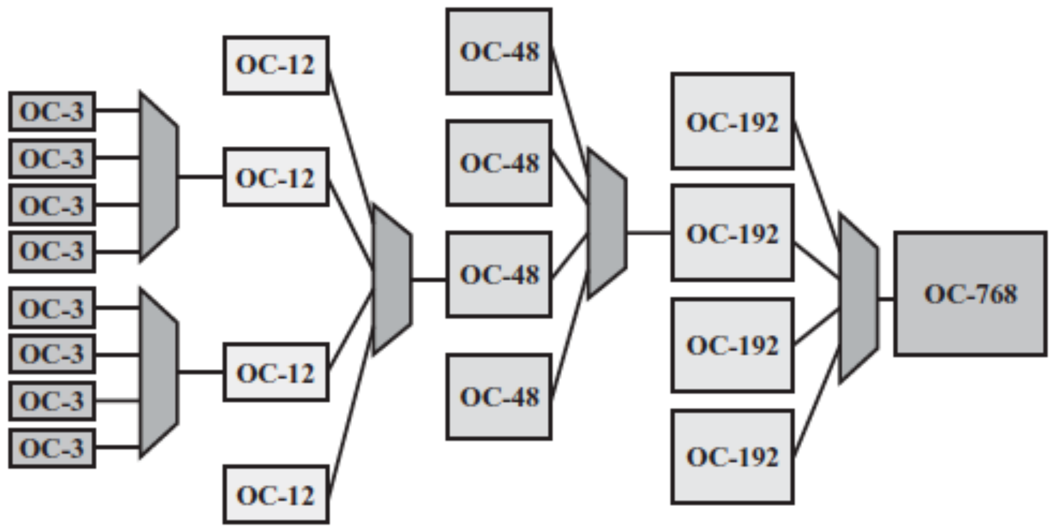


FIGURE 4.9 Finding the beginning of the SONET frame.

SONET Multiplexing



OC-3 STS-3 STM-1 155.52 Mb/s	OC-12 STS-12 STM-4 622.08 Mb/s	OC-48 STS-48 STM-16 2,488.32 Mb/s	OC-192 STS-192 STM-64 9,953.28 Mb/s	OC-768 STS-768 STM-256 39,813.12 Mb/s

FIGURE 4.10 SONET STS multiplexing hierarchy.

SONET Multiplexing

- What to do with overhead structure in multiplexing?
  - Channelization: overhead unchanged in each stream
  - Concatenation: merging overhead structure

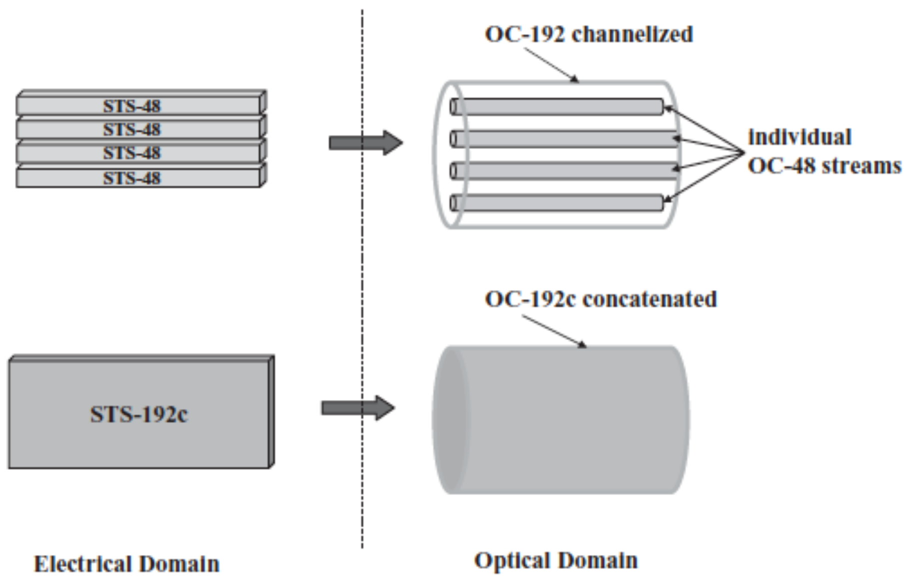


FIGURE 4.11 Channelization vs. concatenation.

Synchronous Payload Envelope (SPE)

- Floating structure, split between two STS-1 frames.
  - H1, H2 pointers

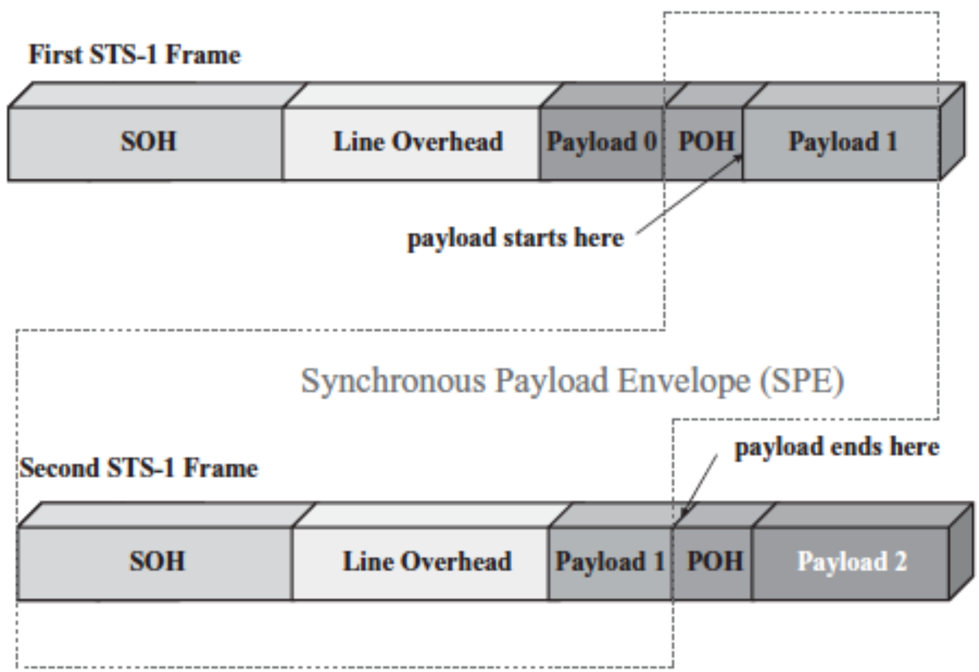


FIGURE 4.12 Synchronous payload envelope position in the STS-1 frame.

SPE

- Synchronization problem (minor clock difference)

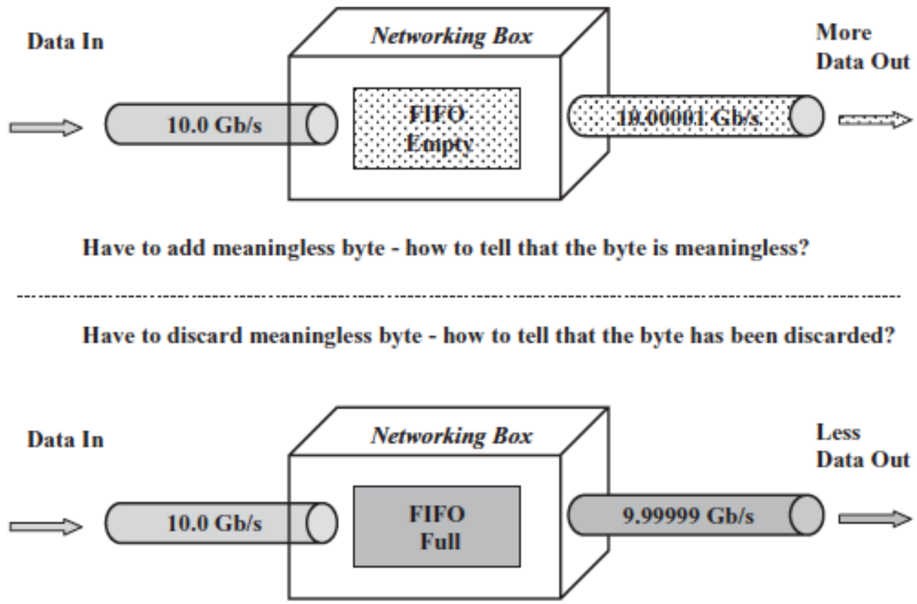


FIGURE 4.13 Pointer functions to accommodate clock difference between input and output.

SPE

- Floating structure and synchronization
  - H1, H2, H3 pointers
- H3:
  - Output rate > input rate: add meaningless byte
  - Output rate < input rate: discard meaningless byte

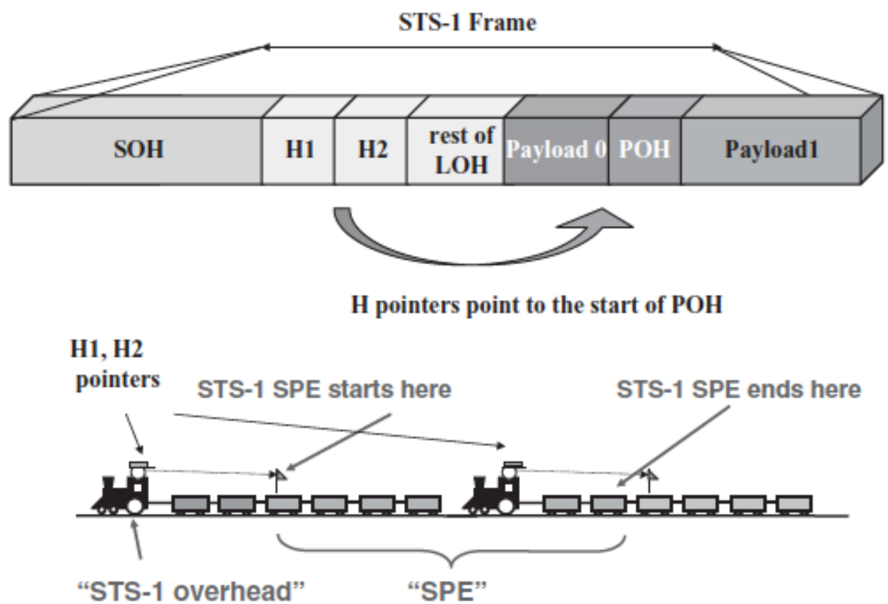
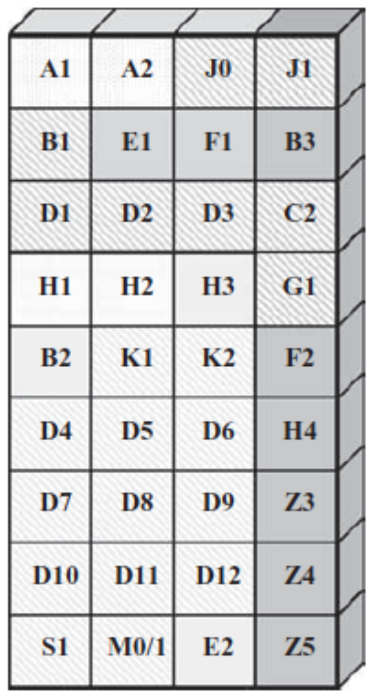


FIGURE 4.14 Finding synchronous payload envelope: H1 and H2 pointers.

Overhead and OAM&P



- **A1, A2 are used to recognize frame boundary**
- **J0 is section trace to verify continuity**
- **B1, B2 represent bit interleaved parity (BIP-8)**
- **D1 to D12 are used for network management**
- **H1, H2 are used point to the SPE beginning**
- **K1, K2 are used for failure messaging (APS)**
- **S1, M0/1 are used for synchronization**
- **J1 is responsible for path tracing**
- **C2 and G1 are indicating path status**

FIGURE 4.15 SONET overhead information.

Overhead and OAM&P

TABLE 4.2 Section Overhead[a]

Byte	Name	Function
A1/A2	Framing bytes	Used to indicate the beginning of an STS-1 frame
J0/Z0	Section trace (J0) and section growth (Z0)	Allocated to trace origins of a frame
B1	Section bit-interleaved parity code (BIP-8) byte	Used to check for transmission errors over a regenerator section
E1	Section orderwire byte	Allocated for local orderwire channel for voice communication for installation operators; not used today
F1	Section user channel byte	Set aside for purposes of network provider
D1/D2/D3	Section data communications channel bytes	Used from a central location for alarms, control, monitoring, administration, and other communication needs

[a]Contains 9 bytes of the transport overhead accessed, generated, and processed by section-terminating equipment. This overhead supports functions such as performance monitoring, framing, and data communication for operation, administration, management, and provisioning.

Overhead and OAM&P

TABLE 4.3 Line Overhead[a]

Byte	Name	Function
H1/H2	STS payload pointers	Allocated to a pointer that indicates an offset between the pointer and the first byte of the SPE
H3	Pointer action byte	Allocated for SPE frequency justification purposes
B2	Line bit-interleaved parity code (BIP-8) byte	Used to determine if a transmission error has occurred over a line; calculated over all bits of the line overhead
K1/K2	Automatic protection switching bytes	Used for protection signaling, detecting alarm indications, and remote defect indication signals
D4–D12	Line data communications channel bytes	Used for OAM&P information (alarms, control, maintenance, remote provisioning, monitoring, and administration)
S1	Synchronization status	Allocated to convey the synchronization status of the network element
Z1	Growth byte	Allocated for future growth
M0	M0 byte	Allocated for a line remote error indication
Z2	Growth byte	Allocated for future growth
E2	Orderwire byte	Allocated for local orderwire channel, voice communication, and installation operators; not used today

[a]Contains 18 bytes of overhead accessed, generated, and processed by line-terminating equipment. This overhead supports functions such as locating SPE in the frame, multiplexing signals, line maintenance, automatic protection switching, and performance monitoring.

OAM&P Example

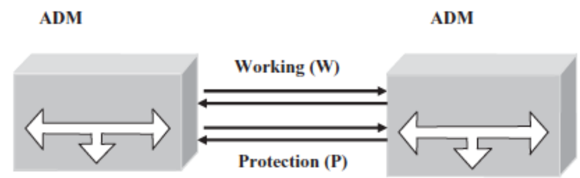


FIGURE 4.16 Work and protection links for automatic protection switching.

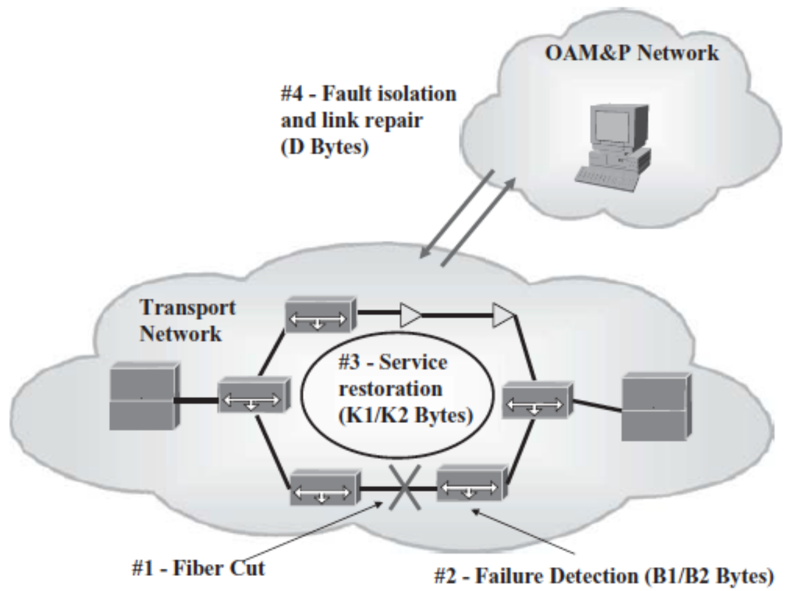


FIGURE 4.17 Example of SONET network failure.

SONET Virtual Tributaries (VTs)

- Handle payloads smaller than STS-1 rate.
  - STS-1 SPE divided into 7 VT groups, each 12 columns.

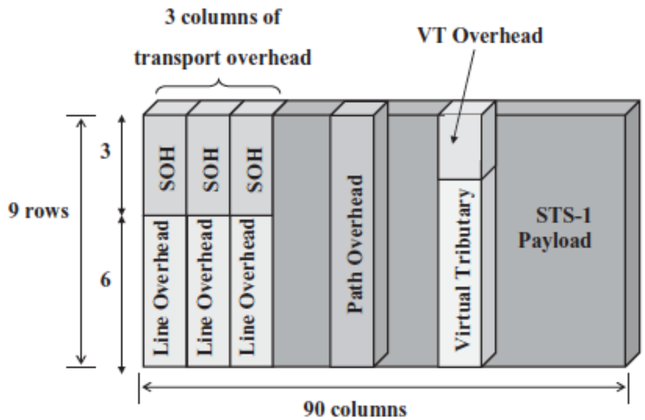


FIGURE 4.18 STS-1 frame and virtual tributaries.

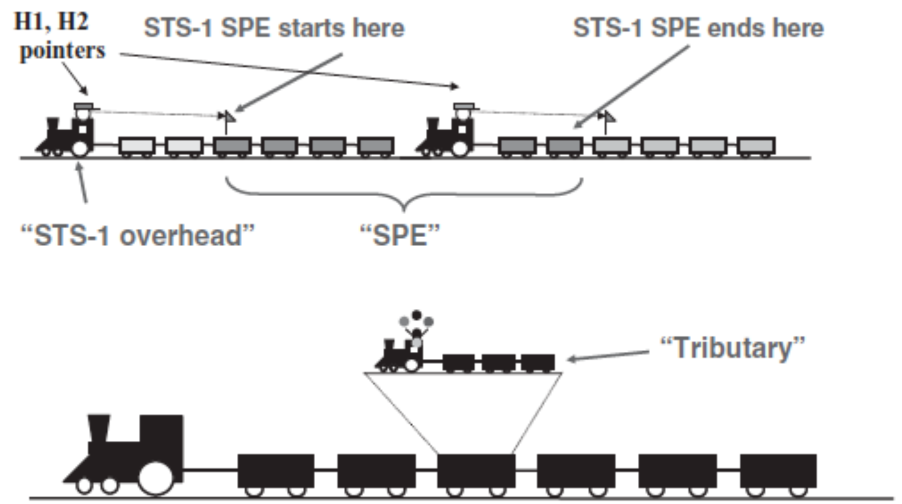
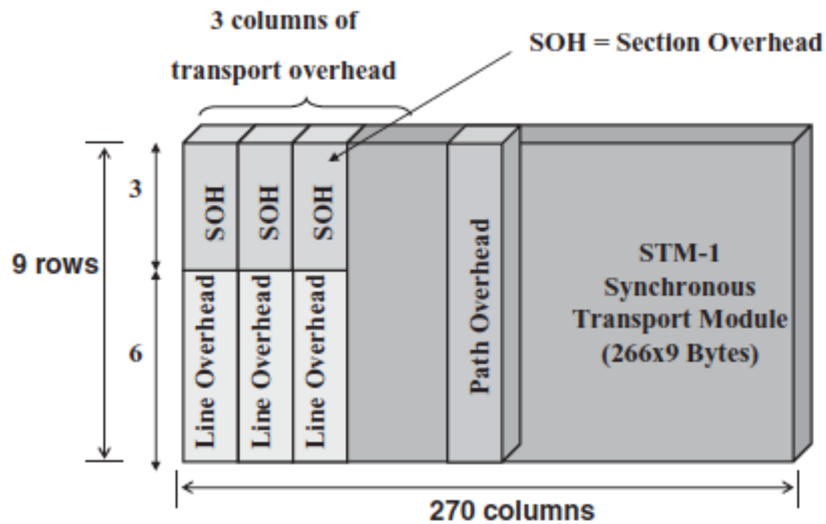


FIGURE 4.19 Relationship between SONET SPE and virtual tributaries.

SDH vs. SONET

- Synchronous digital hierarchy (SDH)
  - Outside North America
  - Based on synchronous transport module STM-1
    - 3 times STS-1: 3 x 51.84 = 155.84 Mb/s
    - STM-1 corresponds to STS-3 in SONET
  - Compatible with a subset of SONET
    - Traffic interworking possible
    - Alarms and performance management not possible between SDH and SONET
  - Virtual containers (VCs) vs. VTs
    - differences from E-carrier vs. T-carrier

SDH Frame



STM-1 = 270 Bytes x 9 = 2430 Bytes = 19,440 bits
19,440 bits x 8 kHz = 155.52 Mb/s

FIGURE 4.20 STM-1 frame for SDH protocol.

SONET Equipment

- Similar to optical devices previously studied (Chap. 3)
- Devices must comply with jitter requirements and SONET standards
  - SONET O-E-O regenerator
    - Short reach (SR): up to 2km; IR: up to 40km; LR: up to 80km; ULR: over 80km;
    - In MANs, IR and LR typical.
  - SONET ADM Multiplexer
    - Multiplexing hub; most versatile equipment.
  - SONET Terminal Multiplexer
    - Specialized ADM used at edges of networks;
    - Handles signals from SONET and non-SONET networks.

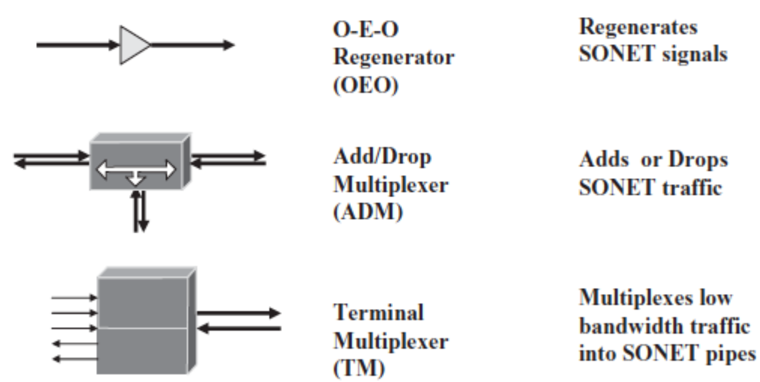


FIGURE 4.2 SONET networking equipment.

SONET Implementation Features

- SONET Scrambling
  - scheme to maximize state changes in data stream
  - facilitates clock recovery
- SONET Clock Distribution
  - cascading of primary clock signal through network
- SONET Byte Stuffing
  - adding or removing of byte in response to clock variations.

SONET Scrambling

- As a synchronous design, SONET relies heavily on clock
  - Separate clock signal transmission too expensive
  - Clock should be embedded in data stream
    - Examine the state changes
    - Need to maximize state changes
- Modulation in SONET:
  - Non-return-to-zero (NRZ): 1 = transmit pulse; 0 = no transmission
  - Potential long runs of 1's or 0's: no transition or change in signal level; not DC balance.
  - Rearrange transmitting bits using scrambling
    - Increase state transitions through pseudorandom operations
    - Scrambler: divide by x^n+1
    - Descrambler: multiply by x^n+1

SONET Scrambling

- XOR of current data with preceding data (n bits delay)
- In SONET, n = 43 to minimize "data killer" patterns

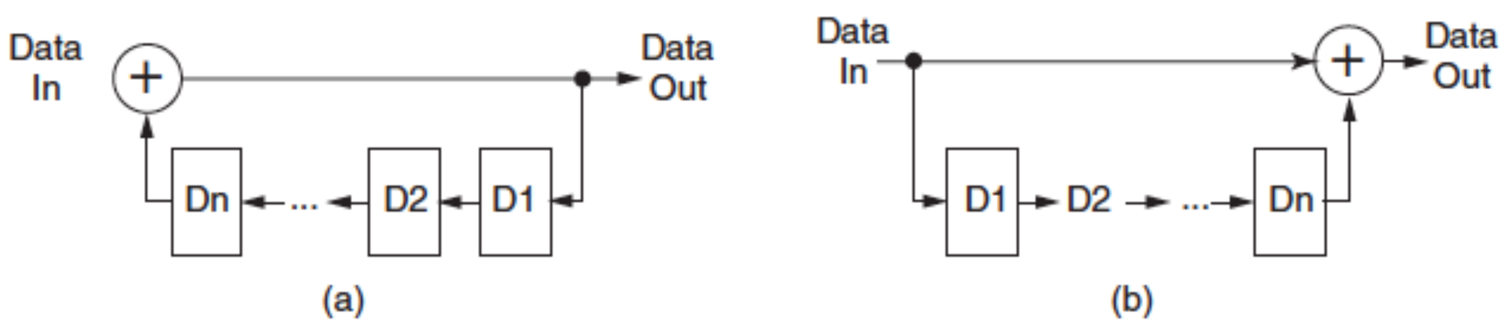


FIGURE 4.21 SONET scrambling process: (a) $x^n + 1$ scrambler; (b) $x^n + 1$ descrambler.

SONET Clock Distribution

- As master clock (reference) is cascaded down hierarchy, clock variations occur:
  - Jitter = frequency variation within duration < 0.1 s
  - Wander = freq. variation within duration > 0.1 s.
  - Recall: H1, H2, H3 and floating SPE to handle slight clock differences.
- Clock classification based on accuracy
  - Stratum 1 (atomic): $\pm 1 \times 10^{-11}$
  - Stratum 2 (atomic): $\pm 1.6 \times 10^{-8}$
  - Stratum 3 (oscillator): $\pm 4.6 \times 10^{-6}$
  - SONET minimum clock (SMC) (oscillator): $\pm 20 \times 10^{-6}$

SONET Clock Distribution

- S1 byte of LOH used to communicate quality info
- Receiving node accordingly derives its own reference clock (a.k.a., line timing or loop timing)

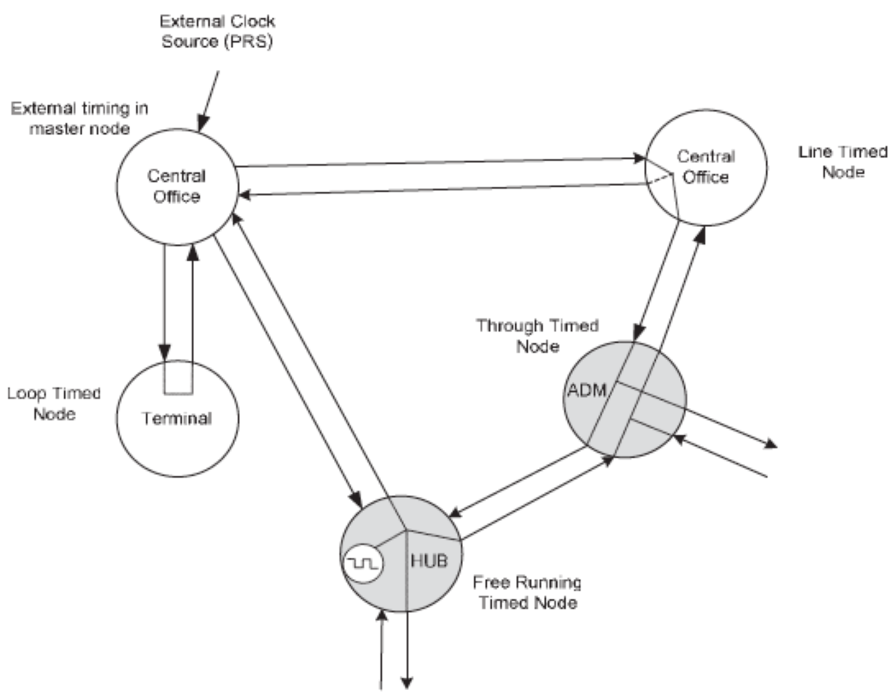


FIGURE 4.22 Examples of clocking schemes in a SONET network.

SONET Byte Stuffing

- Recall pointers H1, H2 (location of SPE)
- Adding byte = Positive byte stuffing
  - Input rate < Output rate
    - Frame rate of SPE < frame rate of STS-1
  - Inversion of increment bits: 7,9,11,13,15 of pointer word
  - Added byte follows H3 byte
- Removing byte = Negative byte stuffing
  - Input rate > Output rate
    - Frame rate of SPE > frame rate of STS-1
  - Inversion of decrement bits: 8,10,12,14,16
  - Actual data byte written in the H3 byte.