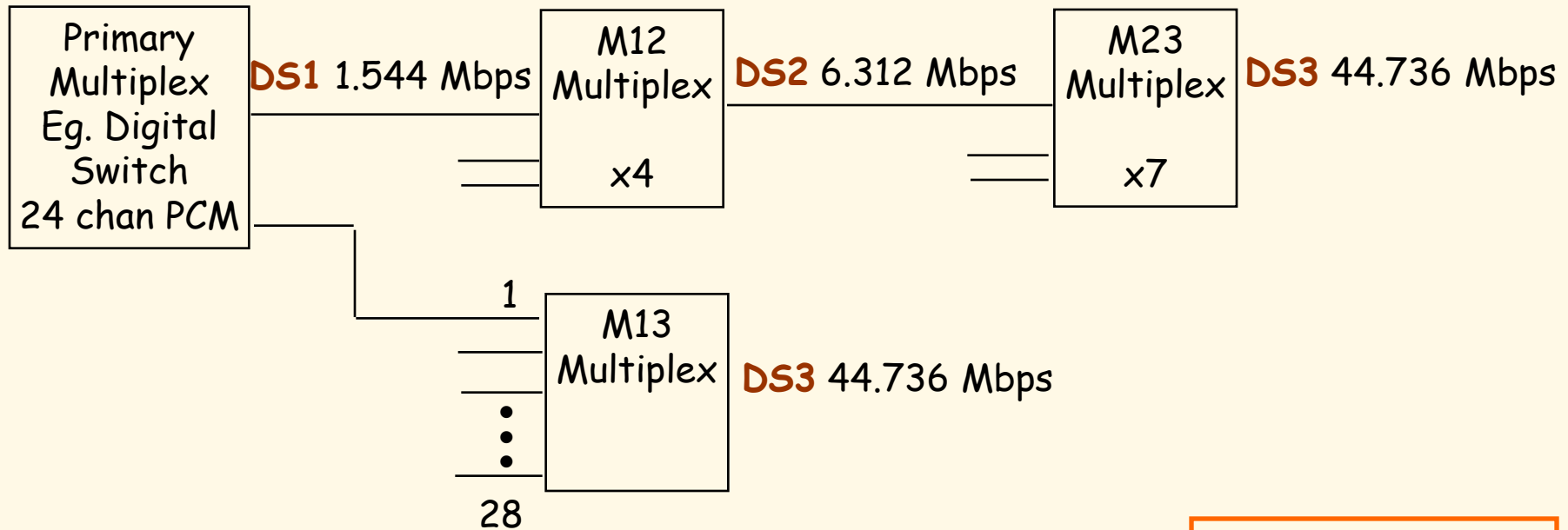# Synchronous Optical Networks (SONET)

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**
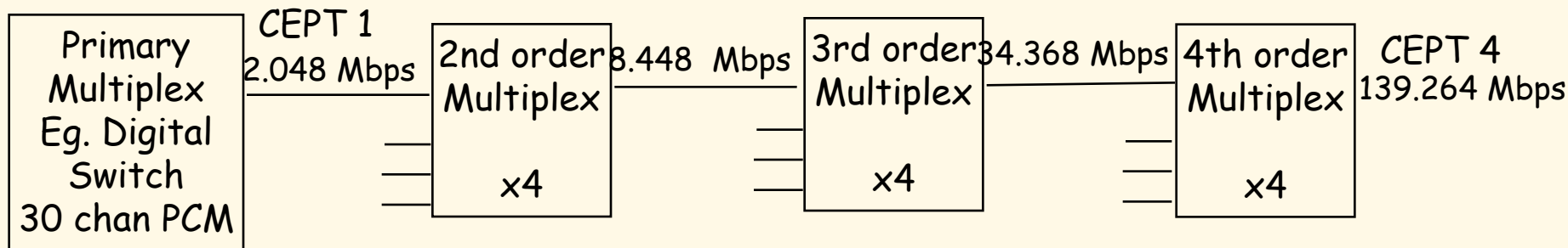
Telephone Networks {Brief History}

- ## 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.
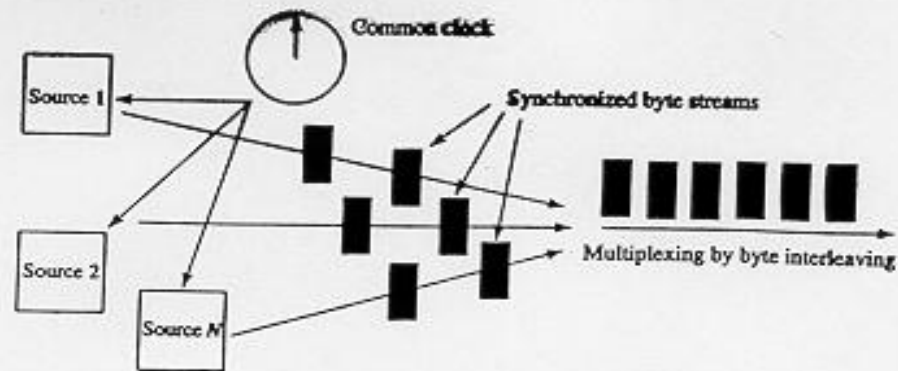
- Previous efforts include: ISDN and BISDN.

North American Digital Hierarchy

| Primary Multiplex Eg. Digital Switch 24 chan PCM | **DS1** 1.544 Mbps | M12 Multiplex ×4 | **DS2** 6.312 Mbps | M23 Multiplex ×7 | **DS3** 44.736 Mbps |

1
⋮
28

M13 Multiplex **DS3** 44.736 Mbps

European Digital Hierarchy

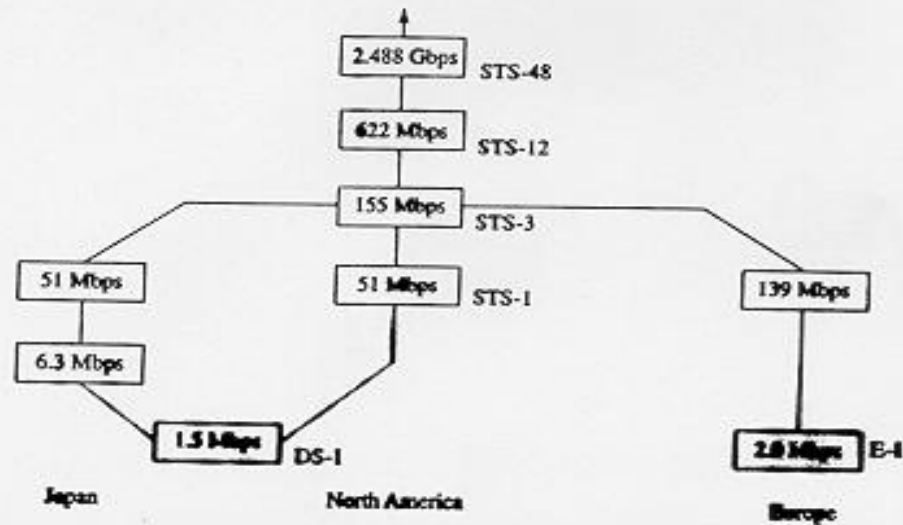| Primary Multiplex Eg. Digital Switch 30 chan PCM | CEPT 1 2.048 Mbps | 2nd order Multiplex ×4 | 8.448 Mbps | 3rd order Multiplex ×4 | 34.368 Mbps | 4th order Multiplex ×4 | CEPT 4 139.264 Mbps |

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

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 Rates

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

10 Gbps

Figure 2-37. SONET and SDH Multiplex Rates

Tanenbaum

SONET Multipexing
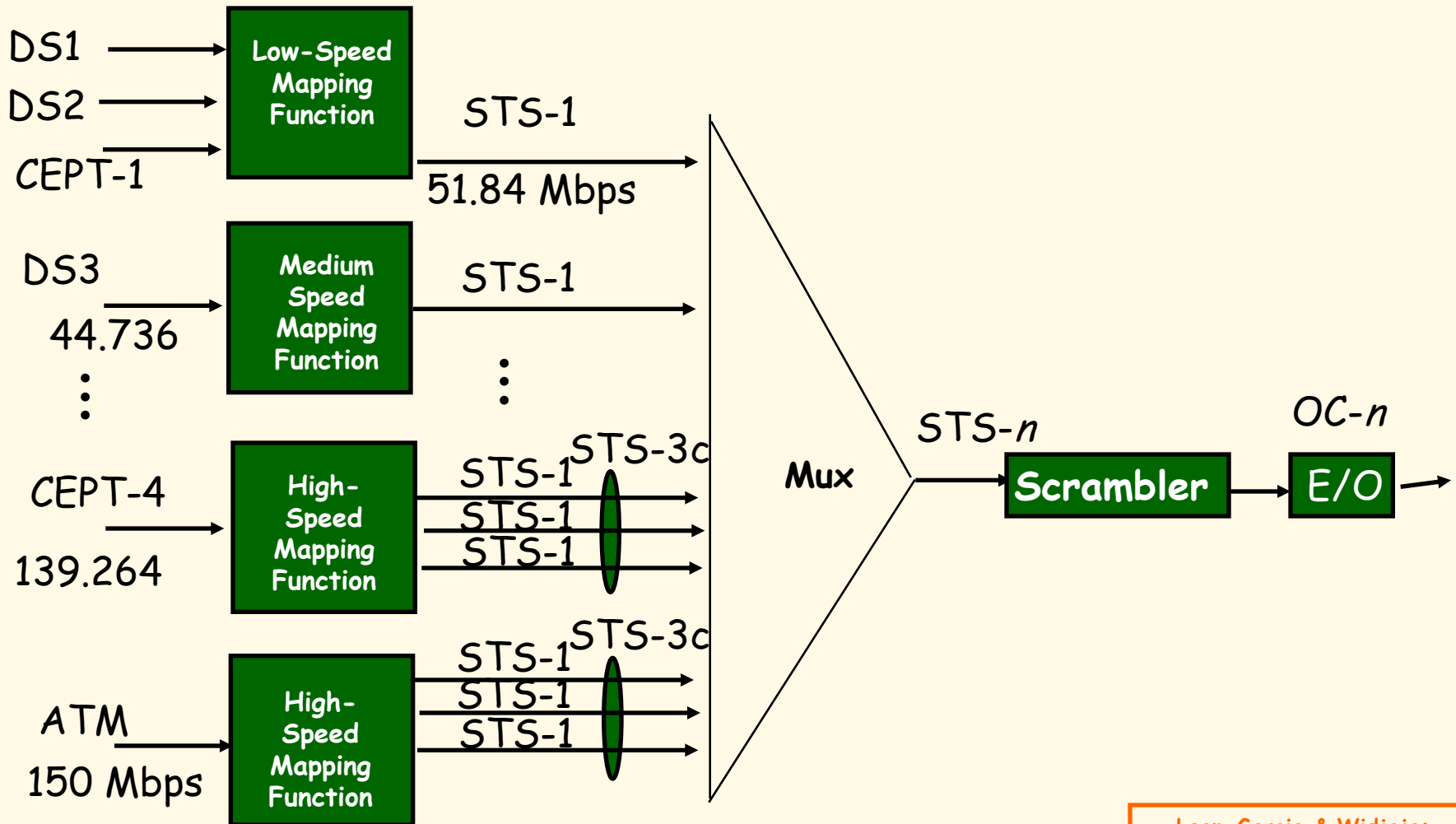
SONET Synchronous Multiplexing

Incoming STS-1 Frames → Map → Synchronized New STS-1 Frames → Byte Interleave → **STS-3**
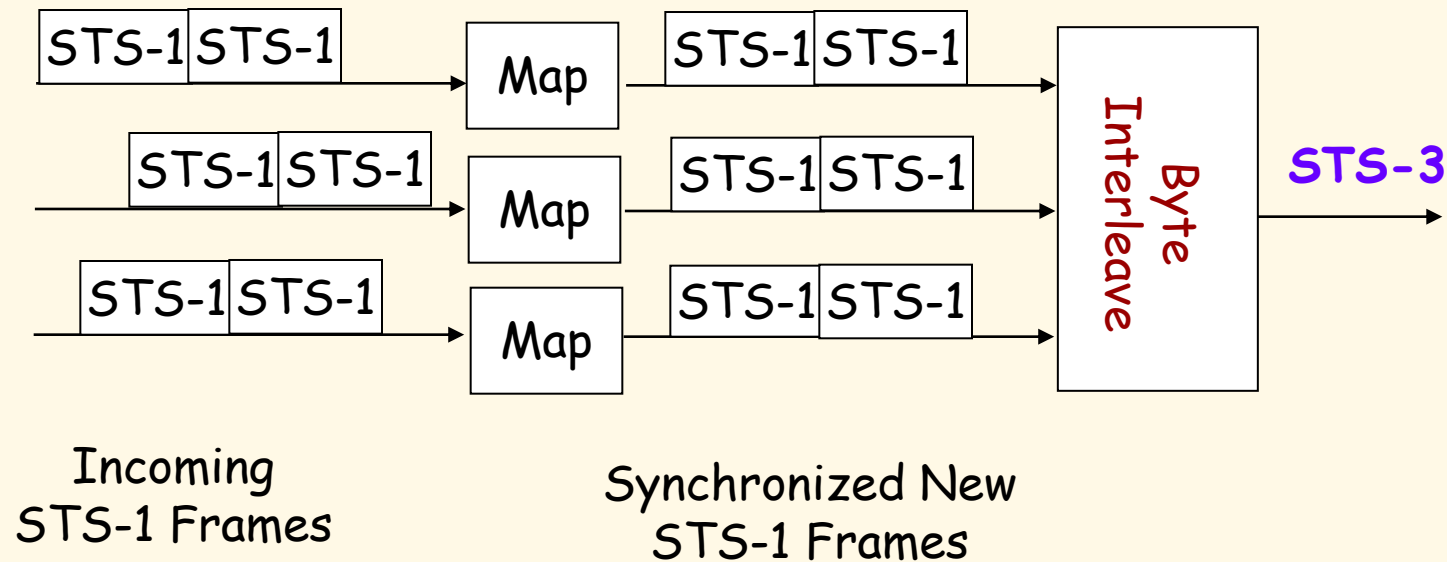
Leon-Garcia & Widjaja:
Communication Networks

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.
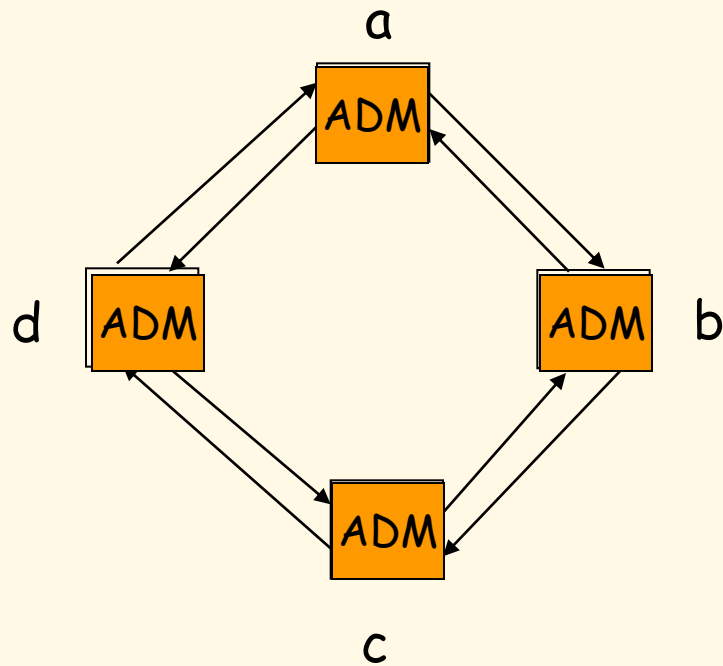
FIRST ALIGN STS-1 FRAMES

- 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
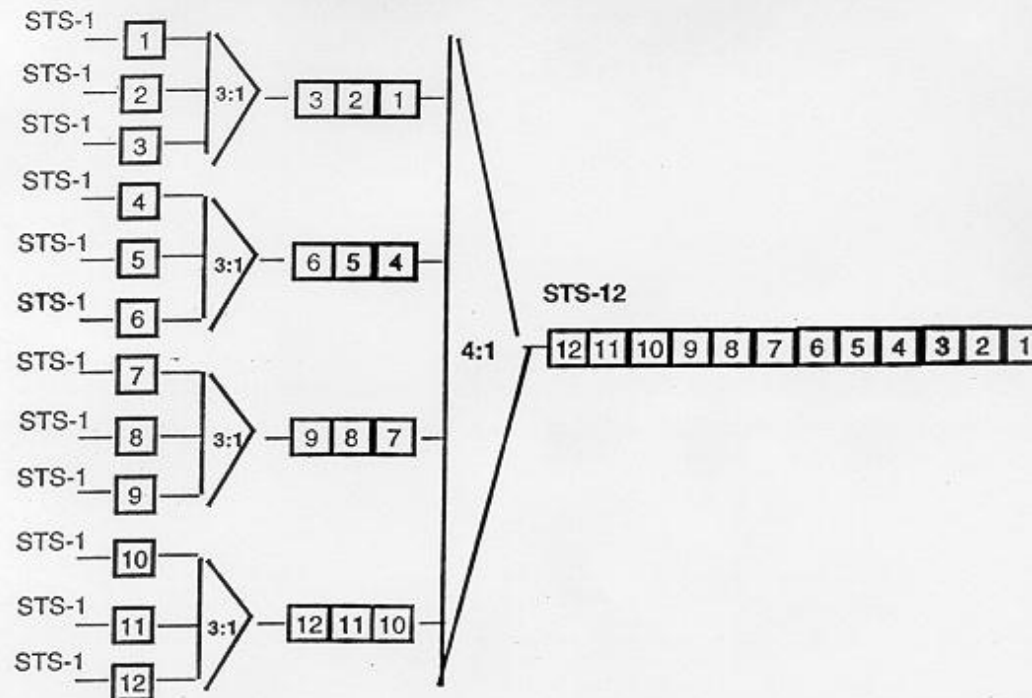
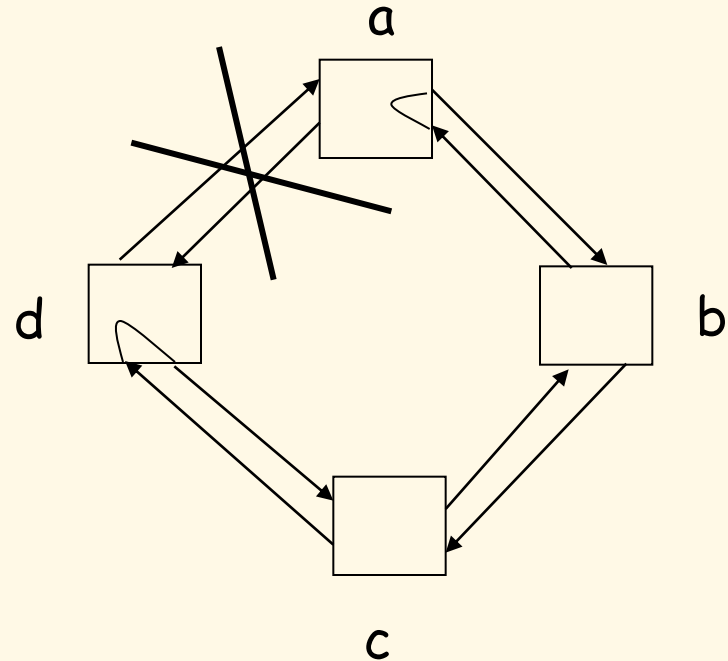# SONET Architecture

- 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.

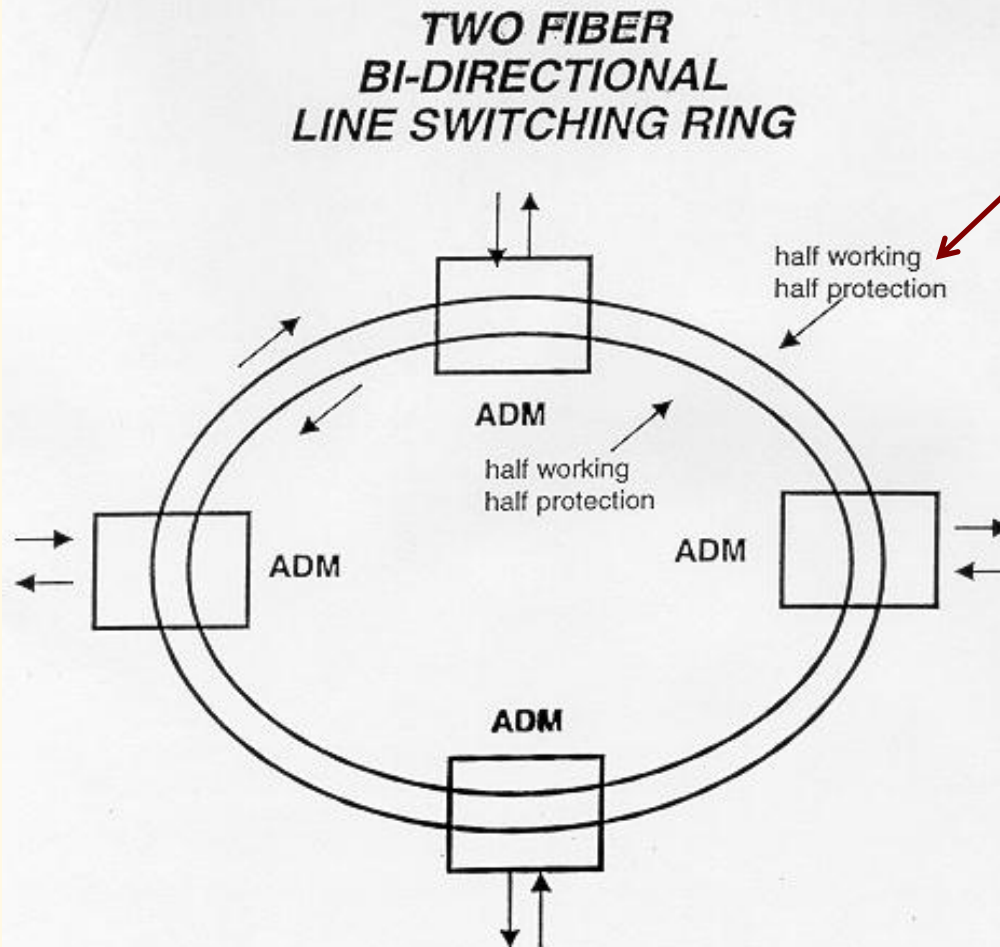 - Used to make up bi-directional line switching rings.

SONET Ring

(a) Dual ring

(b) Loop-around
in response to fault

SONET Ring

TWO FIBER
BI-DIRECTIONAL
LINE SWITCHING RING

Changed from FDDI

half working
half protection

ADM

half working
half protection

ADM

ADM

ADM

ADM

(a) pre-SONET multiplexing

remove
tributary

insert
tributary
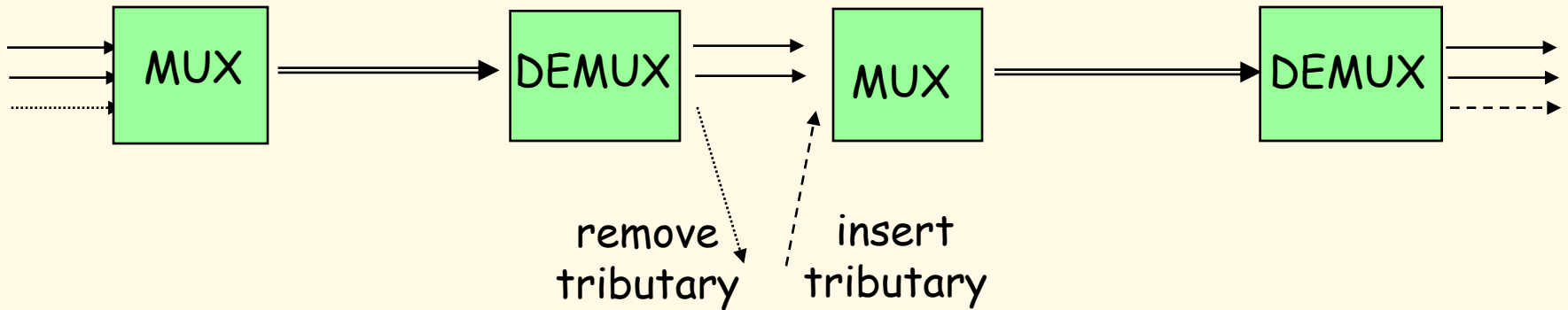
(b) SONET Add-Drop multiplexing

remove
tributary

insert
tributary
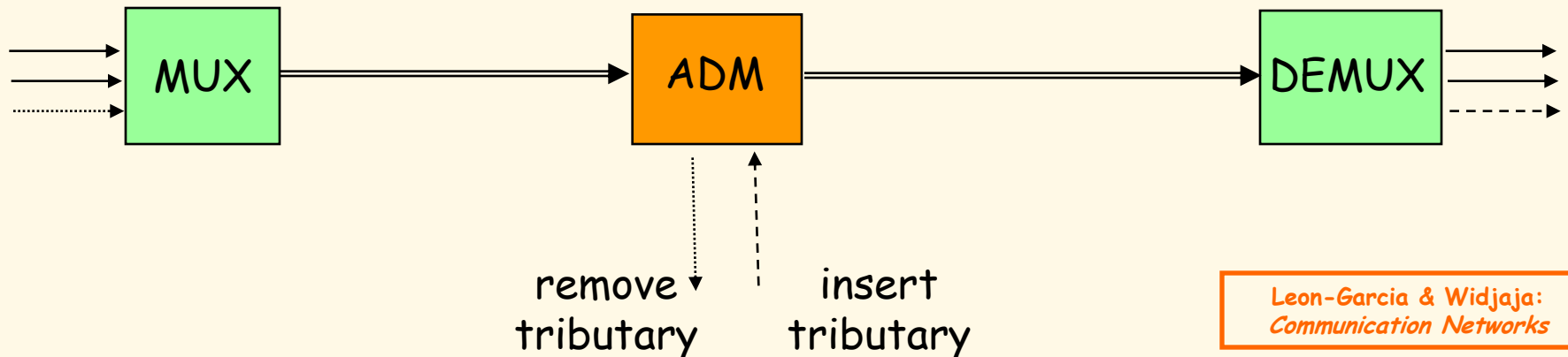
Leon-Garcia & Widjaja:
Communication Networks

SONET Ring

Regional Ring

Metro Ring
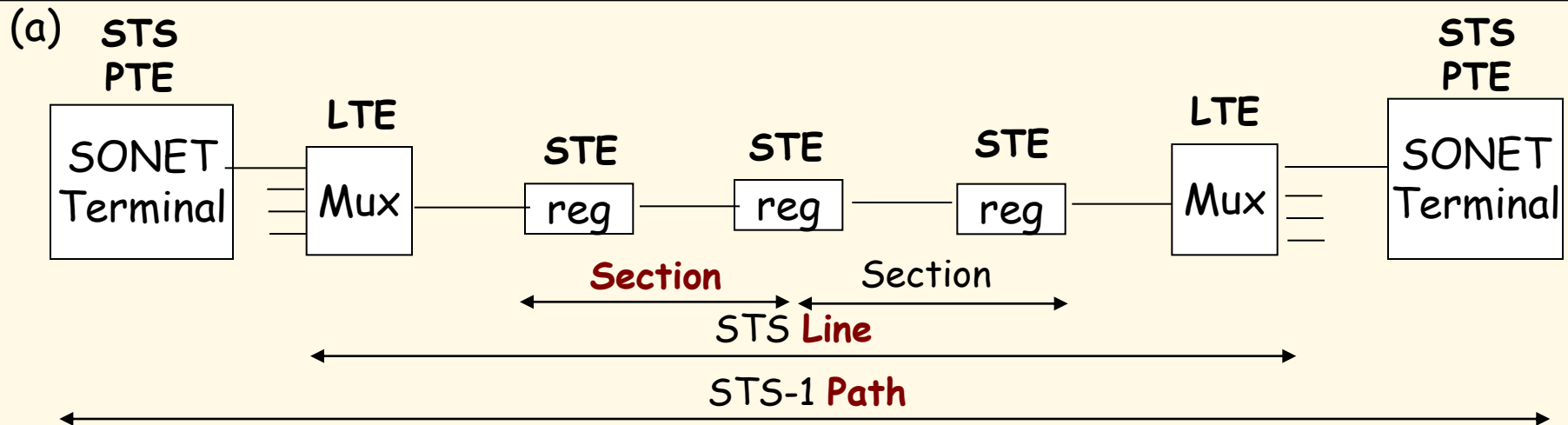
Inter-Office Rings
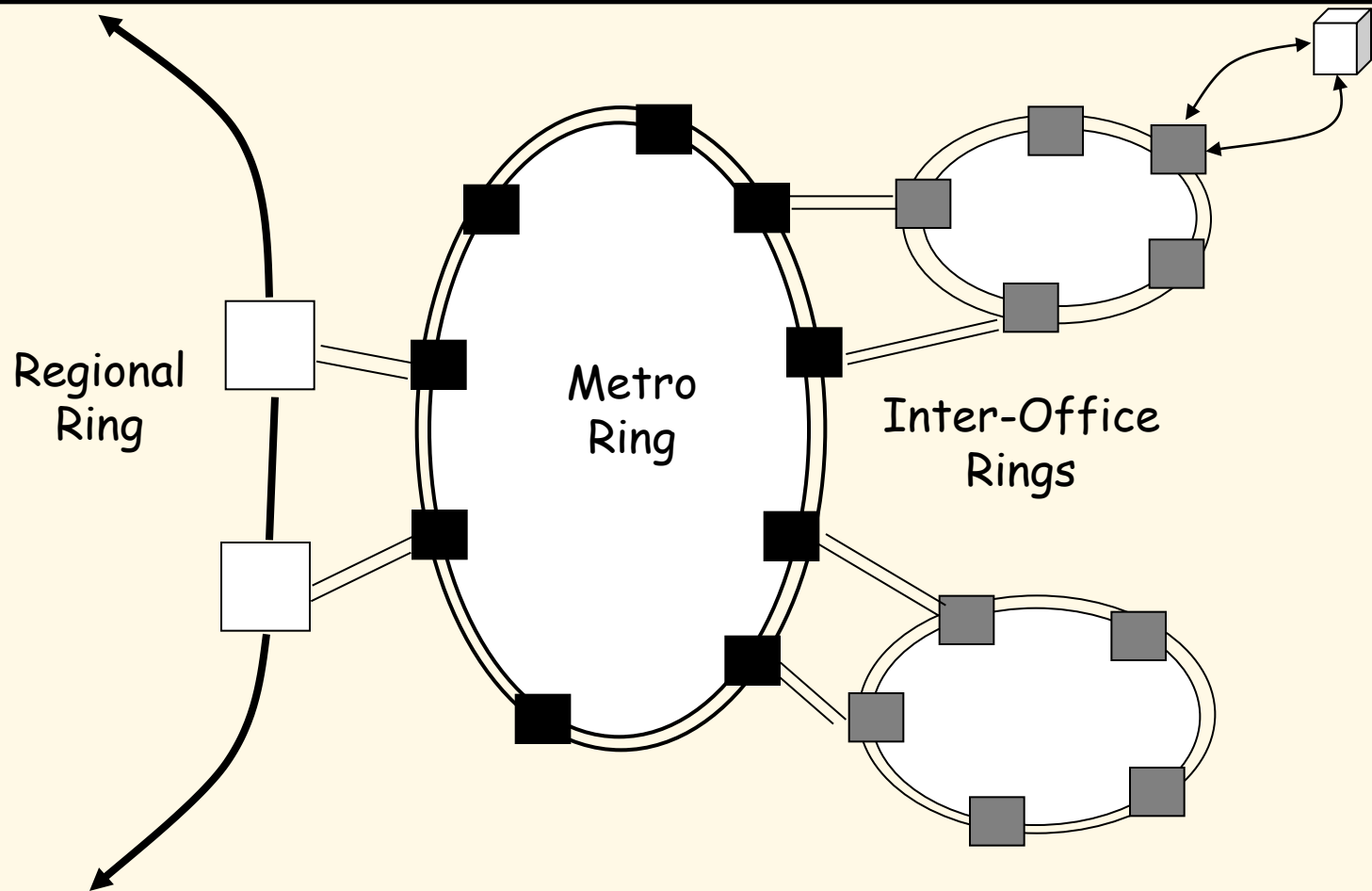
Leon-Garcia & Widjaja:
Communication Networks

Gigabit ATM Over 10 Gb/s SONET Ring
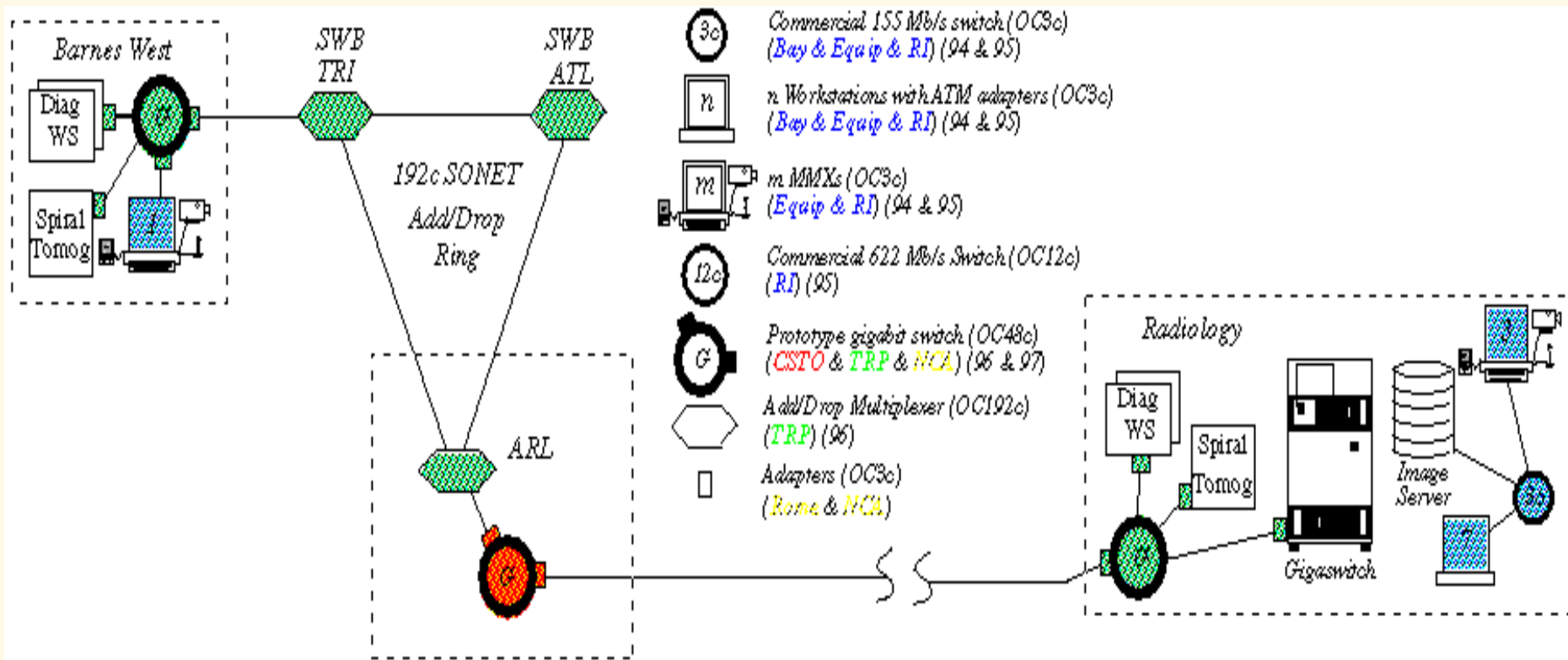
Washington U. St Louis 1995

SONET Architecture

(a)

STS PTE

SONET Terminal

LTE Mux

STE reg

STE reg

STE reg

LTE Mux

STS PTE

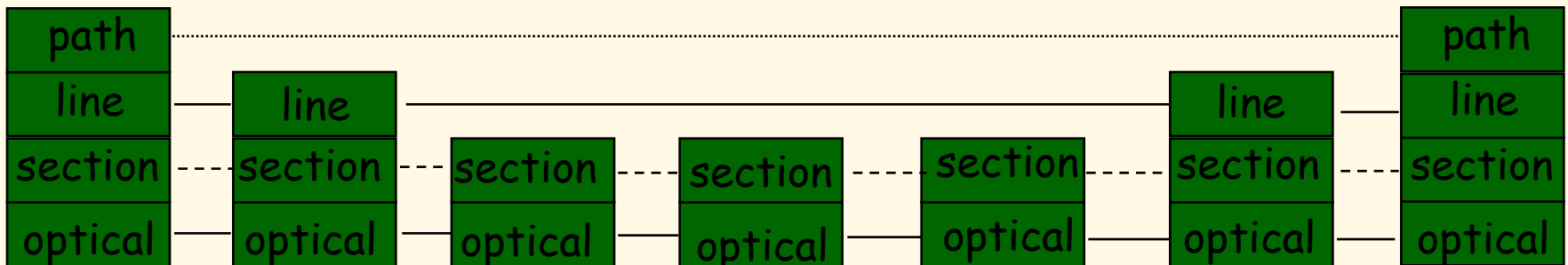SONET Terminal

Section

Section

STS **Line**

STS-1 **Path**

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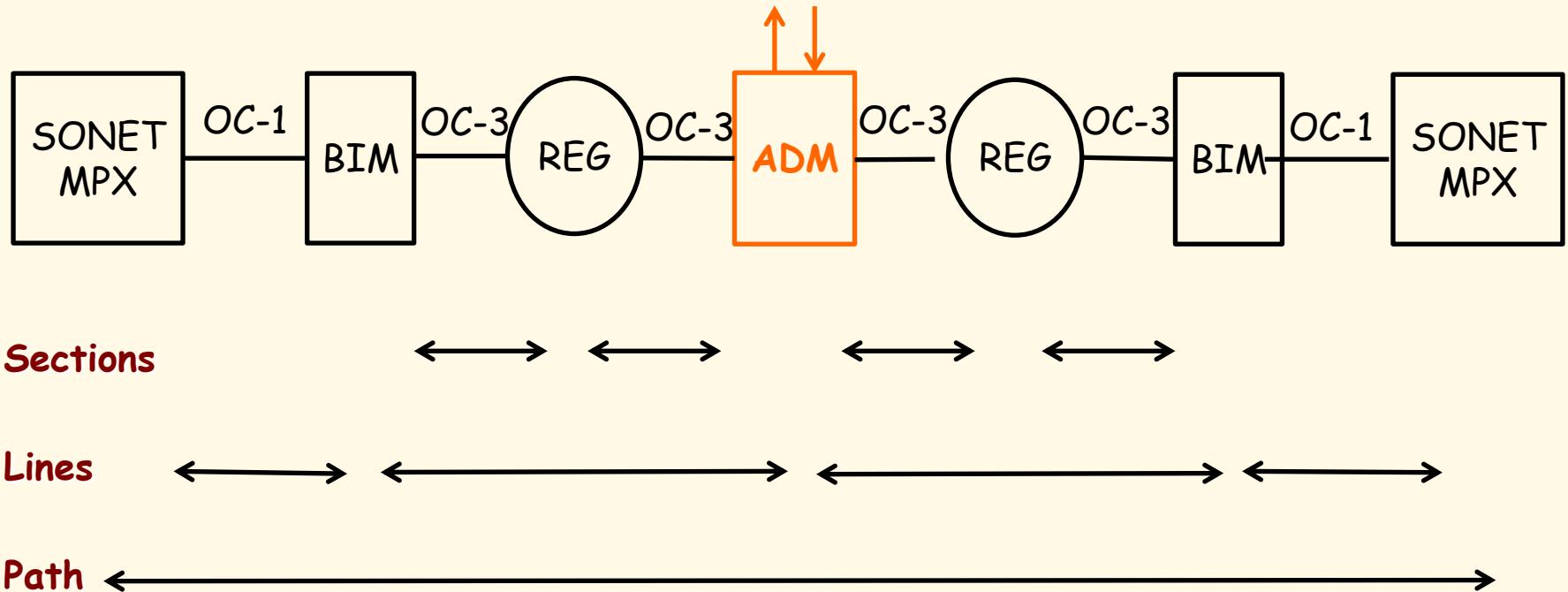PTE: **Path** Terminating Equipment, e.g. an STS-1 multiplexer

Leon-Garcia & Widjaja: Communication Networks

(b)

path							path
line	line				line		line
section	section	section	section	section	section		section
optical	optical	optical	optical	optical	optical		optical

WPI

SONET Architecture

The main SONET elements
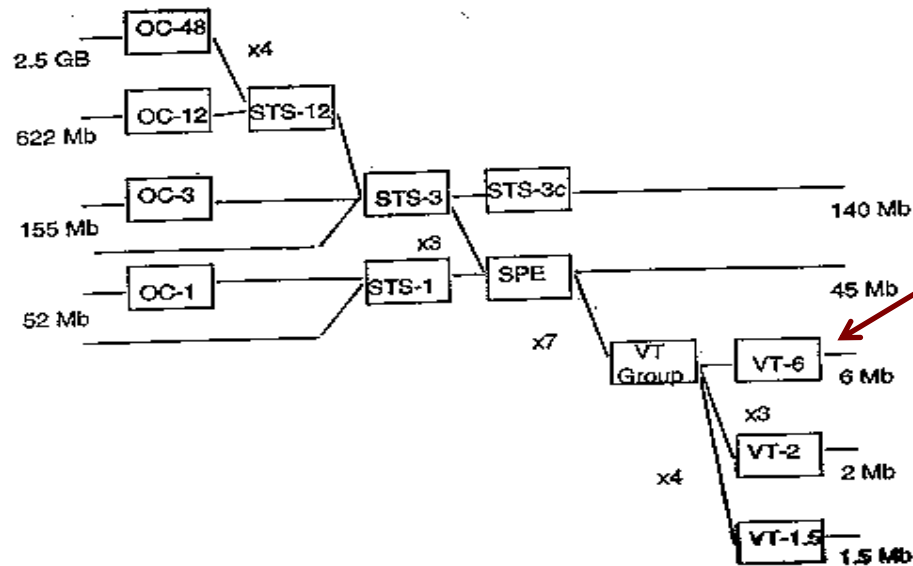
SONET Architecture

| 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.

MULTIPLEXING HIERARCHY

Virtual Tributaries

- *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)
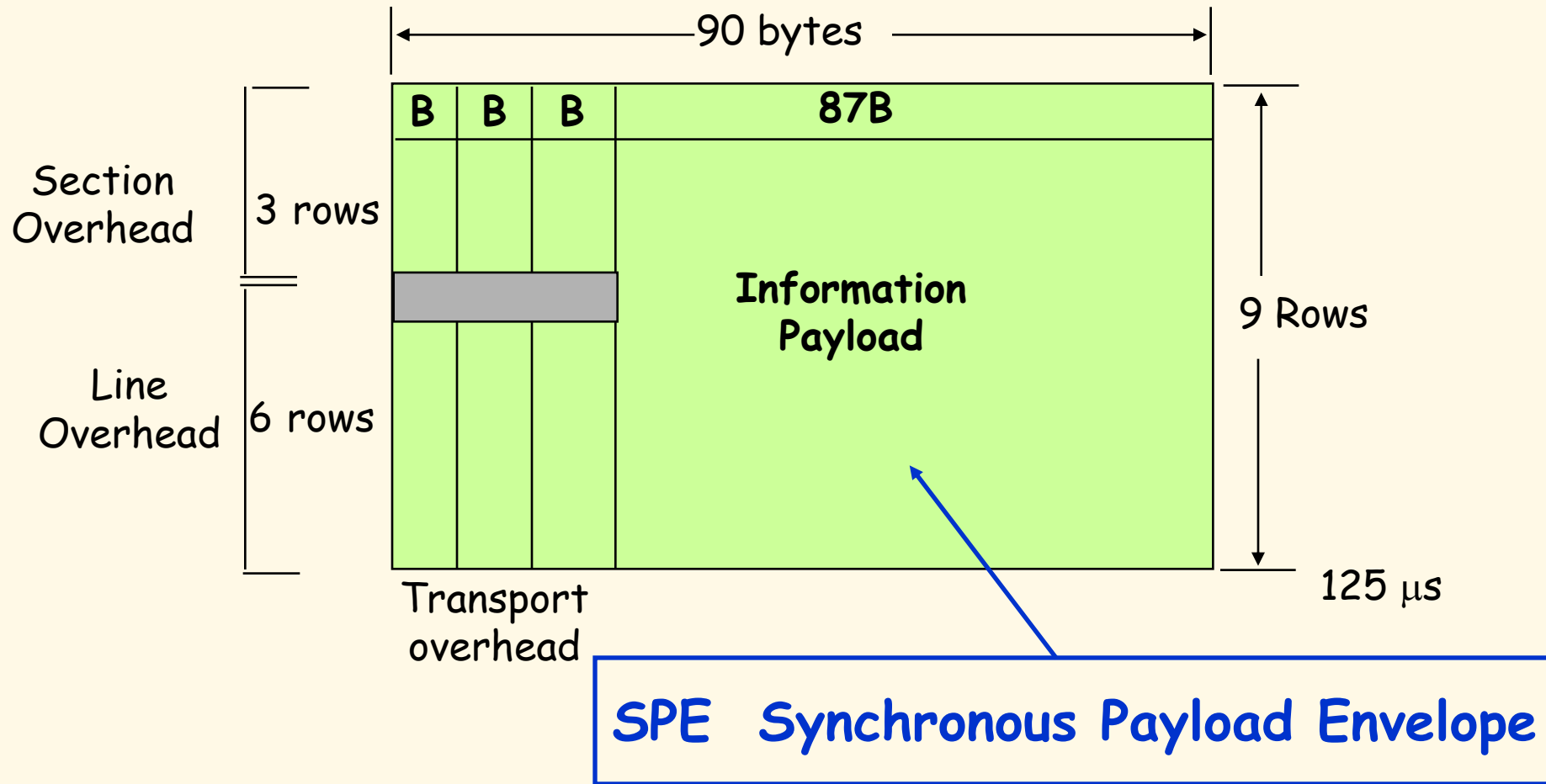
MULTIPLEXING LOWER THAN STS-1 DATA RATES INTO BASIC SONET STS-1

- 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

Section Overhead — 3 rows

Line Overhead — 6 rows

90 bytes

| B | B | B | 87B |

Information Payload

9 Rows

125 μs

Transport overhead

SPE Synchronous Payload Envelope
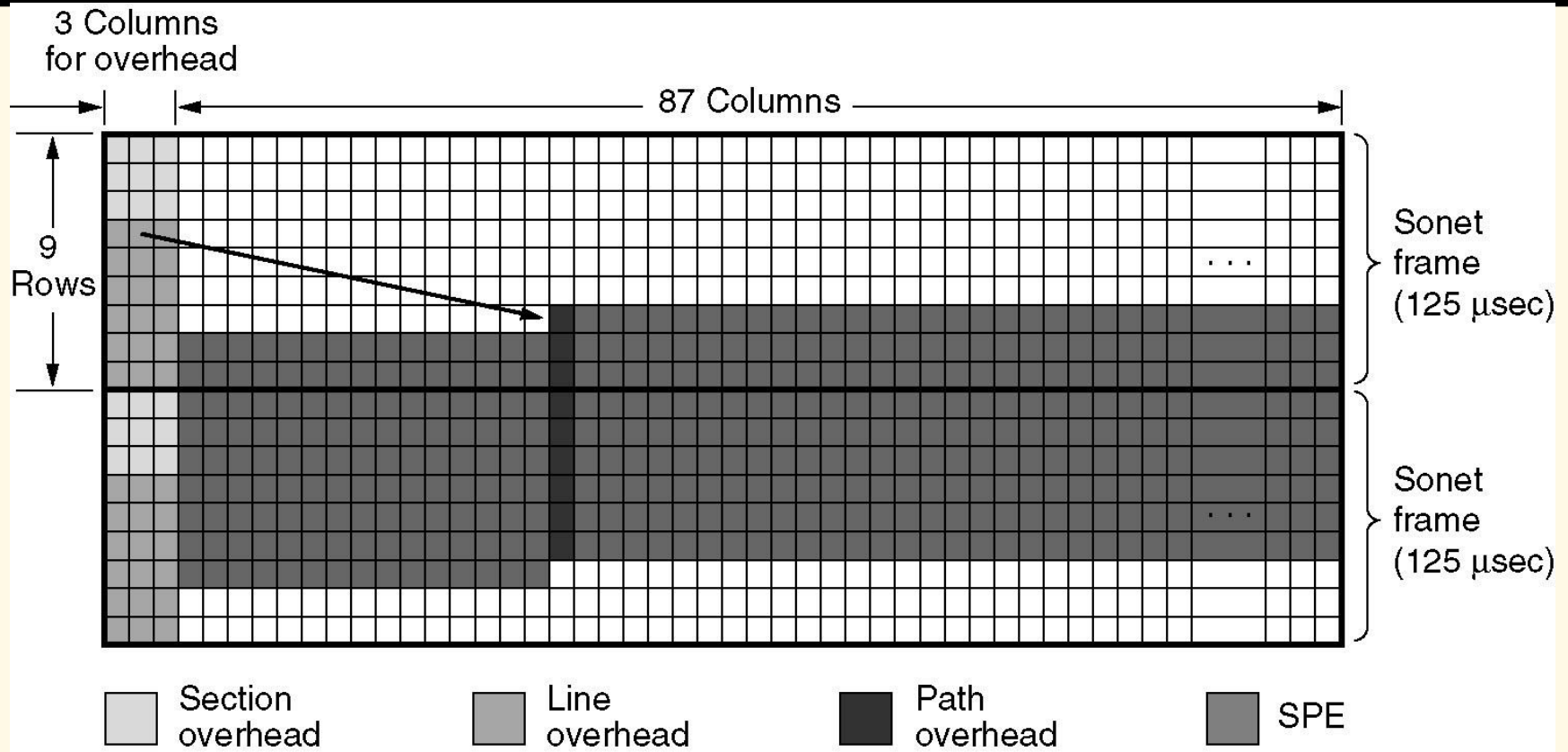
Figure 2-36. Two Back-to-Back SONET Frames

Tanenbaum

SPE straddling SONET Frame

Pointer

frame
k

Pointer

frame
k+1
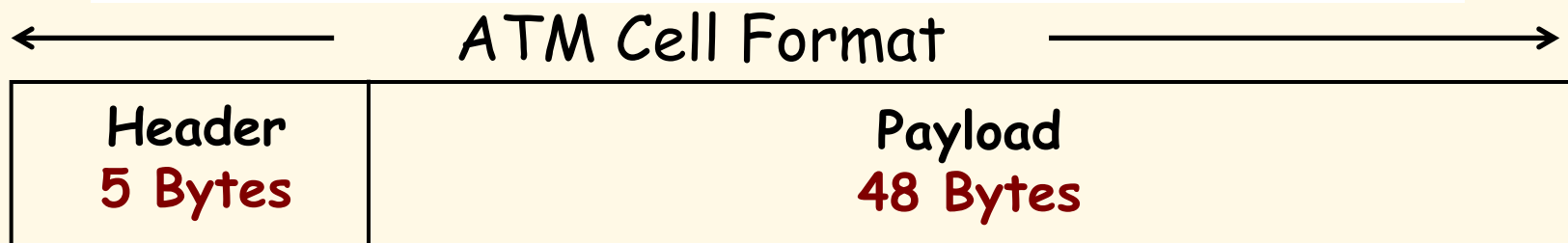
first octet

87 columns

Synchronous
Payload
Envelope

9
rows

last octet

first column is path overhead
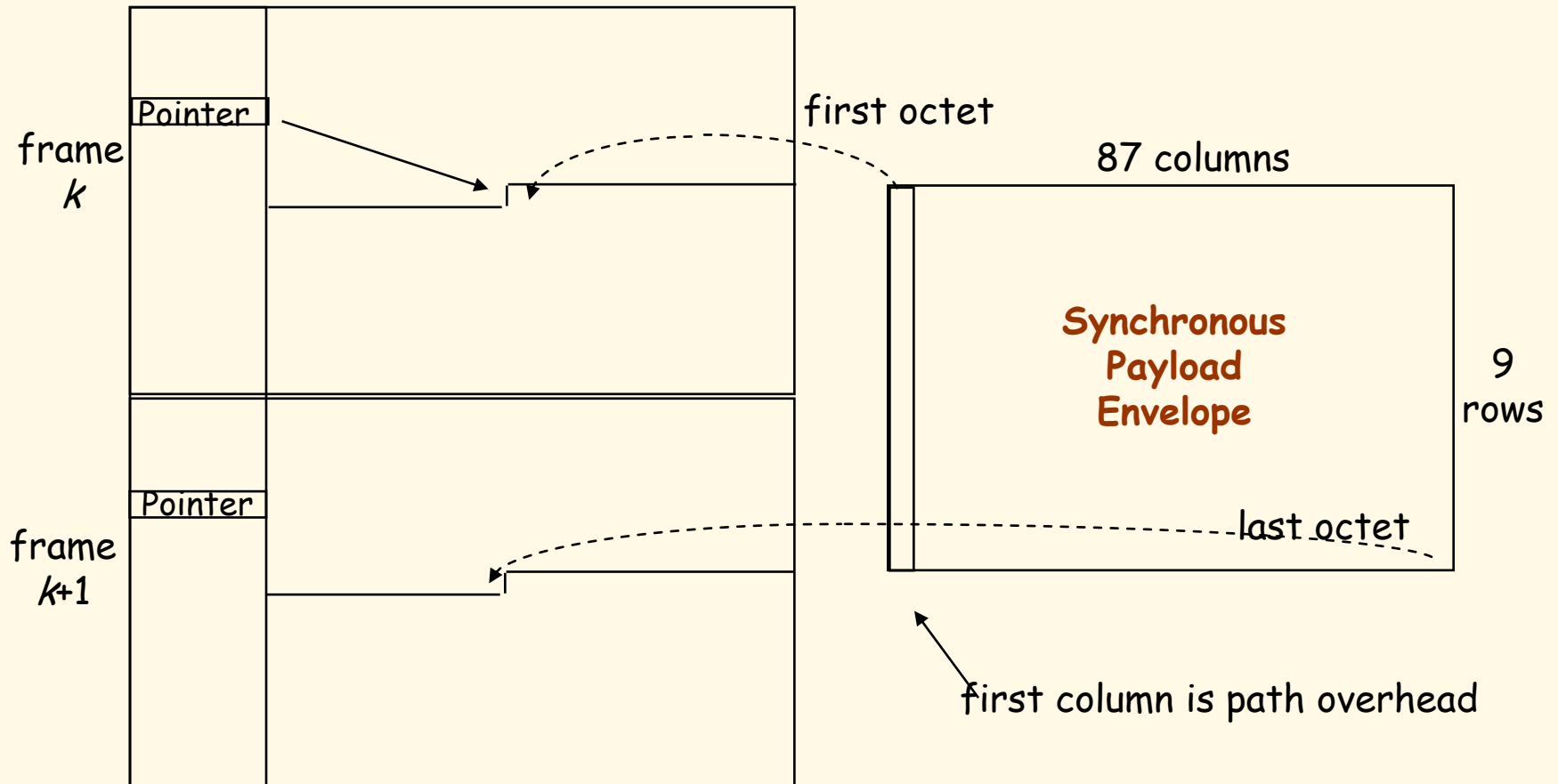
Leon-Garcia & Widjaja:
Communication Networks

ATM Cells in an STS-3 Frame

ATM cell

44 ATM cells

9

10 (OH)

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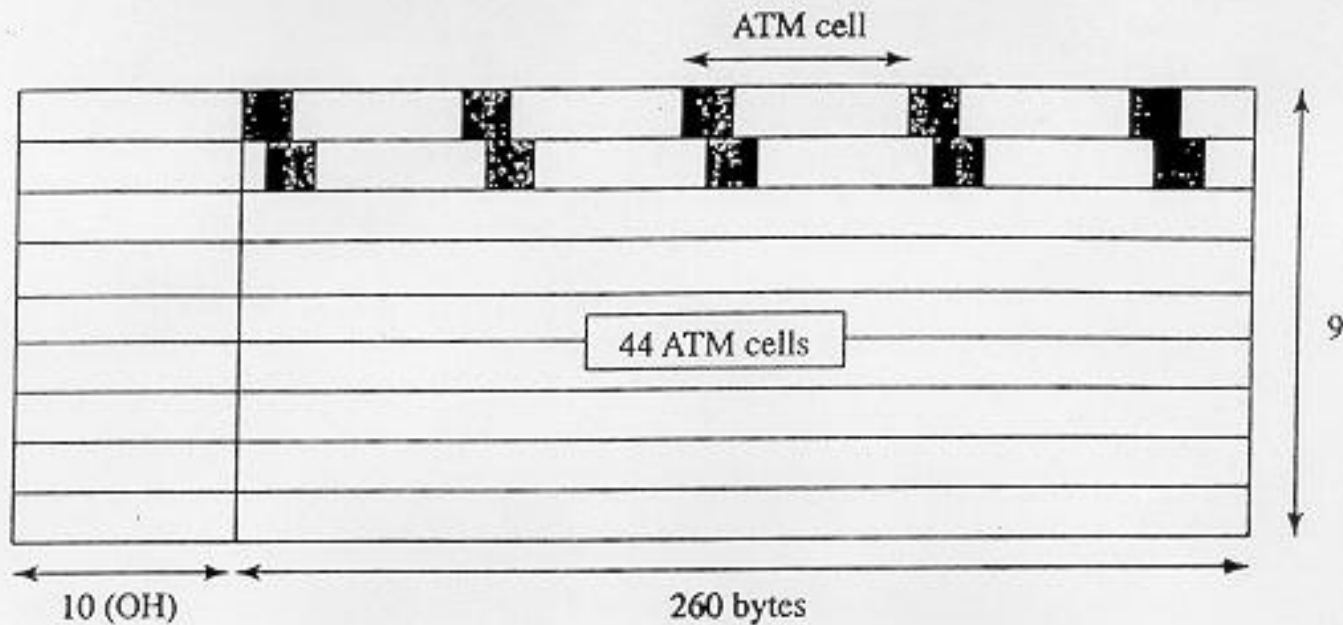
An STS-3 frame accommodates 44 ATM cells. No framing bits are provided to delimit the cell boundary.

ATM Cell Format

Header 5 Bytes	Payload 48 Bytes

SONET Summary

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