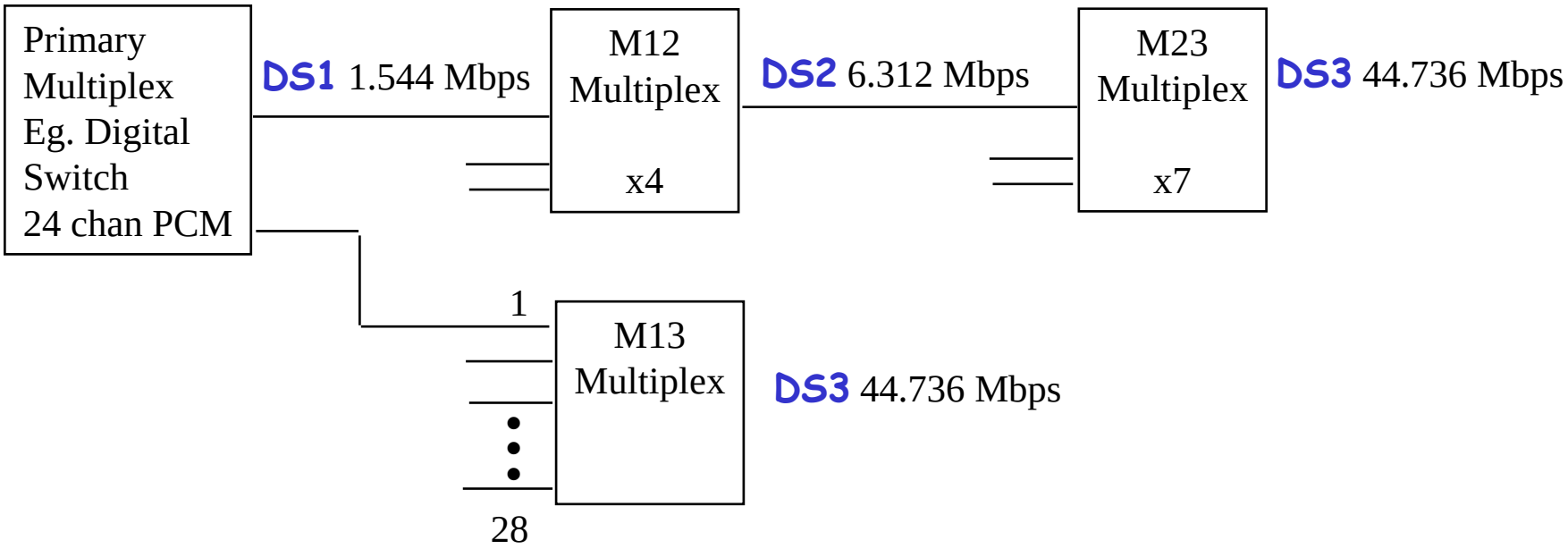
Synchronous Optical Networks
SONET

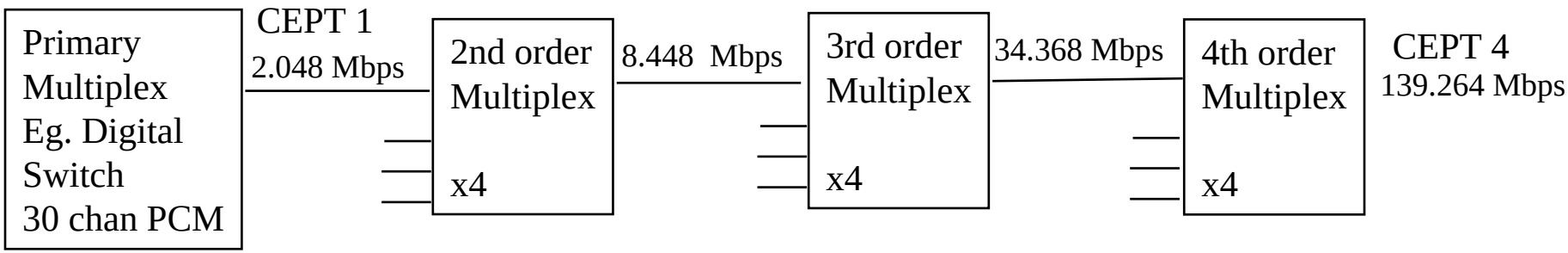
Telephone Networks {Brief History}

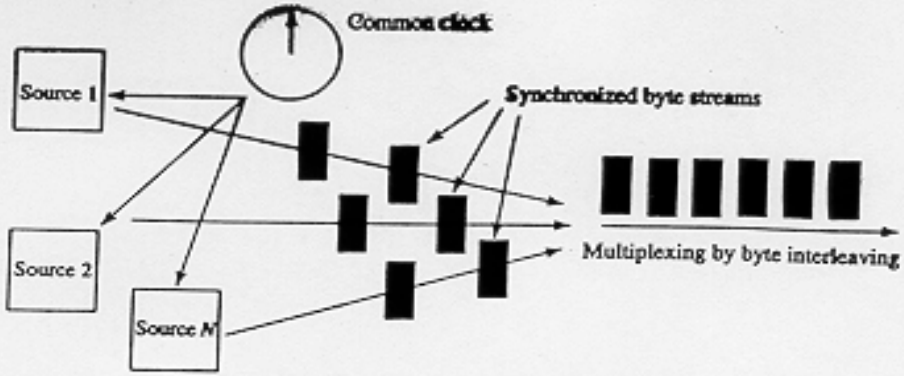
- Digital carrier systems
  - The hierarchy of digital signals that the telephone network uses.
  - Trunks and access links organized in **DS (digital signal) hierarchy**
  - Problem: rates are not multiples of each other.
- In the 1980's Bellcore developed the Synchronous Optical Network (**SONET**)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

North American Digital Hierarchy

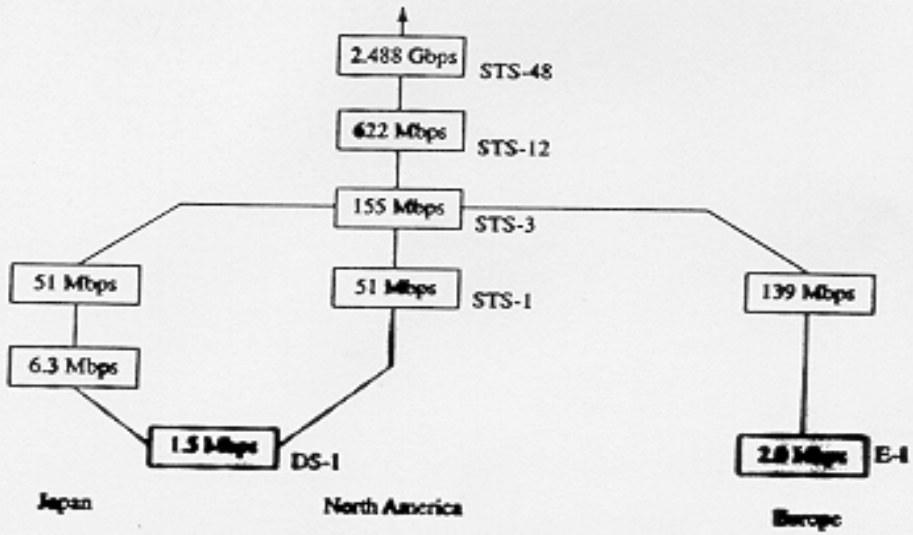


European Digital Hierarchy





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* × 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.

Medium	Signal	Voice circuits	North America	Japan	Europe
T-1 paired cable	DS-1	24	1.5	1.5	2.0
T-1C paired cable	DS-1C	48	3.1		
T-2 paired cable	DS-2	96	6.3	6.3	8.4
T-3 coax, radio, fiber	DS-3	672	45.0	34.0	32.0
Coax, waveguide, radio, fiber	DS-4	4032	274.0		

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.

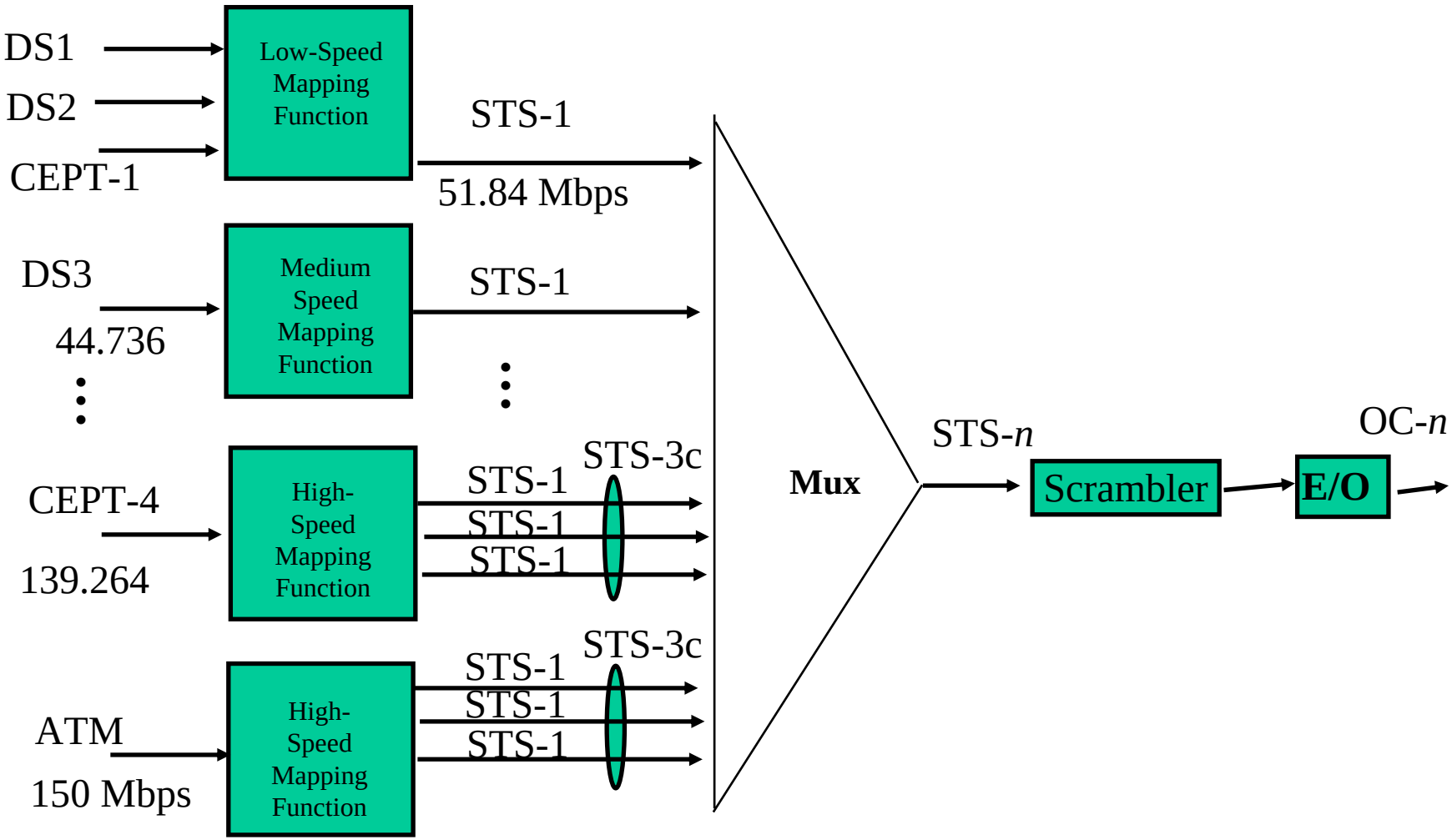
Carrier	Signal	Rate in Mbps
OC-1	STS-1	51.840
OC-3	STS-3	155.520
OC-9	STS-9	466.560
OC-12	STS-12	622.080
OC-18	STS-18	933.120
OC-24	STS-24	1244.160
OC-36	STS-36	1866.240
OC-48	STS-48	2488.320

1.3 TABLE

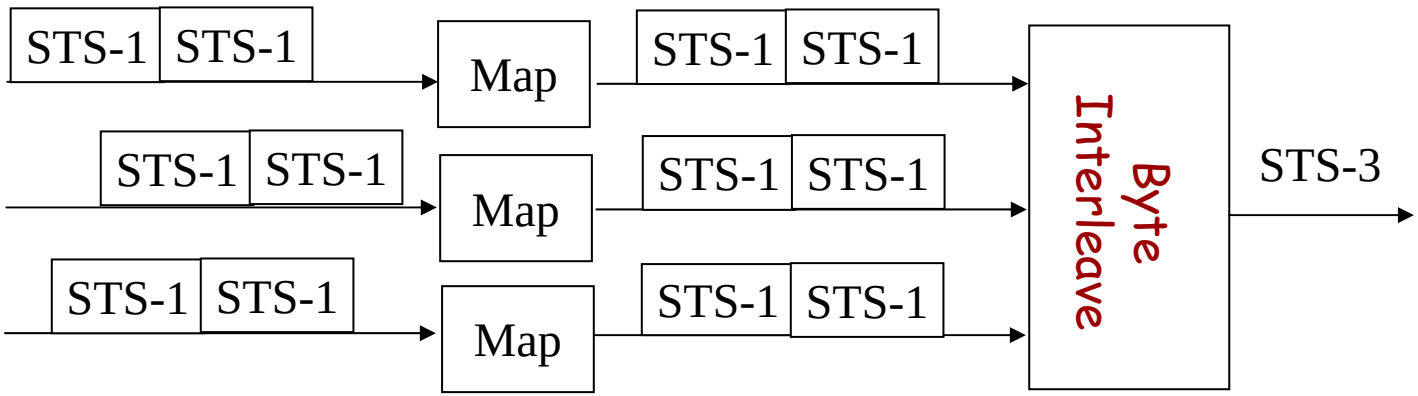
SONET rates. The rates of multiplexed STS-1 signals are exact multiples; no additional framing bits are used.

SONET		SDH	Data rate (Mbps)		
Electrical	Optical	Optical	Gross	SPE	User
STS-1	OC-1		51.84	50.112	49.536
STS-3	OC-3	STM-1	155.52	150.336	148.608
STS-9	OC-9	STM-3	466.56	451.008	445.824
STS-12	OC-12	STM-4	622.08	601.344	594.432
STS-18	OC-18	STM-6	933.12	902.016	891.648
STS-24	OC-24	STM-8	1244.16	1202.688	1188.864
STS-36	OC-36	STM-12	1866.24	1804.032	1783.296
STS-48	OC-48	STM-16	2488.32	2405.376	2377.728
STS-192	OC-192	STM-64	9953.28	9621.504	9510.912

Figure 2-37. SONET and SDH Multiplex Rates



Synhcronous Multiplexing in SONET

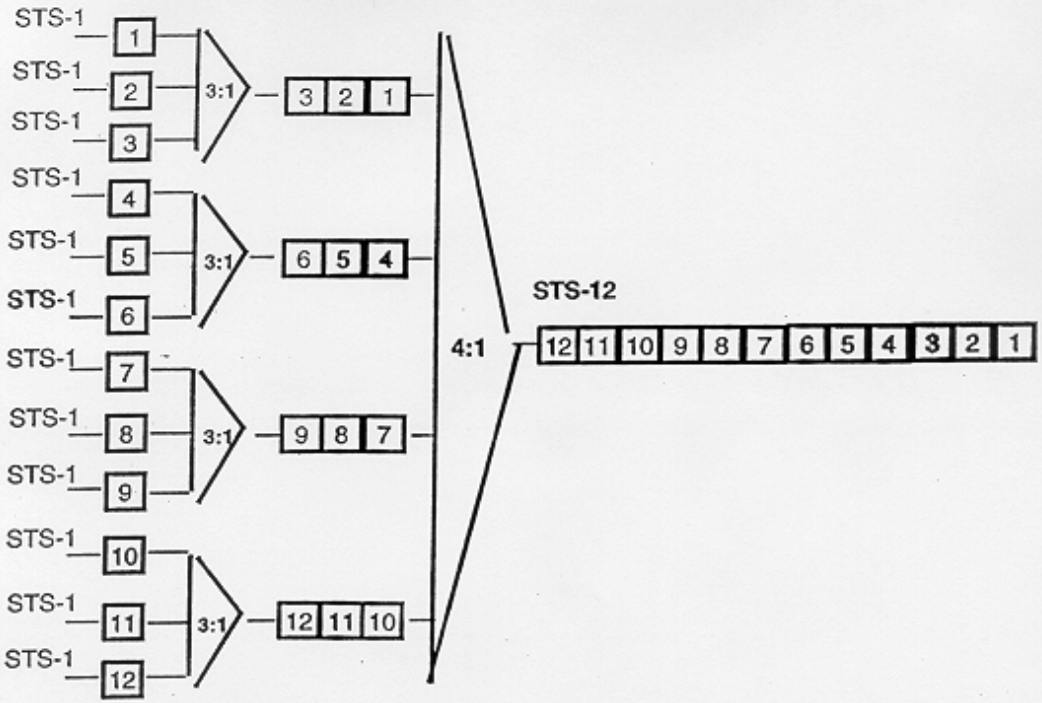


INTERLEAVING

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

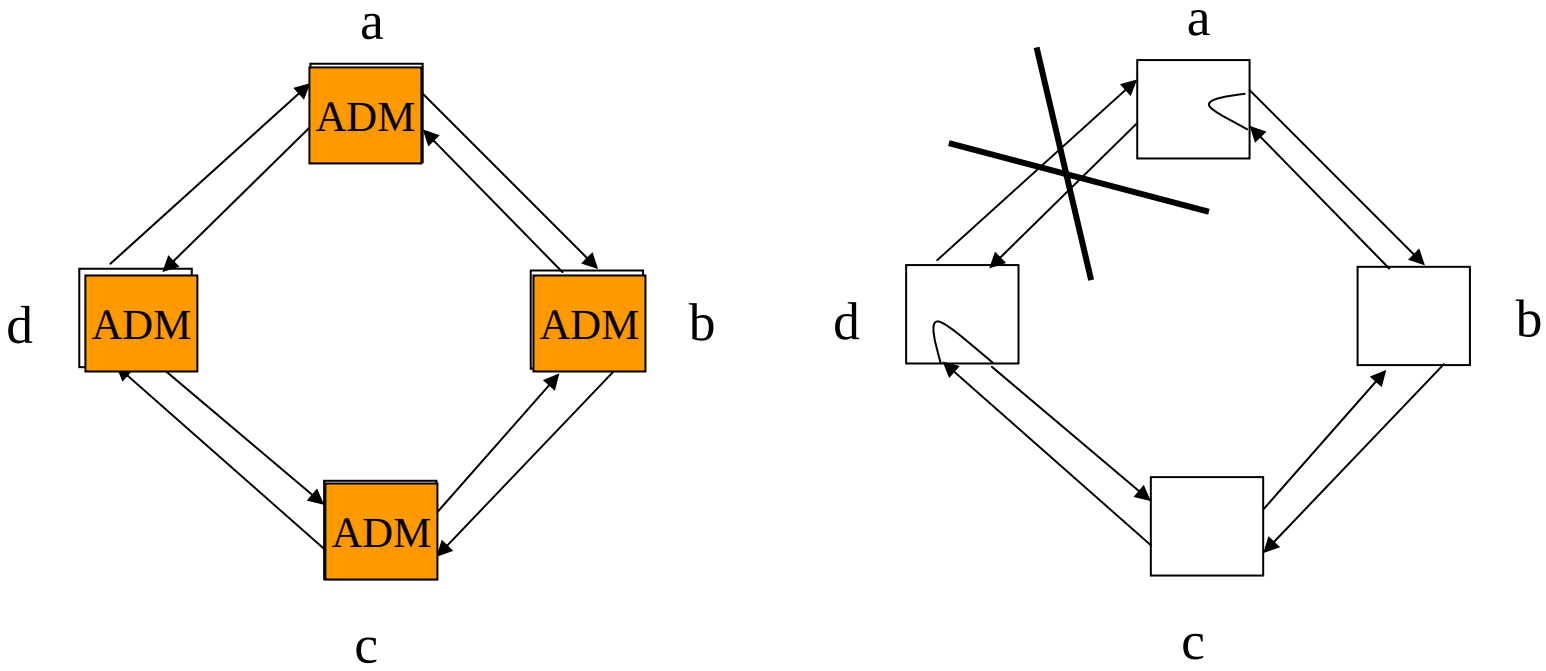
- NEXT BYTE INTERLEAVE TO FORM STS-N SIGNAL
- THE TRANSPORT OVERHEAD IS NOW 3 X N
- THE SPE (SYNCHRONOUS PAYLOAD ENVELOP - "DATA") IS NOW N X 87 COLUMNS
- BYTE SEQUENCE IS ROW 1 COLUMN 1 TO ROW 9 COLUMN 90



SONET Architecture

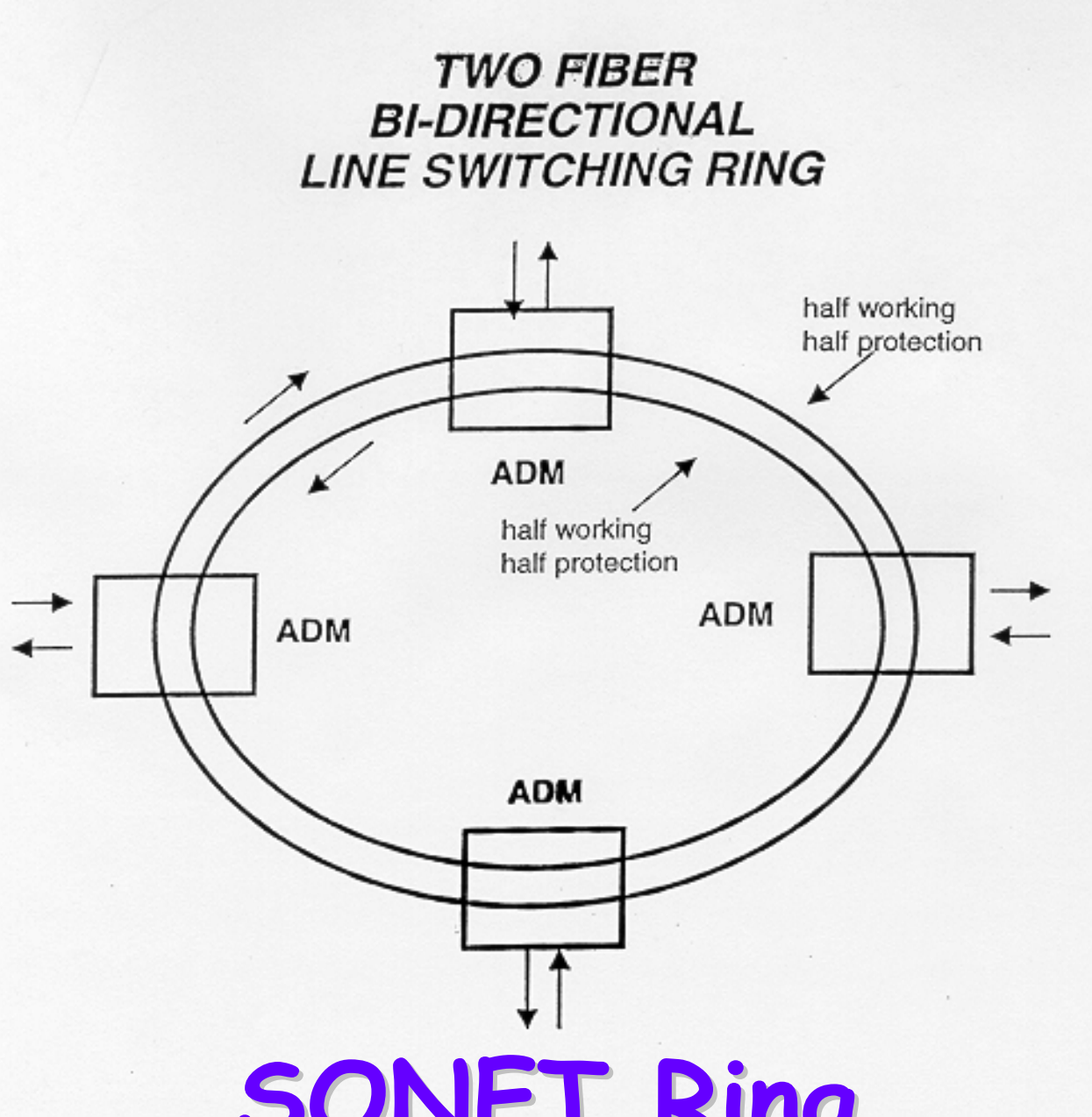
- SONET topology can be a mesh, but most often it is a dual ring.
- Standard component of SONET ring is an ADM (Add/Drop Multiplexer)
  - Drop one incoming multiplexed stream and replace it with another stream.
  - Used to make up bi-directional line switching rings.

SONET Ring



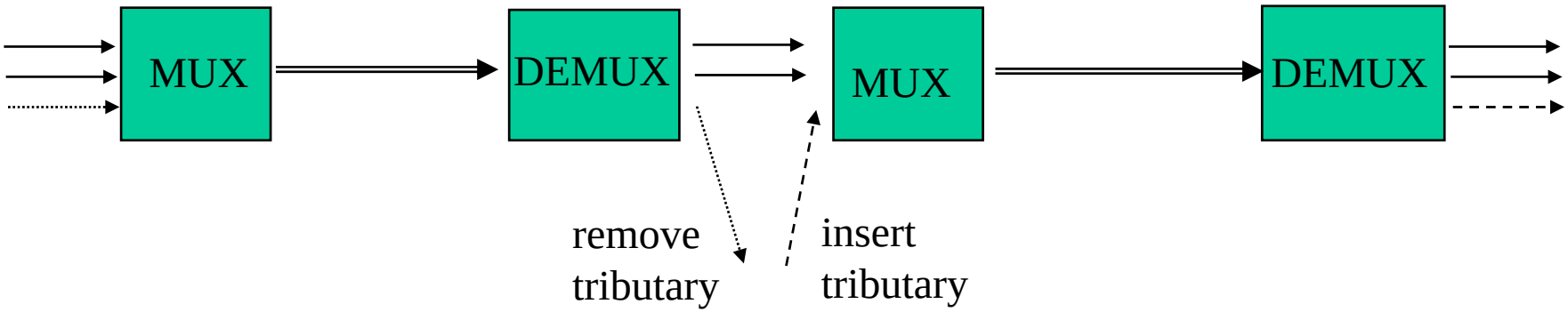
(a) Dual ring

(b) Loop-around in response to fault

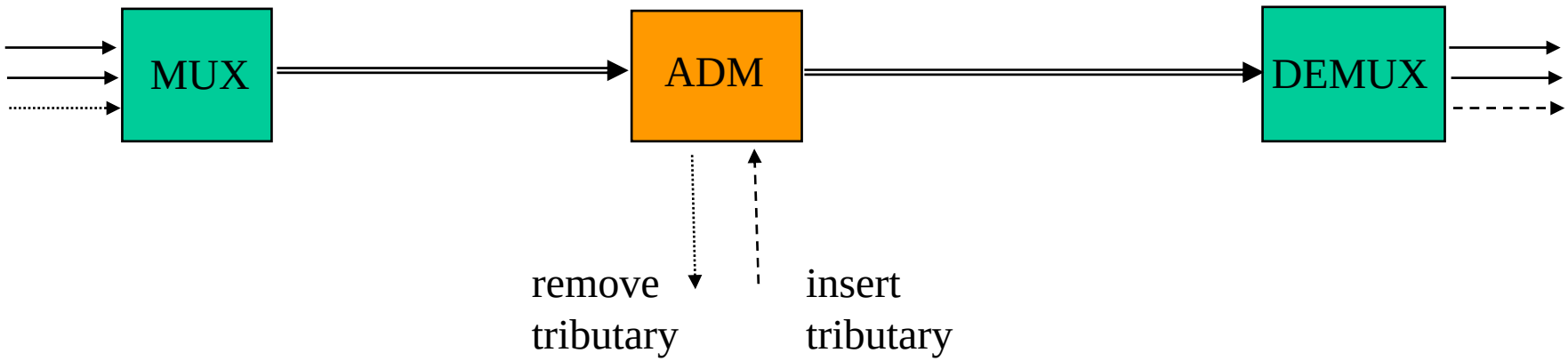

TWO FIBER
BI-DIRECTIONAL
LINE SWITCHING RING
half working
half protection
ADM
half working
half protection
ADM
ADM
ADM

SONET Ring

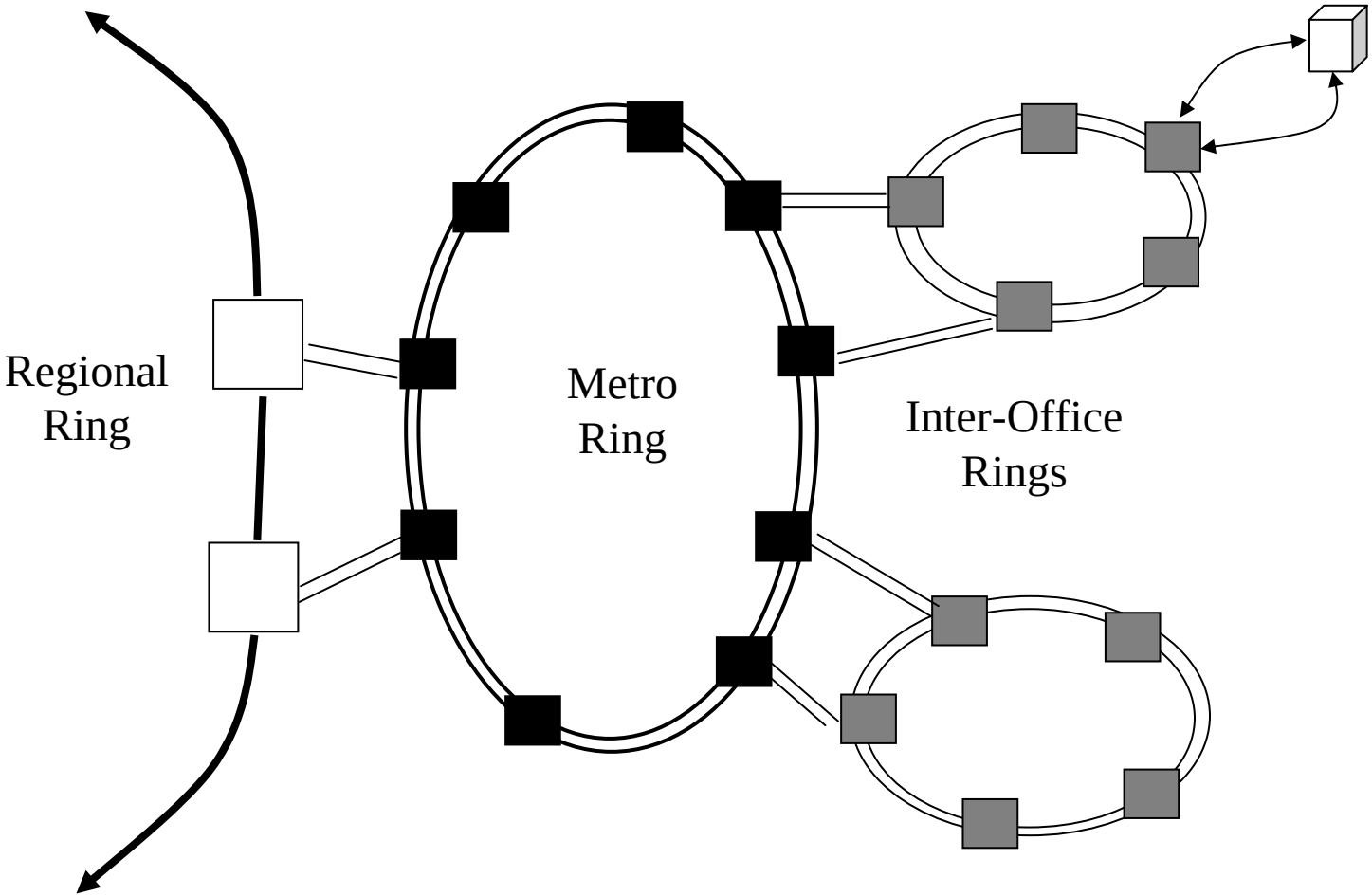
(a) pre-SONET multiplexing



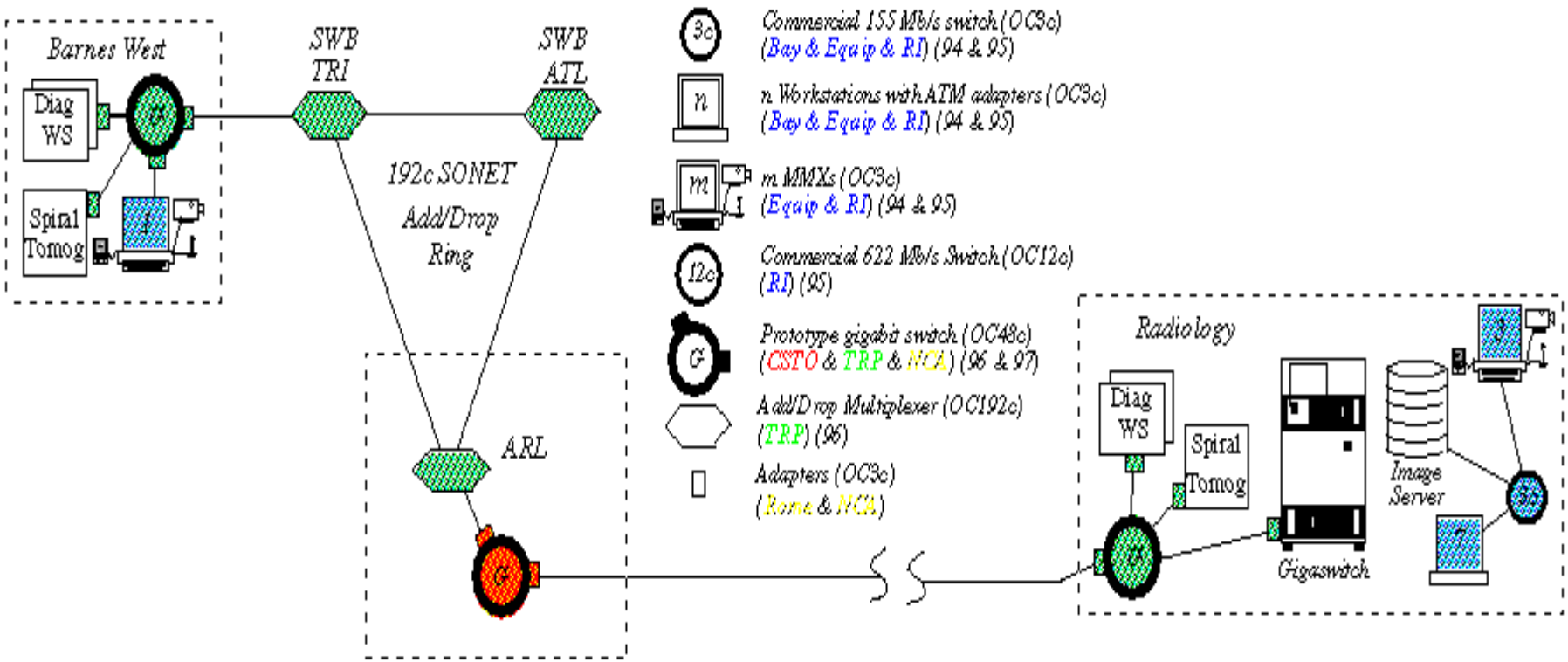
(b) SONET Add-Drop multiplexing



SONET Ring



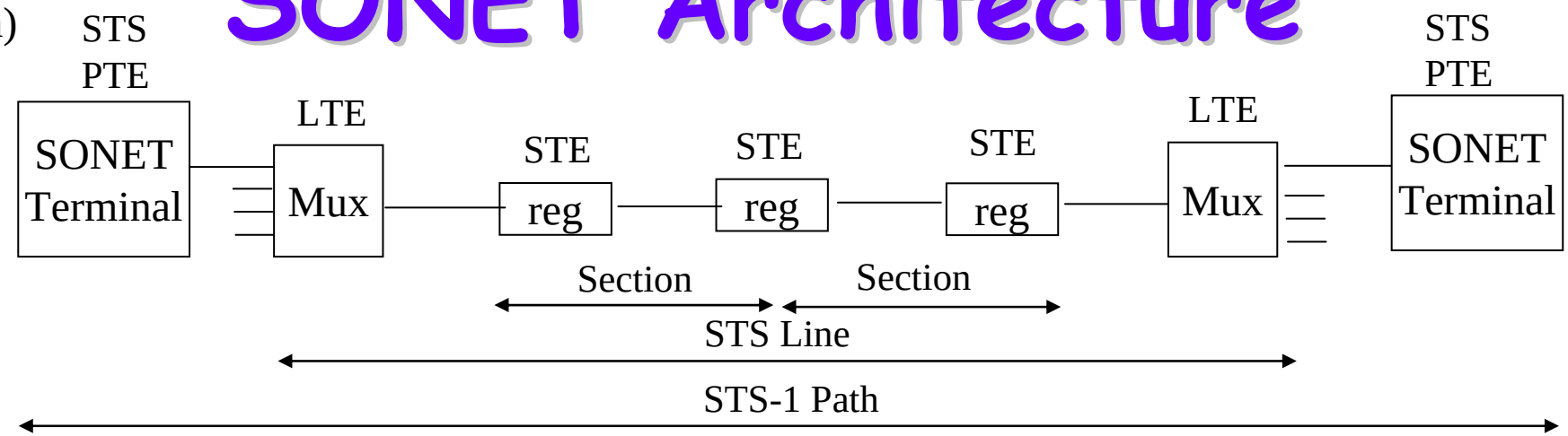
Gigabit ATM Applications Over 10 Gb/s SONET Ring



Washington U. St Louis 1995

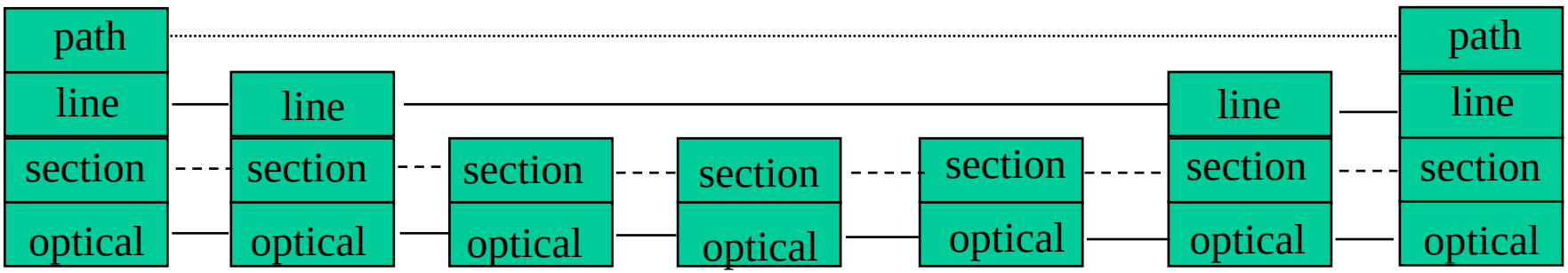
SONET Architecture

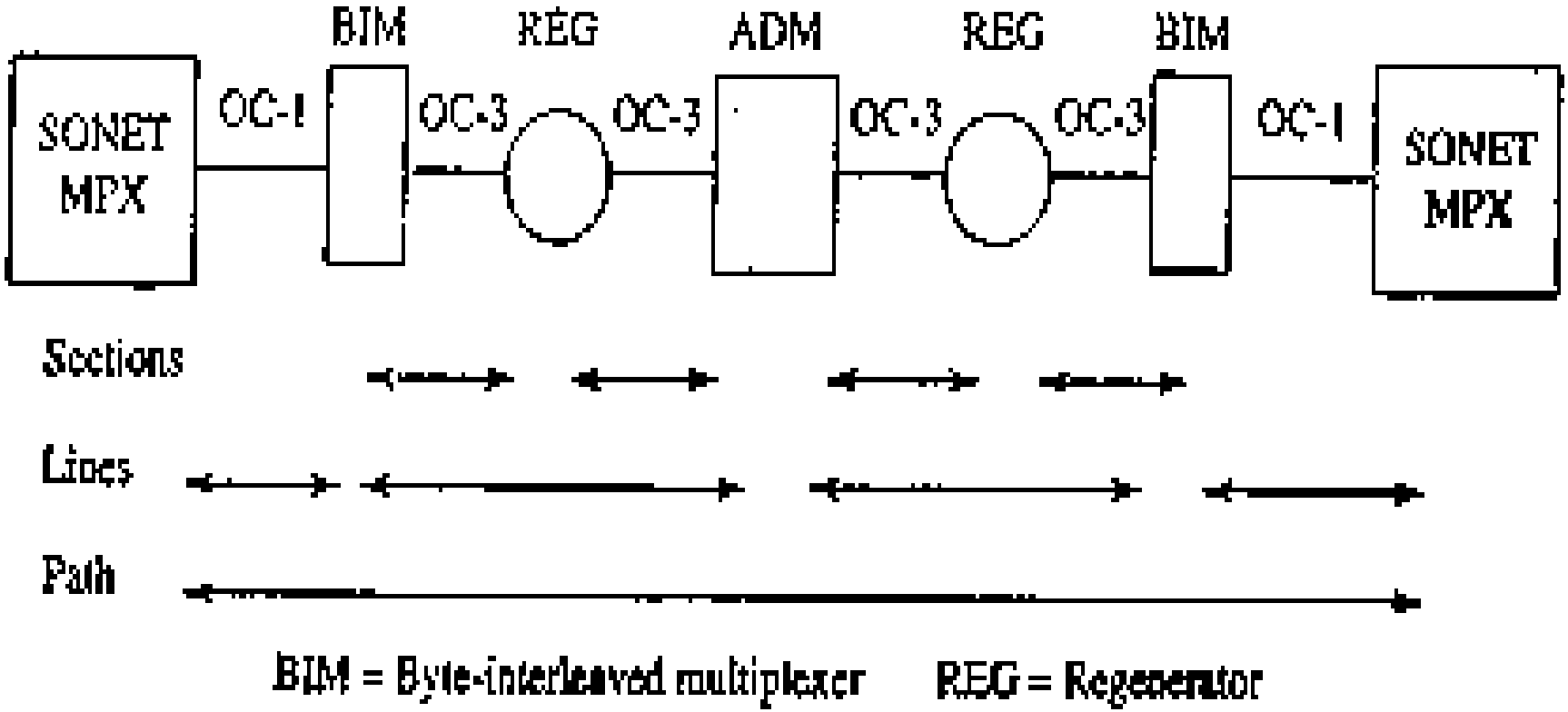
(a)



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)





The main SONET network elements.

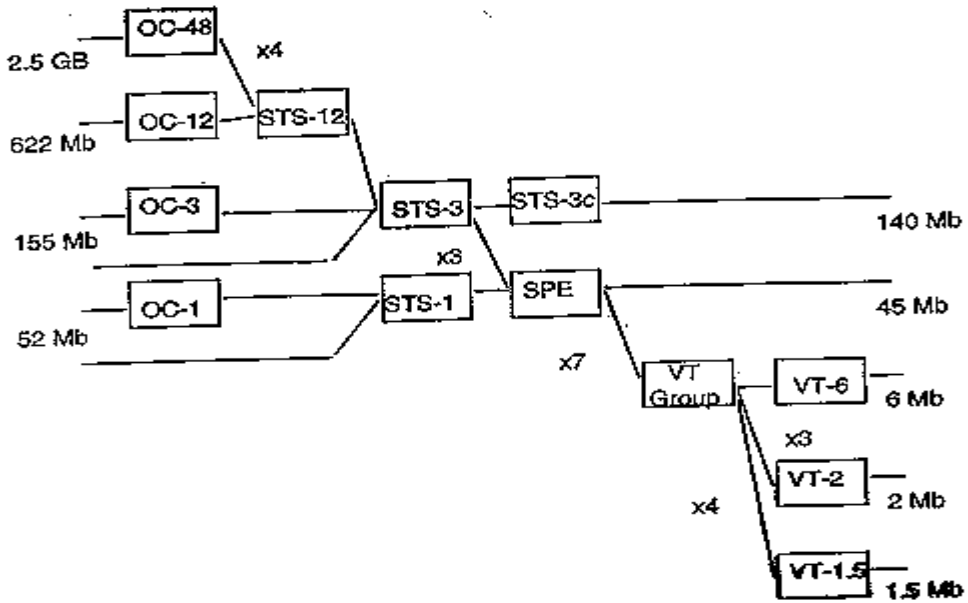
SONET Architecture

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.

MULTIPLEXING HIERARCHY



- *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

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

- *VIRTUAL TRIBUTARY* GROUPS ARE DEFINED TO CONTAIN COMBINATIONS OF VARIOUS VTs SUCH THAT THE TOTAL IS 12 COLUMNS.

  1 X VT-6 = 12

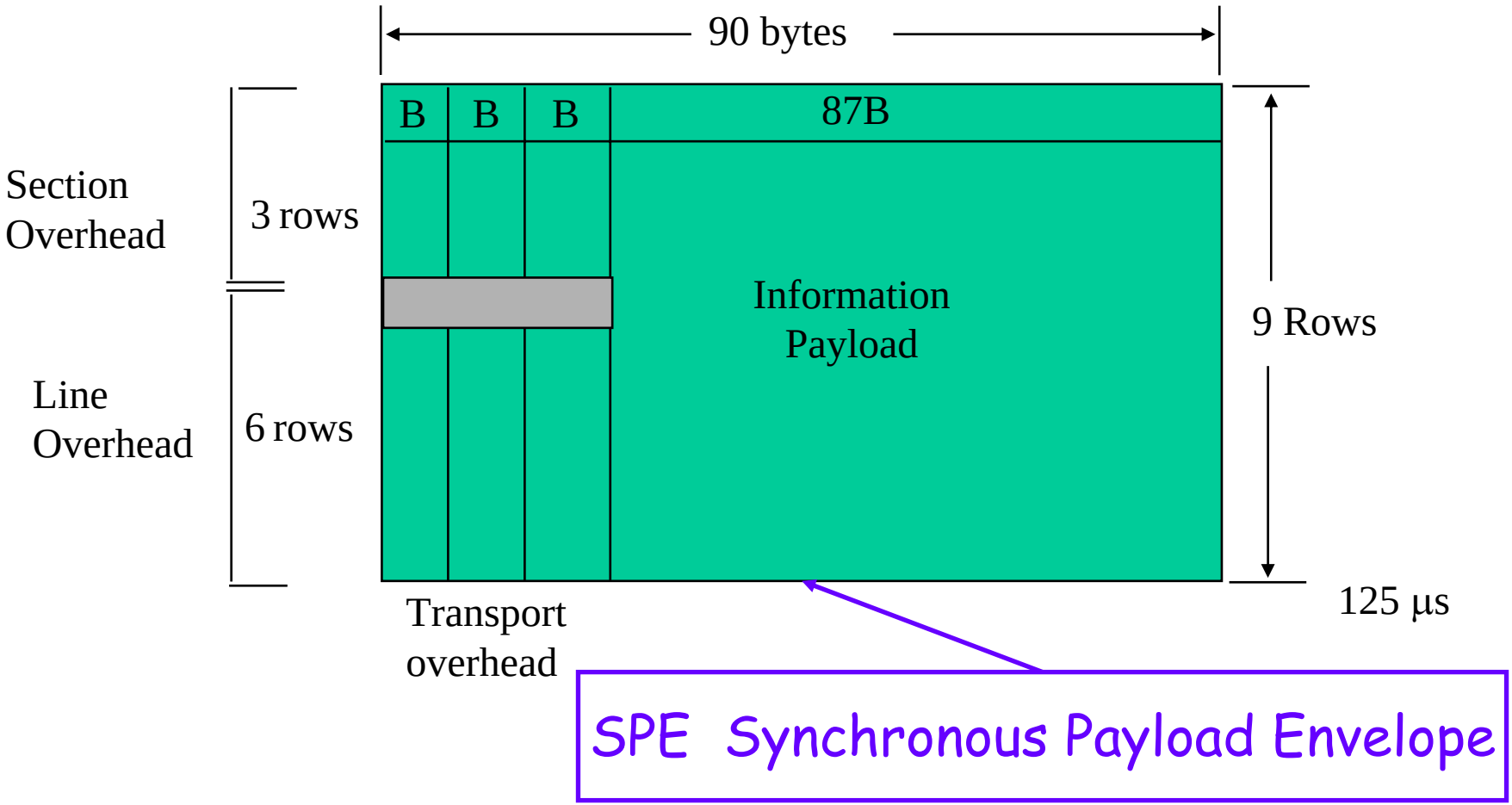
  2 X VT-3 = 12

  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



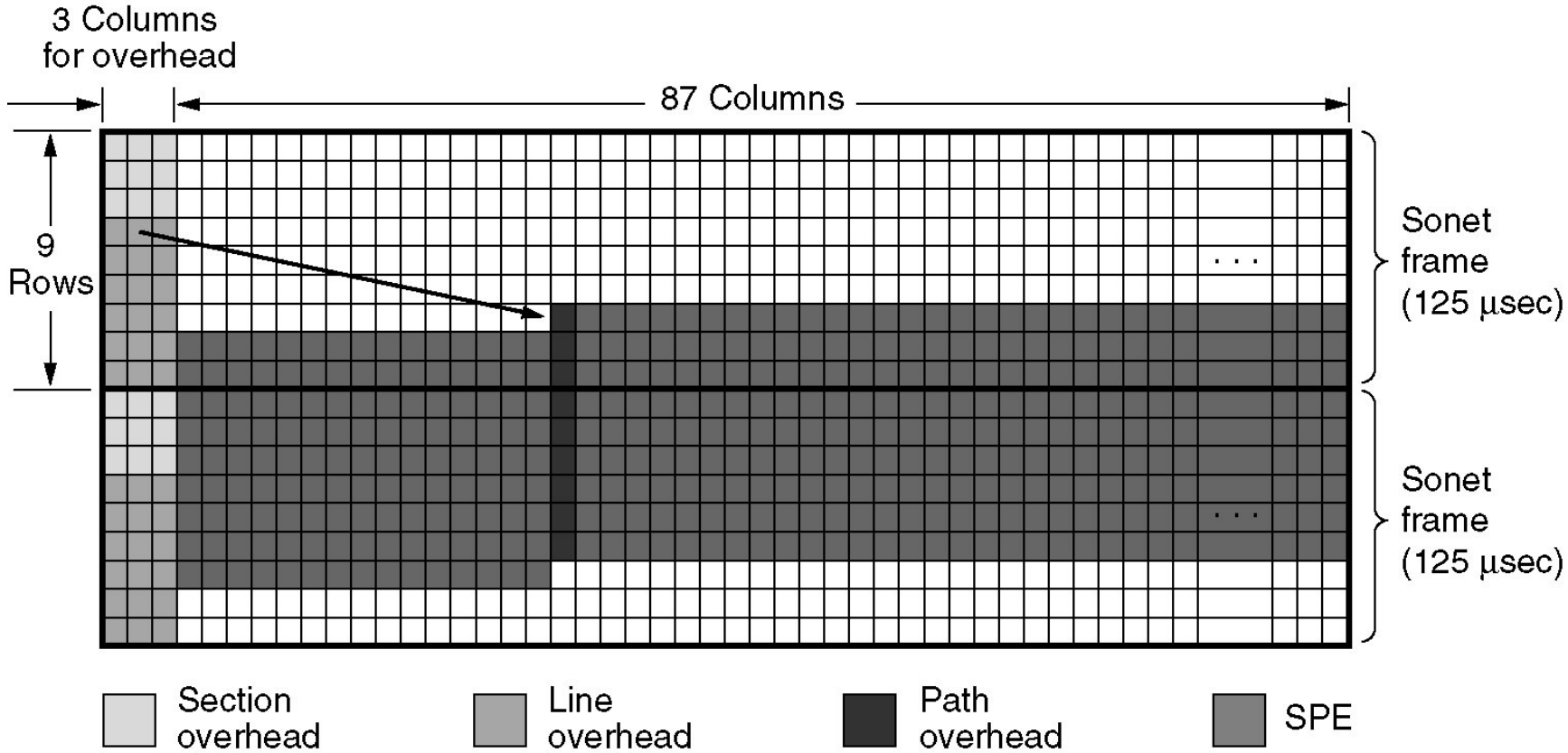
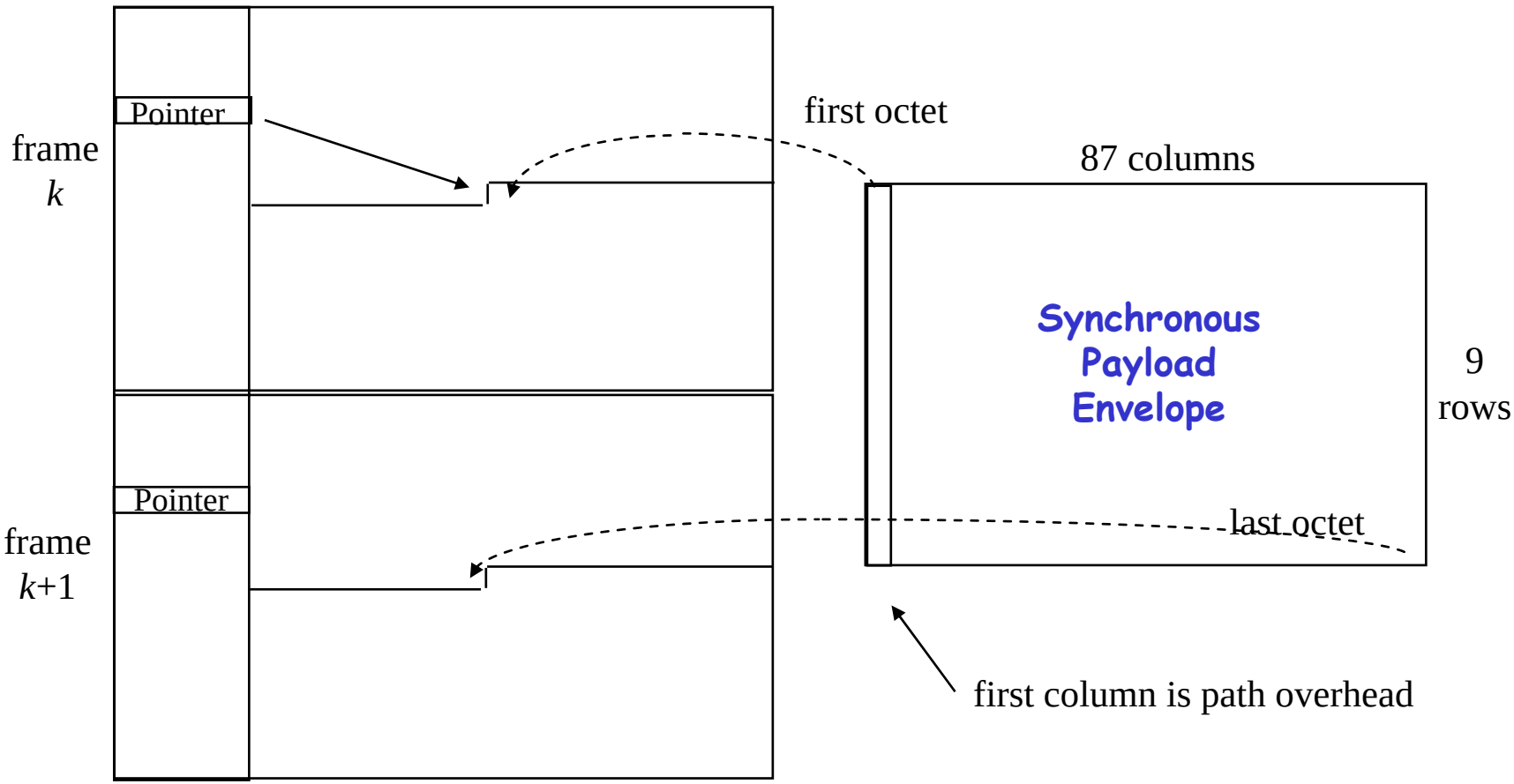
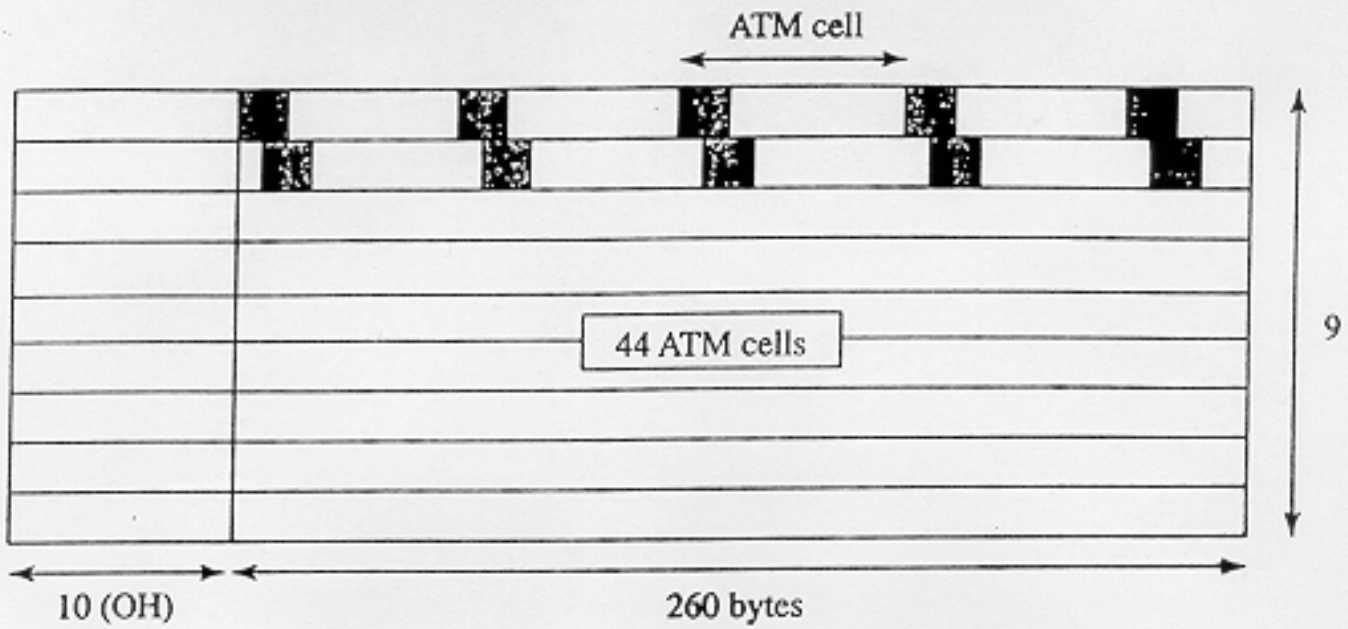


Figure 2-36. Two Back-to-Back SONET Frames

SPE straddling SONET Frame



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.