Introduction to SONET

Optical Networks

- Networks using optical fiber can be thought as client layers of optical layer
    - Backbone
    - Access
    - Metro
- Backbone optical fiber client layers
    - SONET / SDH
    - Ethernet
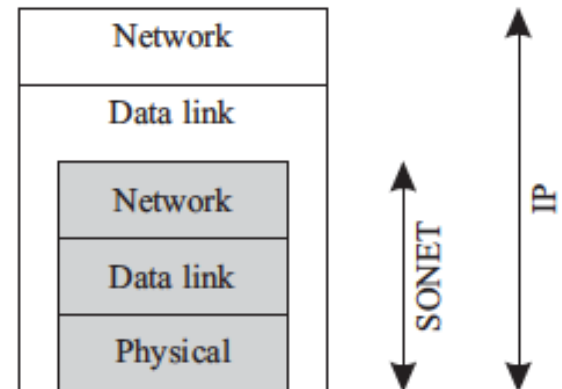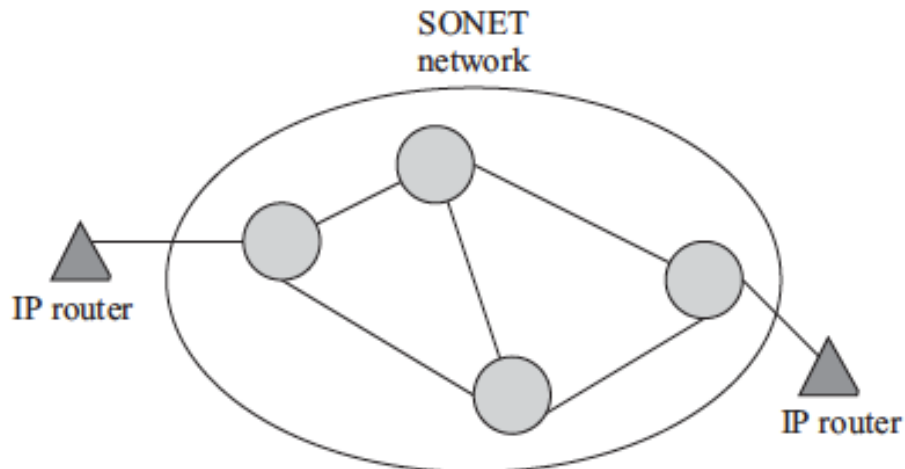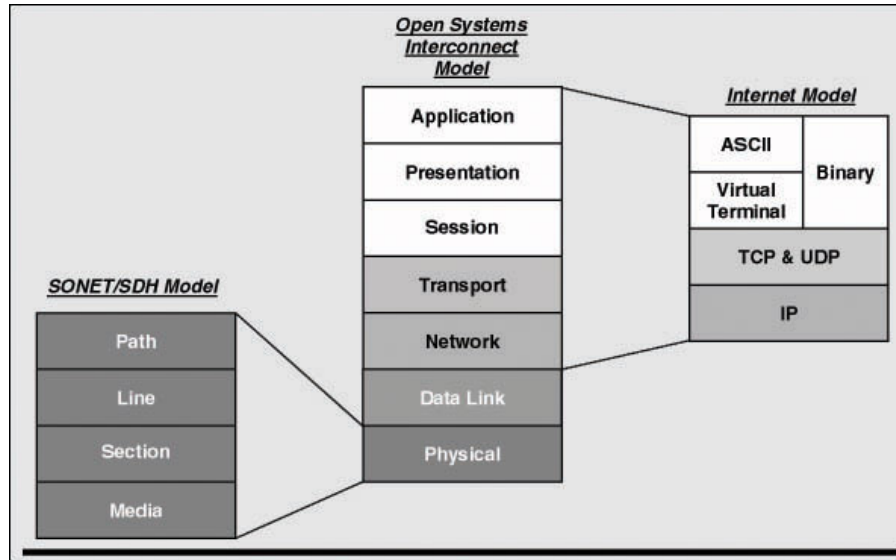   - Optical Transport Network

Other Client Layers - Metro

- Gigabit Ethernet
- 10-Gigabit Ethernet
- Fibre Channel (storage network)
- Resilient Packet Ring (RPR) – packet traffic
- SONET/SDH

SONET/SDH

- SONET/SDH: first generation of optical networks deployed in backbone networks
- Supports constant bit rate (CBR) connections
- Multiplexes CBR connections into higher speed optical connections by using time division multiplexing
- Originally designed for low speed voice and CBR connections, up to 51 Mb/s
- Supports data network, packet traffic that can have link transmission rates in the tens of gigabits per second.
- It provides carrier grade service of high availability

SONET Layers

Open Systems Interconnect Model

Internet Model

SONET/SDH Model

SONET/SDH Model	OSI Model	Internet Model
	Application	ASCII / Binary
	Presentation	Virtual Terminal
	Session	
	Transport	TCP & UDP
Path	Network	IP
Line	Data Link	
Section	Physical	
Media		

SONET network

IP router

IP router

Network

Data link

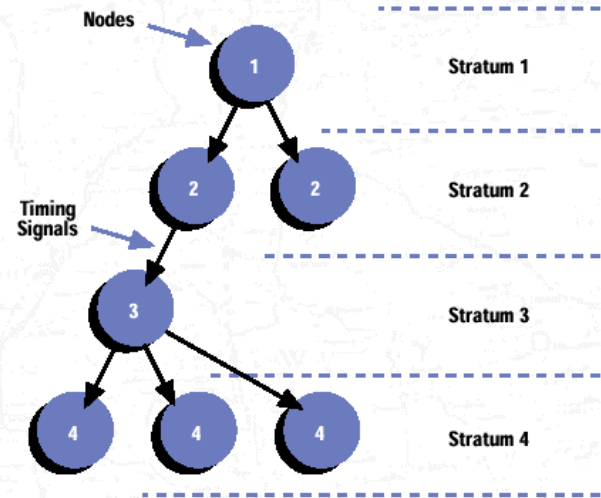Network

Data link

Physical

SONET

IP

SONET/SDH

- Synchronous Optical Network
  - Transmission and multiplexing standard for high-speed signals within the carrier infrastructure in North America

- SDH (Synchronous Digital Hierarchy), has been adopted in Europe and Japan

SONET Timing
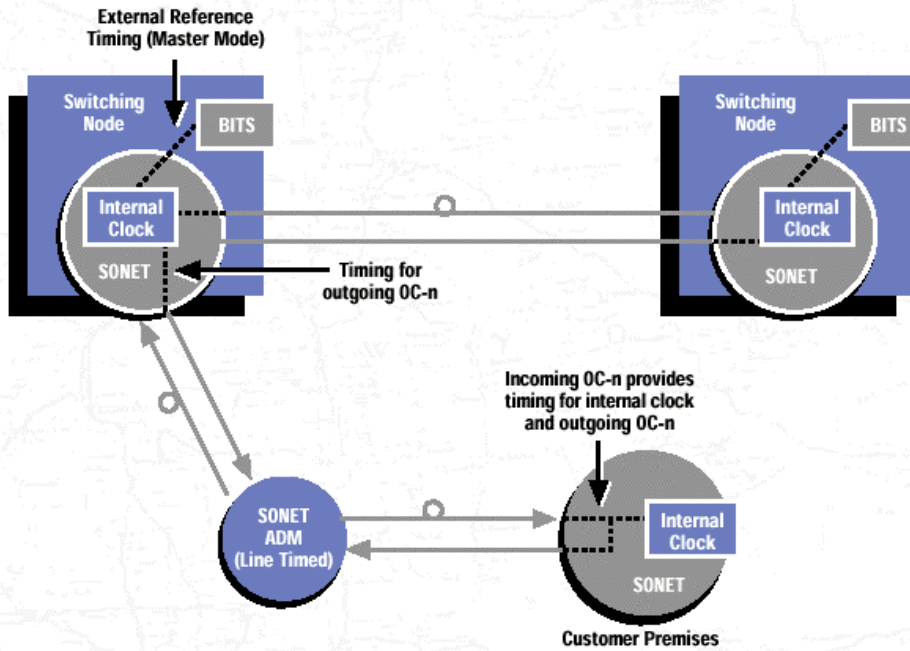
Synchronizing a SONET Network

Digital Network Synchronization Hierarchy

Synchronization vs. Plesiochronous

- Plesiochronous digital hierarchy (PDH)
  - Known as asynchronous digital hierarchy in North America
  - Used for multiplexing digital voice circuits
    - 4KHz Bandwidth
    - Sampled at 8KHz
    - Bit rate of 64 kbps (basic stream)
    - Higher speeds are achieved by multiple of basic stream
- In North America the basic voice rate is called digital signal – n
  - E.g., DS0, DS1,
- In Europe this hierarchy is labeled as E0, E1, E2, E3, & so on

Level	North America	Europe	Japan
0	0.064 Mb/s	0.064 Mb/s	0.064 Mb/s
1	1.544 Mb/s	2.048 Mb/s	1.544 Mb/s
2	6.312 Mb/s	8.448 Mb/s	6.312 Mb/s
3	44.736 Mb/s	34.368 Mb/s	32.064 Mb/s
4	139.264 Mb/s	139.264 Mb/s	97.728 Mb/s

Plesiochronous - Issues

- Each system has its own clock (asynchronous) – nominal clock
  - Difference in clock can generate serious synch. Issues
    - 20 ppm difference between clocks → 1.8 kbps bit rate difference
  - Bit stuffing is typically used to compensate for difference in transmission rates
    - Transmission rates are not exactly integral multiple of the basic rate (64 kbps)
    - DS1 (1.544 Mbps) > 24 x 64 kbps !
  - In order to extract lower rate the entire signal has to be demultiplexed – expensive!
- Provides little/no management information including performance monitoring
- Offers little standards for reliability

SONET / SDH Standards - Advantages

- Higher bit rates are integral multiples of lower rates

- All clocks are perfectly synchronized (via a master clock)

- Incorporate extensive management information, e.g., performance monitoring

- Provides interoperability between different devices by different vendors

- Fast restoration time (much longer in PDH)

SONET / SDH Multiplexing

- SONET basic rate is 51.84 Mbps
  - Called the synchronous transport signal level-1 (STS-1)
  - STS is an electrical signal
  - It uses scrambling (to avoid long runs of 1s and zeros)
  - Higher rate signals (STS-N) are obtained by interleaving N frames
    - No need for bit stuffing
    - Simple demultiplexing process
- Optical interfaces of STS-N are labeled as OC-N

SONET Signal	SDH Signal	Bit Rate (Mb/s)
STS-1		51.84
STS-3	STM-1	155.52
STS-12	STM-4	622.08
STS-24		1244.16
STS-48	STM-16	2488.32
STS-192	STM-64	9953.28
STS-768	STM-256	39, 814.32

Level	North America	Europe	Japan
0	0.064 Mb/s	0.064 Mb/s	0.064 Mb/s
1	1.544 Mb/s	2.048 Mb/s	1.544 Mb/s
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3	44.736 Mb/s	34.368 Mb/s	32.064 Mb/s
4	139.264 Mb/s	139.264 Mb/s	97.728 Mb/s

SONET Hierarchy

SONET Hierarchy

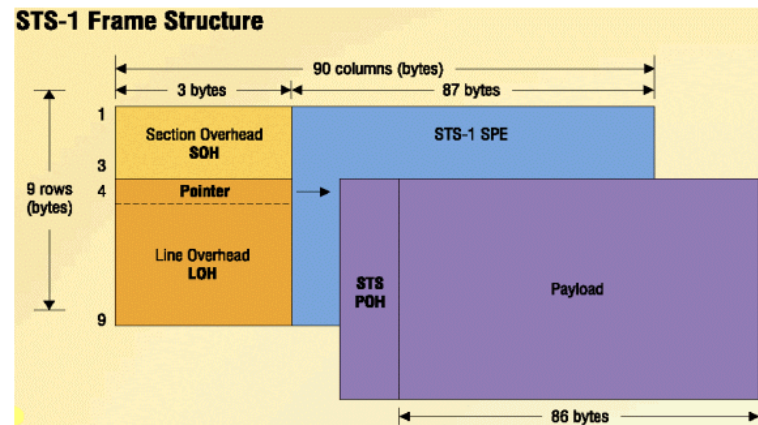| Signal	Bit Rate	Capacity
STS-1, OC-1	51.840 Mb/s	28 DS1s or 1 DS3
STS-3, OC-3	155.520 Mb/s	84 DS1s or 3 DS3s
STS-12, OC-12	622.080 Mb/s	336 DS1s or 12 DS3s
STS-48, OC-48	2488.320 Mb/s	1344 DS1s or 48 DS3s
STS-192, OC-192	9953.280 Mb/s	5376 DS1s or 192 DS3s
STS-768, OC-768	39813.12 Mb/s	21504 DS1s or 768 DS3s

STS = Synchronous Transport Signal

OC = Optical Carrier

Non-Synchronous Hierarchy

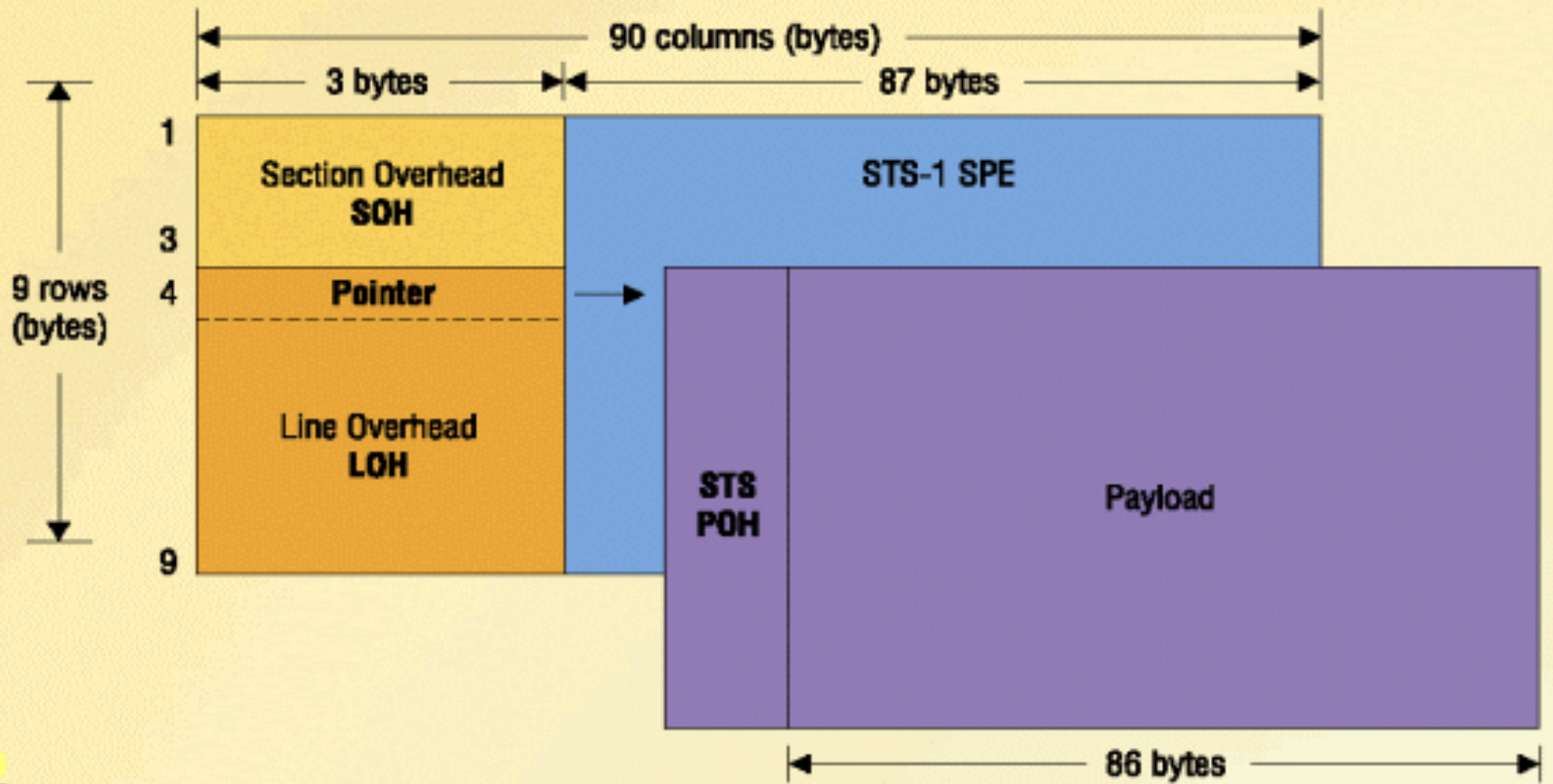| Signal	Bit Rate	Channels
DS0	64 kb/s	1 DS0
DS1	1.544 Mb/s	24 DS0s
DS2	6.312 Mb/s	96 DS0s
DS3	44.736 Mb/s	28 DS1s

SONET Frame

- SONET frame
  - Overhead bytes called transport overhead
  - Payload
  - STS payload is carried in synchronous payload envelope (SPE)
    - SPE contains additional path overhead
- SONET uses pointers to indicate the location of the payload data within the frame
  - Clock phase differences can be compensated using pointer adjustments (no bit stuffing)
   - Pointer processing is complex!

STS-1 Frame Structure

90 columns (bytes)
3 bytes — 87 bytes
9 rows (bytes)
Section Overhead SOH
STS-1 SPE
Pointer
Line Overhead LOH
STS POH
Payload
86 bytes

Framing

STS-1 Frame Structure

SONET Frame

- Lower-speed non-SONET streams below the STS-1 rate are mapped into virtual tributaries (VTs)
  - Four VT sizes
  - SDH uses Virtual Container (VC) to accommodate for lower speed signals
- SONET allows multiplexing lower-speed asynchronous streams into Virtual Tributary
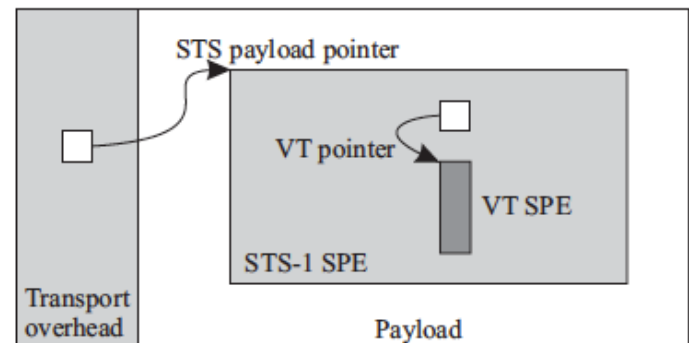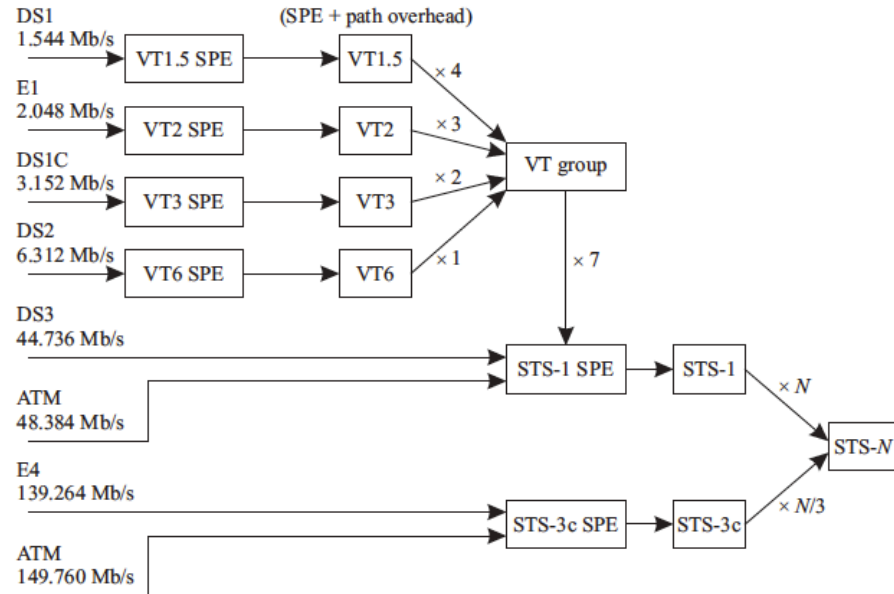
SONET Concatenation

- An STS-**N**c signal with a locked payload is also defined in the standards
  - The "c" stands for concatenated
  - **N** is the number of STS-1 payloads
- The concatenated or locked payload implies that this signal cannot be demultiplexed into lower-speed streams
- Example: 150 Mb/s client signal can be mapped into an STS-3c signal
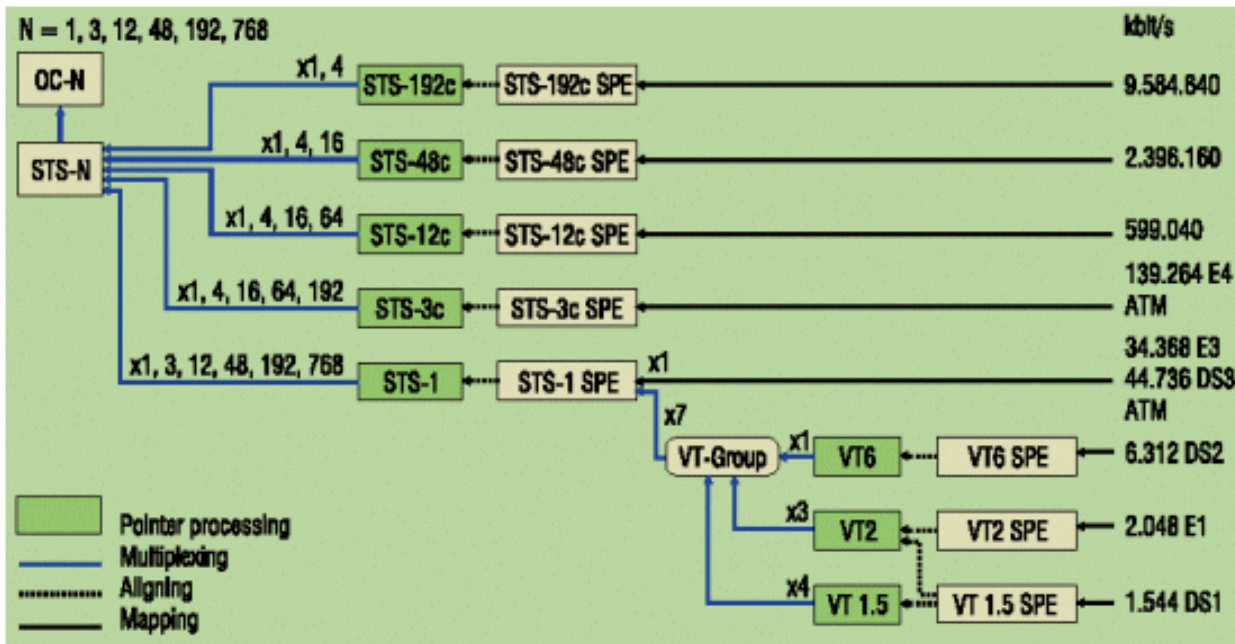
How do we use SONET to carry Gigabit Ethernet?

Virtual Concatenation

- Virtual Concatenation (VCAT) allows noncontiguous payloads to be combined as a single connection

- Such a grouping is referred to as a virtual concatenation group (VCG)

- The VCAT notation for SONET
  - STS-**N** -**M** v
  - **N** is the size of a member & **M** is the number of members in a VCG

- Example: How do we carry GigabitE

STS-3-7V (155 Mbps x 7) about 1.05 (excluding the overhead) – 5 percent overprovisioning!

SONET Layers
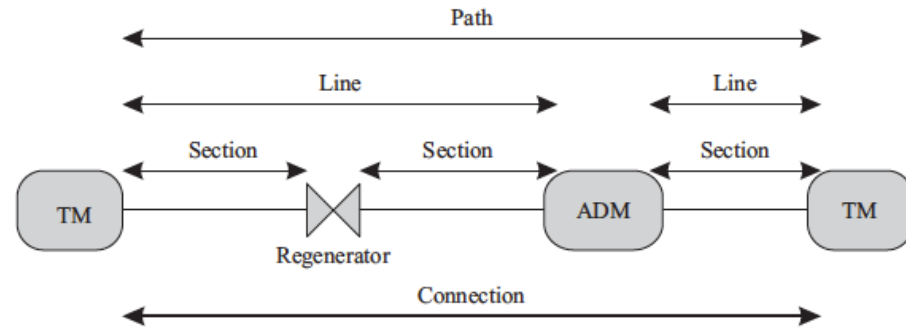
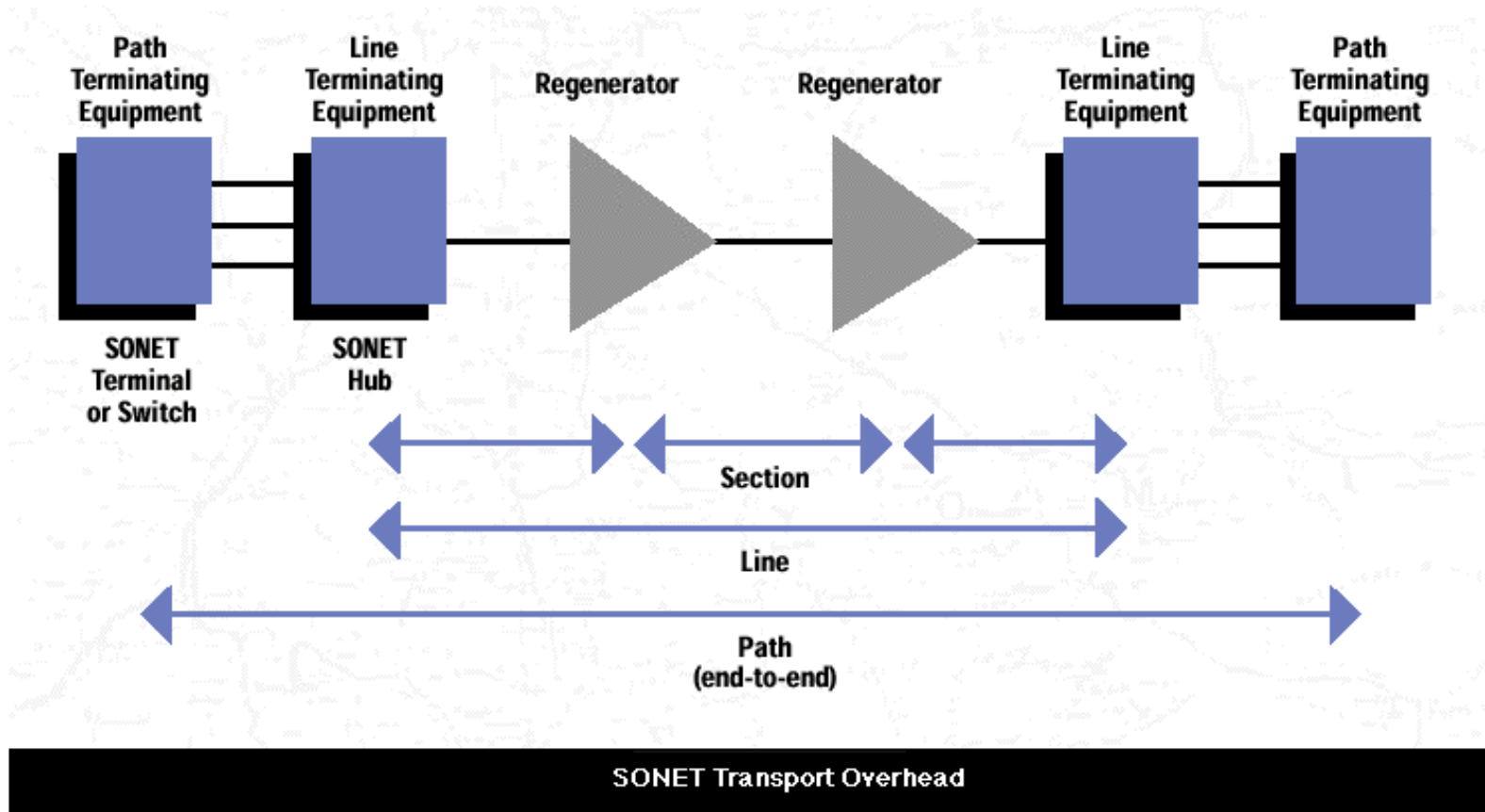TM: terminal multiplexer (end-to-end) connection
ADM: Add/drop multiplexer

- SONET layer consists of four sublayers
  - path, line, section, and physical layers
- Physical layer interfaces
  - Different rates
  - Electrical / optical
  - Distance (code):
    - Intraoffice (short reach) – I
    - Short haul 15km/1310 or 40km/1550 - S
    - Long haul 40km/1310 or 80km/1550 (400-600 km with Amplifiers) - L
    - Very long haul 60km/1310 or 120km/1550
    - ultra long haul 160km
- Fiber type
  - Standard single-mode fiber (G.652)
  - Dispersion-shifted fiber (G.653)
  - Nonzero dispersion-shifted fiber (G.655)
- The transmitter types
 - LEDs or multilongitudinal mode (MLM), single-longitudinal mode (SLM) distances

Different Physical Interfaces for SDH (similar for SONET)

Bit Rate	Code	Wavelength (nm)	Fiber	Loss (dB)	Transmitter	Dispersion (ps/nm)
STM-1	I-1	1310	G.652	0-7	LED/MLM	18/25
	S-1.1	1310	G.652	0-12	MLM	96
	S-1.2	1550	G.652	0-12	MLM/SLM	296/NA
	L-1.1	1310	G.652	10-28	MLM/SLM	246/NA
	L-1.2	1550	G.652	10-28	SLM	NA
	L-1.3	1550	G.653	10-28	MLM/SLM	296/NA

Physical Layer
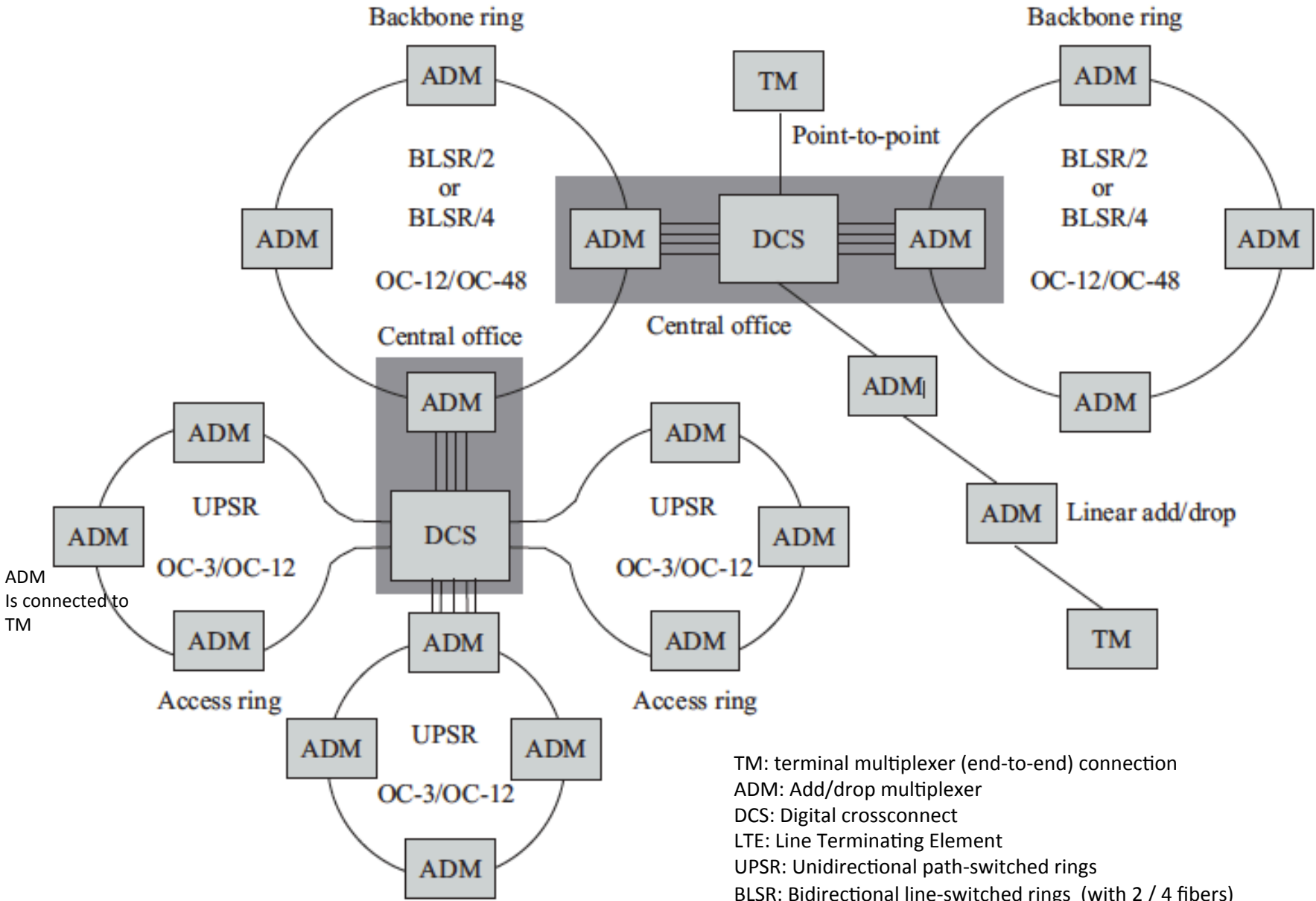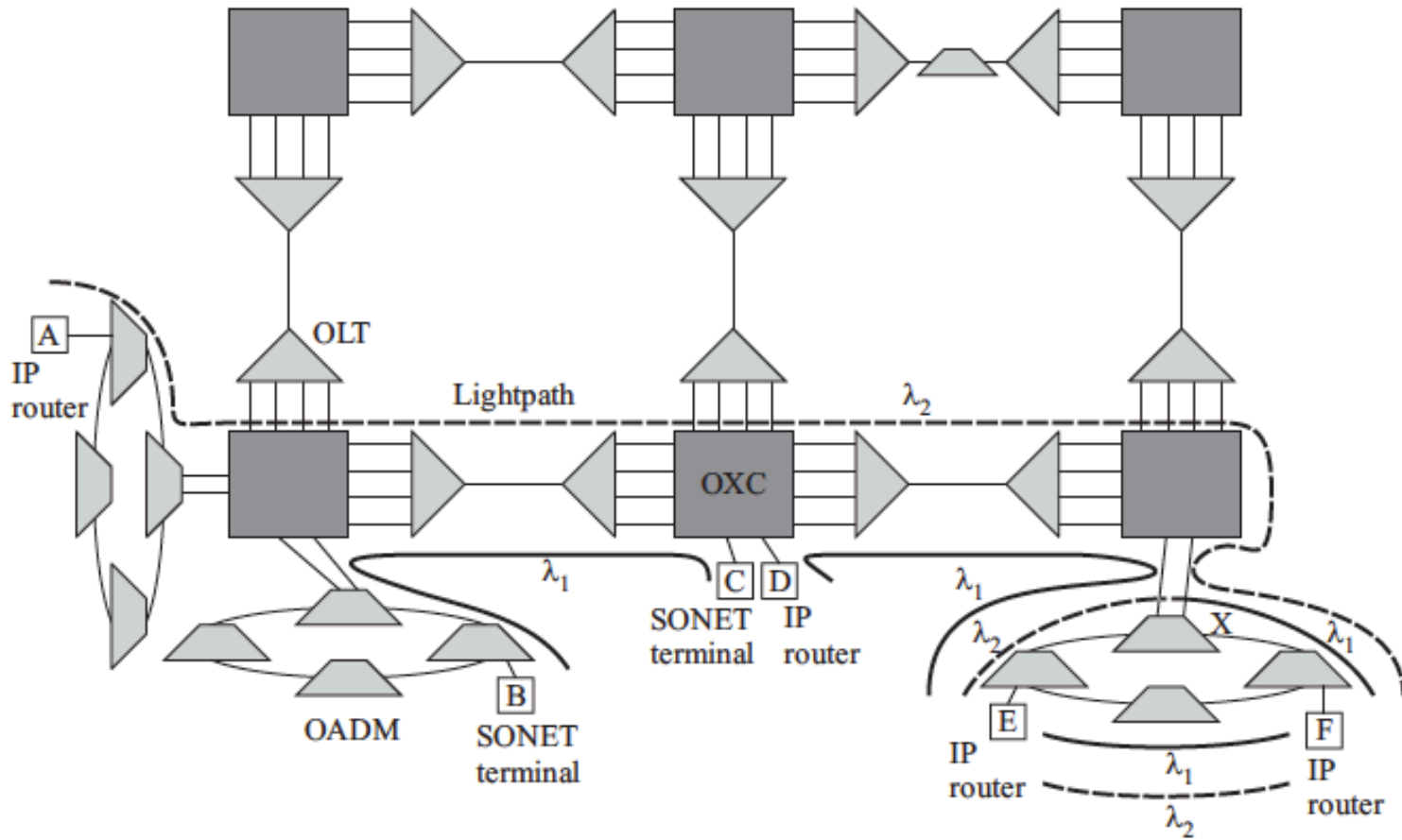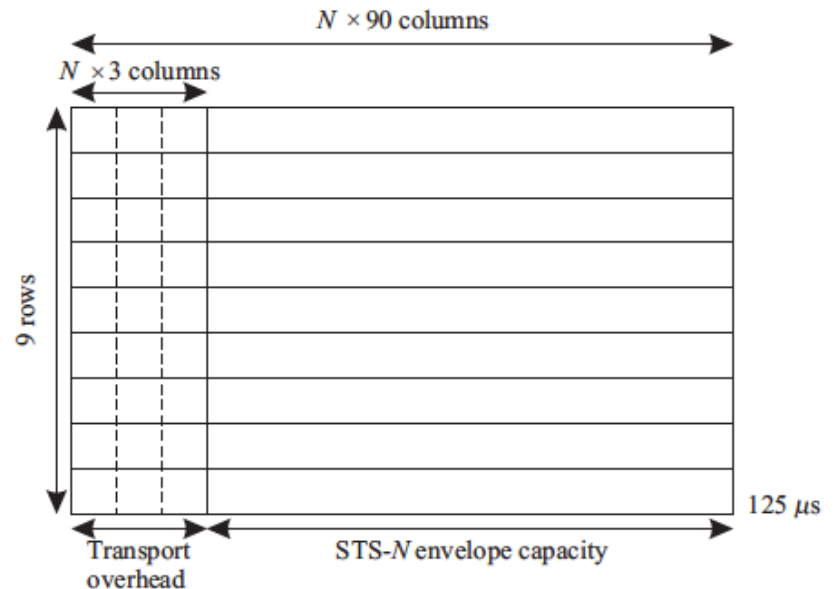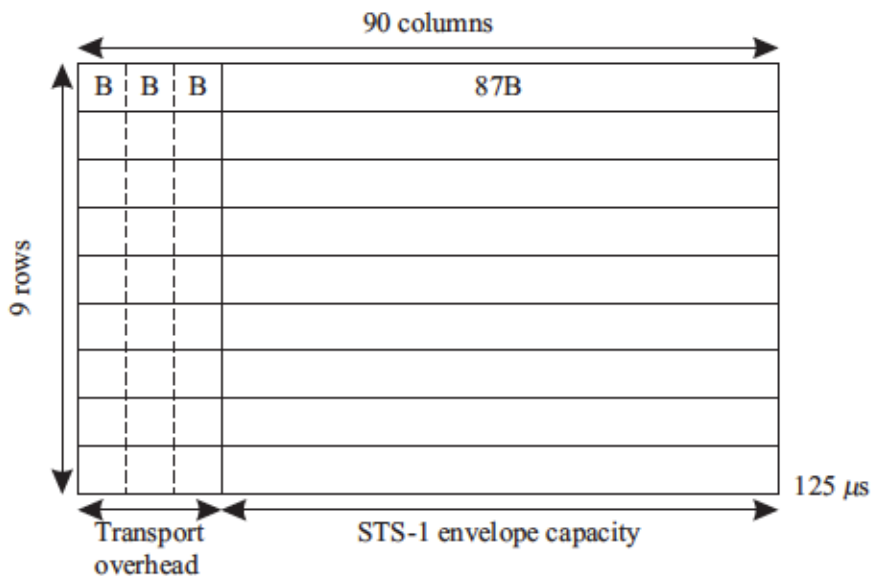
SONET Elements
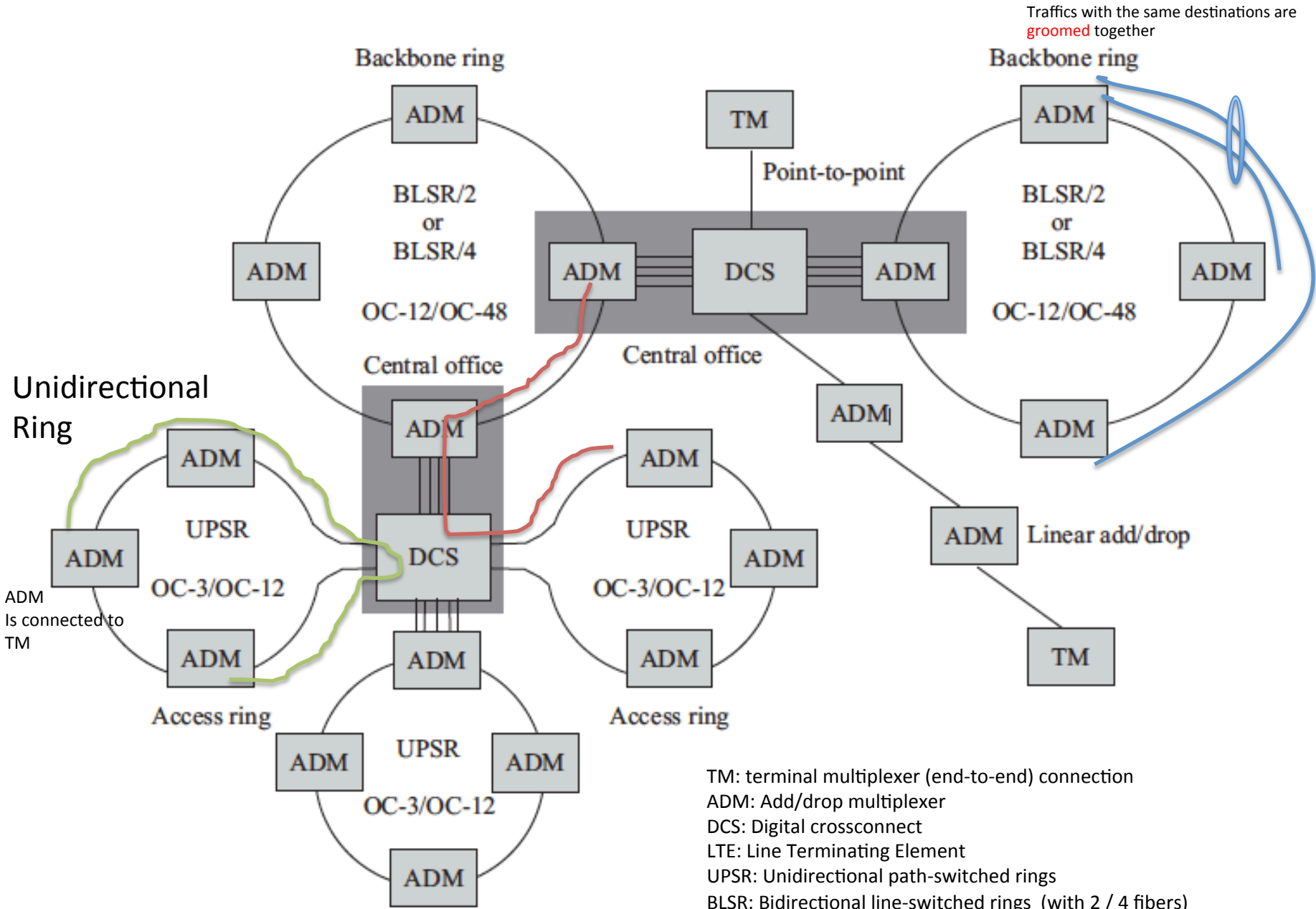
TM: terminal multiplexer (end-to-end) connection
ADM: Add/drop multiplexer
DCS: Digital crossconnect
LTE: Line Terminating Element
UPSR: Unidirectional path-switched rings
BLSR: Bidirectional line-switched rings (with 2 / 4 fibers)

SONET Elements

Traffics with the same destinations are groomed together

Backbone ring

ADM

BLSR/2
or
BLSR/4

OC-12/OC-48

ADM

TM

Point-to-point

Central office

ADM — DCS — ADM

Backbone ring

ADM

BLSR/2
or
BLSR/4

OC-12/OC-48

ADM

Central office

ADM

ADM

Unidirectional
Ring

ADM

UPSR

ADM

OC-3/OC-12

ADM

DCS

ADM

ADM

Is connected to

TM

Access ring

ADM

UPSR

ADM

OC-3/OC-12

ADM

Access ring

ADM

UPSR

ADM

OC-3/OC-12

ADM

ADM

ADM   Linear add/drop

TM

TM: terminal multiplexer (end-to-end) connection
ADM: Add/drop multiplexer
DCS: Digital crossconnect
LTE: Line Terminating Element
UPSR: Unidirectional path-switched rings
BLSR: Bidirectional line-switched rings (with 2 / 4 fibers)
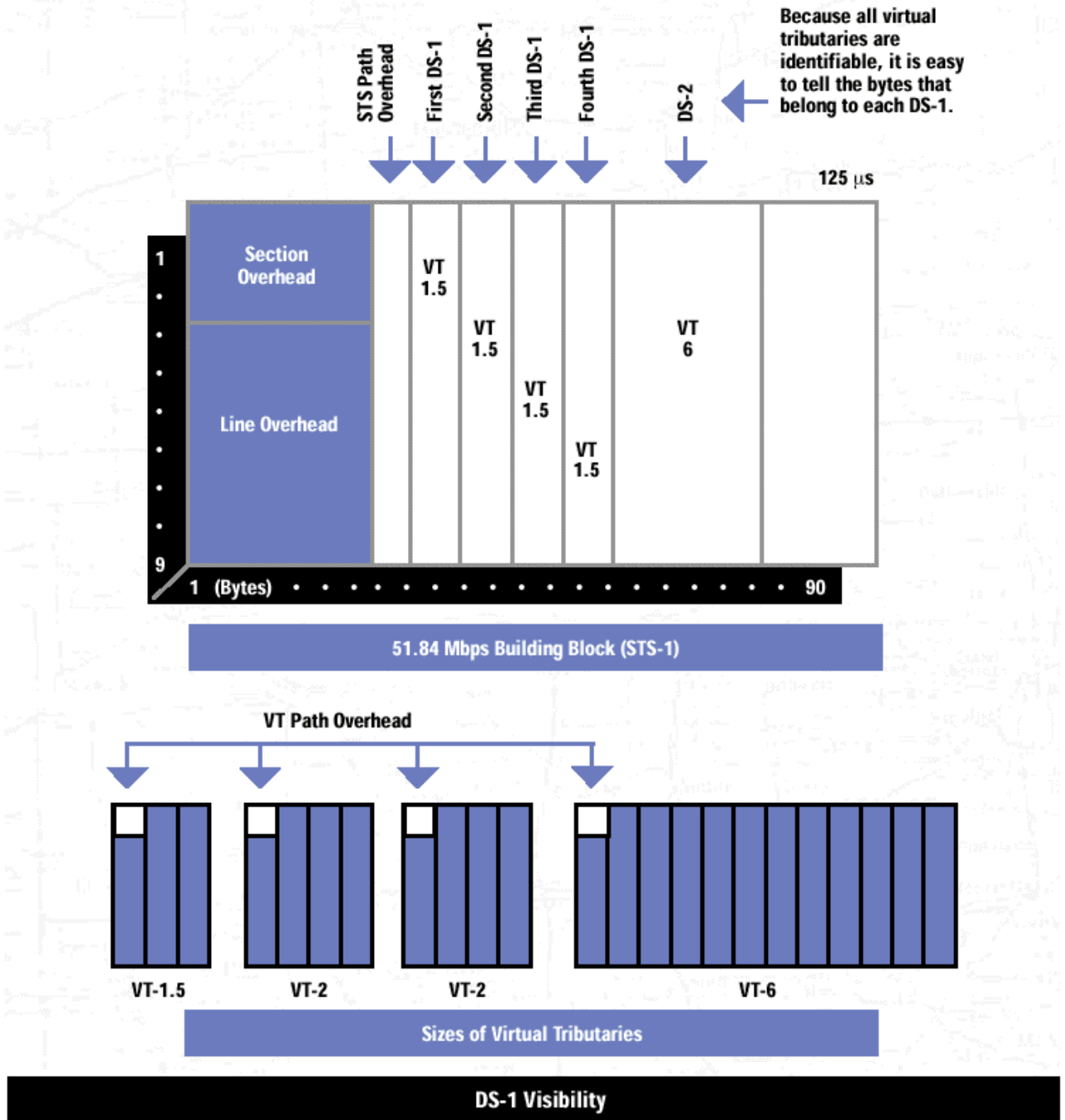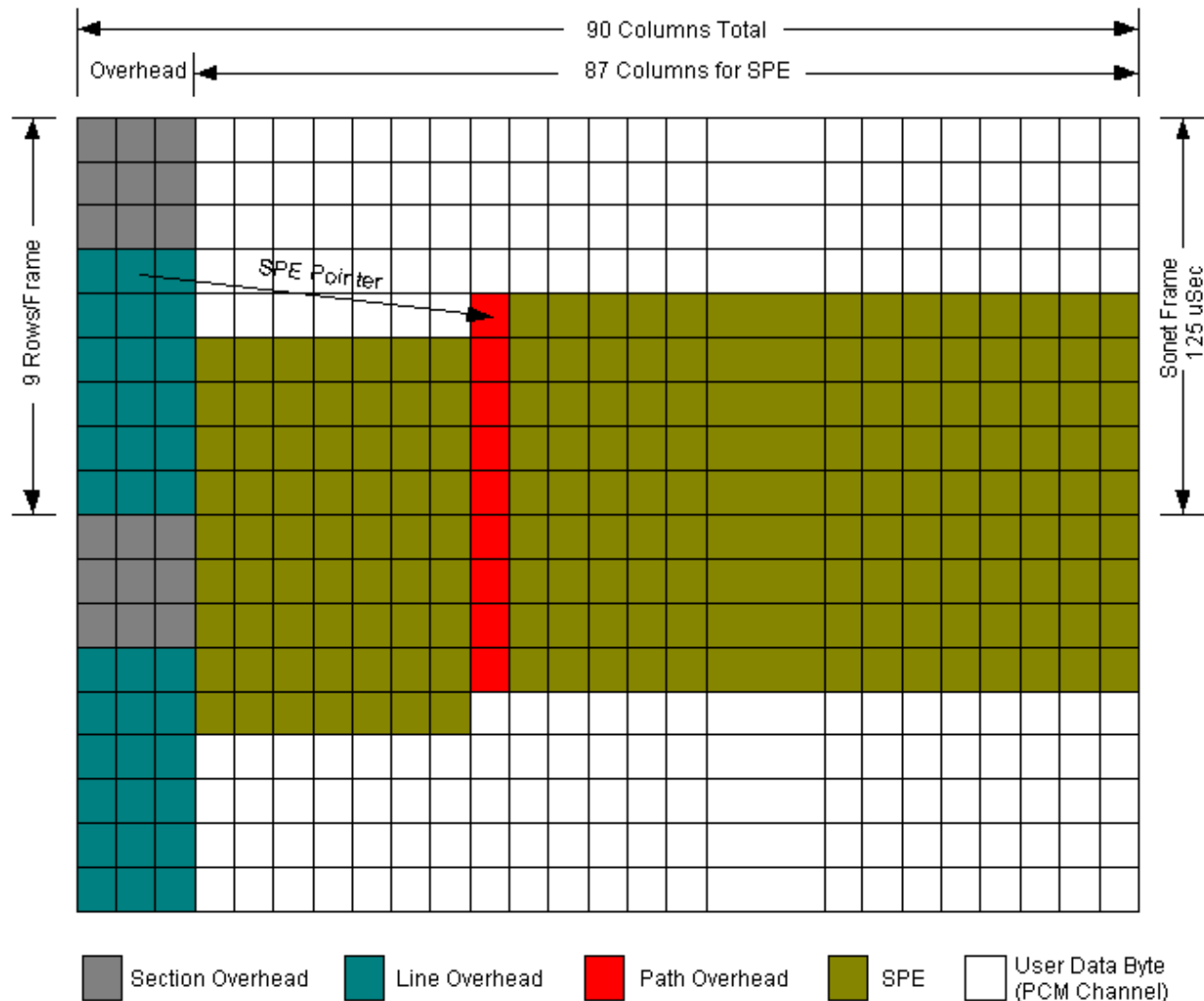
IP/SONET over WDM

SONET Frame Structure

- STS-1 frame is 125 usec (1/8000 sec/frame)
- There are 810 bytes per frame
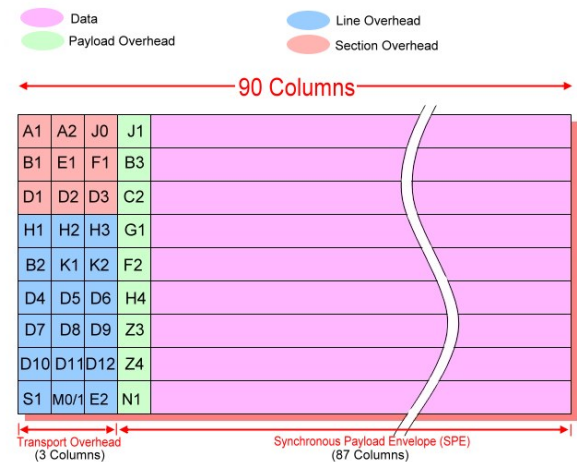 - Transmission row-by-row, left-to-right, MSB first
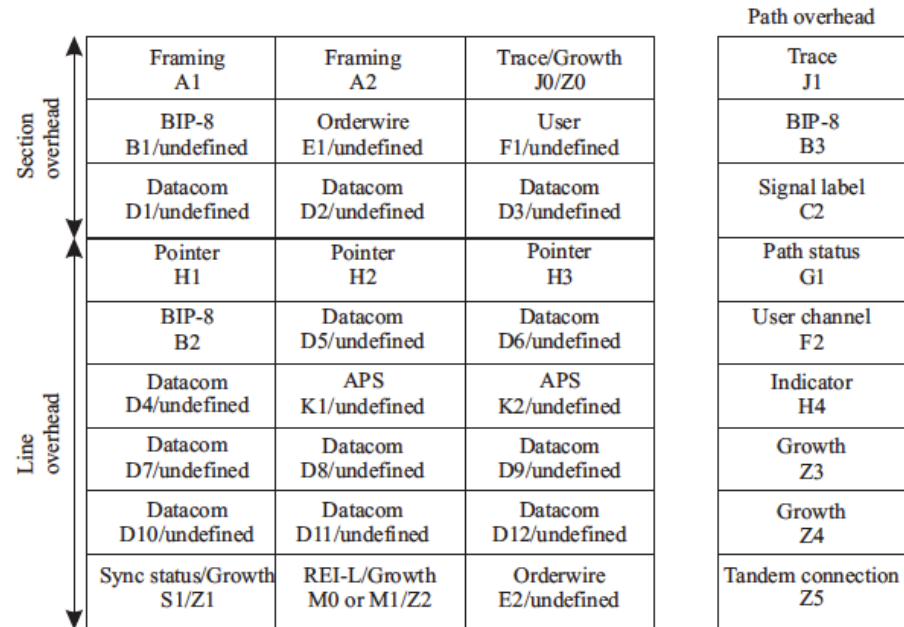
Frame Structure
 - Overhead

Because all virtual tributaries are identifiable, it is easy to tell the bytes that belong to each DS-1.

STS Path Overhead | First DS-1 | Second DS-1 | Third DS-1 | Fourth DS-1 | DS-2

125 μs

Section Overhead

Line Overhead

VT 1.5

VT 1.5

VT 1.5

VT 1.5

VT 6

1 (Bytes) · 90

51.84 Mbps Building Block (STS-1)

VT Path Overhead

VT-1.5 | VT-2 | VT-2 | VT-6

Sizes of Virtual Tributaries

DS-1 Visibility

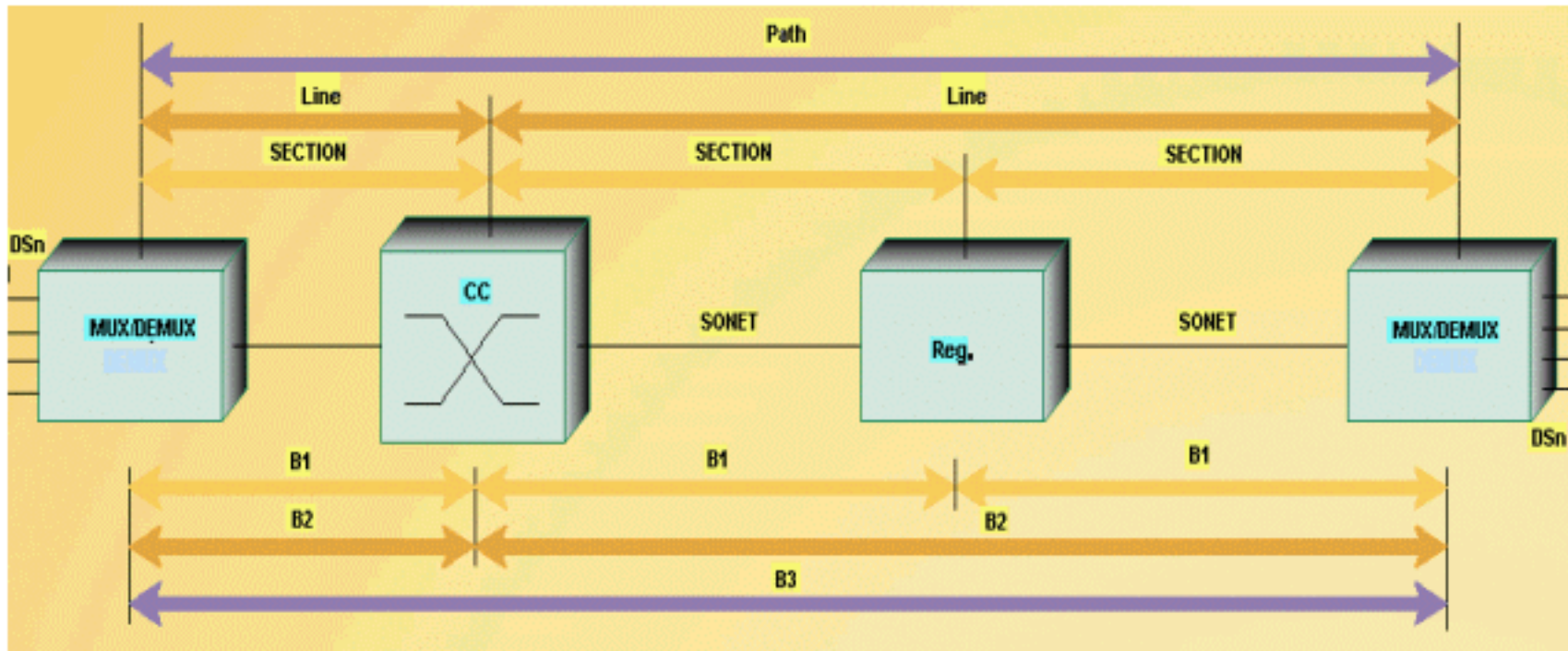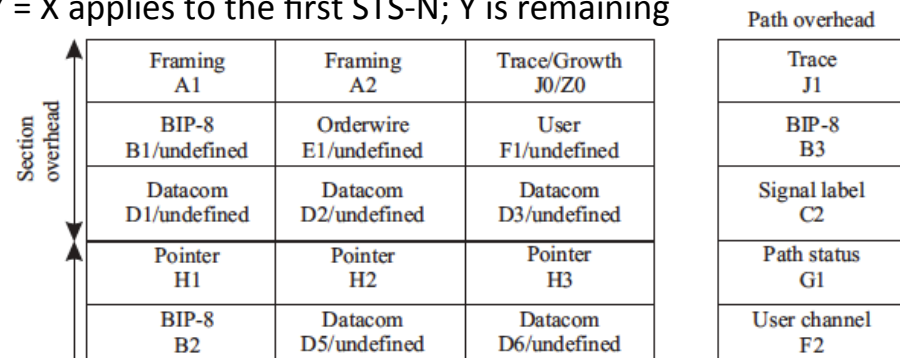# Use of Pointers – Pointer H2 Line Overhead

Frame Structure

- A/A2: Network elements use these bytes to determine the start of a new frame
- G1 is Yellow alarm to upstream nodes
- K2 (FERF) alarm for upstream node
- APS indicating automatic switching

				Path overhead
Section overhead	Framing A1	Framing A2	Trace/Growth J0/Z0	Trace J1
	BIP-8 B1/undefined	Orderwire E1/undefined	User F1/undefined	BIP-8 B3
	Datacom D1/undefined	Datacom D2/undefined	Datacom D3/undefined	Signal label C2
Line overhead	Pointer H1	Pointer H2	Pointer H3	Path status G1
	BIP-8 B2	Datacom D5/undefined	Datacom D6/undefined	User channel F2
	Datacom D4/undefined	APS K1/undefined	APS K2/undefined	Indicator H4
	Datacom D7/undefined	Datacom D8/undefined	Datacom D9/undefined	Growth Z3
	Datacom D10/undefined	Datacom D11/undefined	Datacom D12/undefined	Growth Z4
	Sync status/Growth S1/Z1	REI-L/Growth M0 or M1/Z2	Orderwire E2/undefined	Tandem connection Z5

Legend:
- Data
- Payload Overhead
- Line Overhead
- Section Overhead

90 Columns

A1	A2	J0	J1				
B1	E1	F1	B3				
D1	D2	D3	C2				
H1	H2	H3	G1				
B2	K1	K2	F2				
D4	D5	D6	H4				
D7	D8	D9	Z3				
D10	D11	D12	Z4				
S1	M0/1	E2	N1				

Transport Overhead (3 Columns)

Synchronous Payload Envelope (SPE) (87 Columns)

BIP-8 Errors

X/Y = X applies to the first STS-N; Y is remaining

- Monitoring BIPs
  - Bit interleaved parity
  - Even parity
  - Calculated for the previous frame

Section overhead	Framing A1	Framing A2	Trace/Growth J0/Z0
	BIP-8 B1/undefined	Orderwire E1/undefined	User F1/undefined
	Datacom D1/undefined	Datacom D2/undefined	Datacom D3/undefined
	Pointer H1	Pointer H2	Pointer H3
	BIP-8 B2	Datacom D5/undefined	Datacom D6/undefined

Path overhead
Trace J1
BIP-8 B3
Signal label C2
Path status G1
User channel F2

Calculating BIP-8

- Calculated BIP-8 (B1) is based on the previous STS-N frame after scrambling
  - Odd parity means there is an error
- B2 is based on calculating line overhead of the line overhead – checked by the line terminating equipment

Client Layers of Optical Fiber
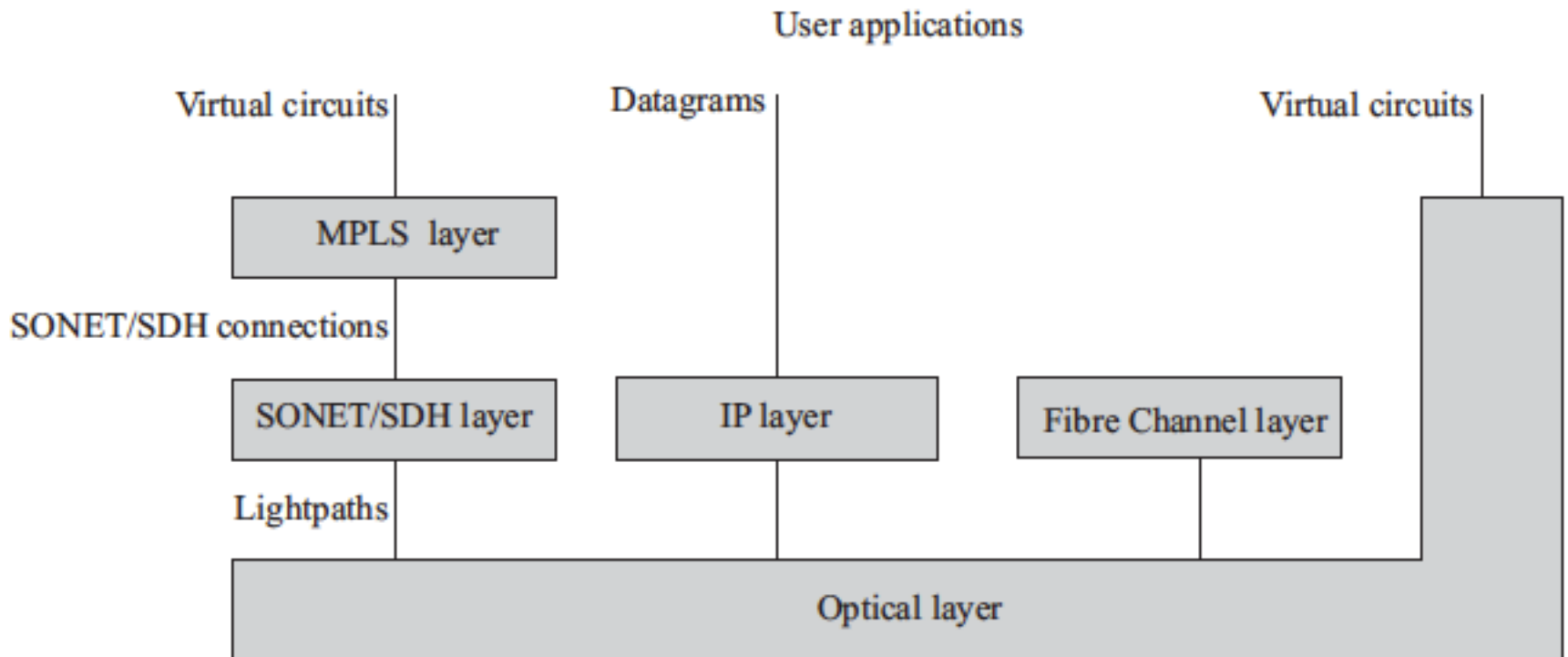
SONET Protection

- Chapter 9 - up to 9.3

SONET Protection

- Availability: A common requirement that the connection will be available 99.999%
- Thus network has to be survivable
  - continue providing service in the presence of failures
- Protection switching is the key technique used to ensure survivability
  - The term restoration to schemes where traffic is restored
- There are many failures
  - Human errors / disasters / Attacks / etc.
  - Component failures
  - Link failures:
    - There are estimates that long-haul networks annually suffer 3 fiber cuts for every 1000 miles of fiber
    - For a large network of 30,000 miles of fiber cable, that would be 90 cuts per year

Protection Key Parameters

- Detect failures
- Protect against failures (single failures)
- Restoration time (60 msec – including detection and restoration)
- Topology (Ring / Mesh)
- Signaling

Basic Protection Concepts

- Failures must be protected!
- Failure types:
  - Single / multiple / double (a series of shared links can fail)
- Failure example:
  - Node / Link (Fiber) / Components
- Protection type
  - Shared
  - Dedicated
- Scheme
  - Revertive – when shared protection is used
  - Non-revertive – when 1+1 is used
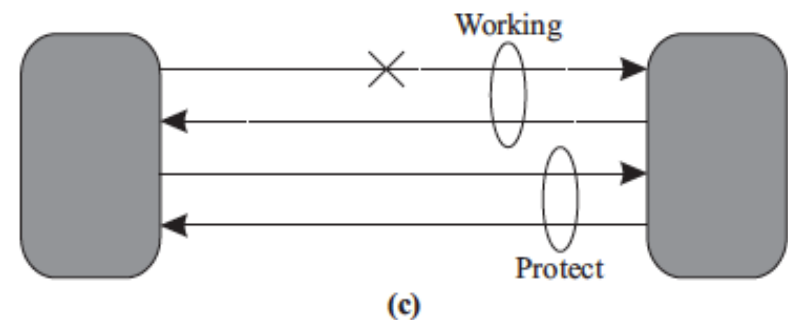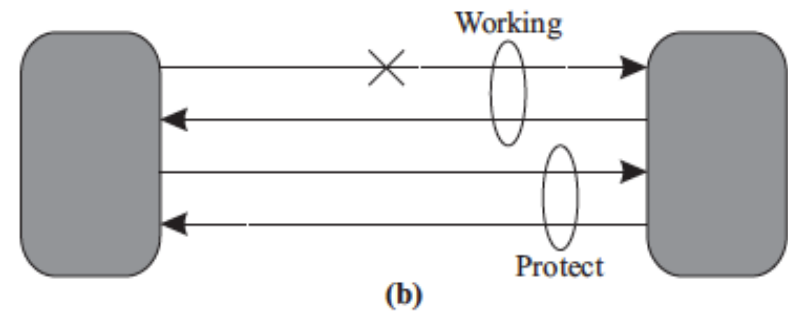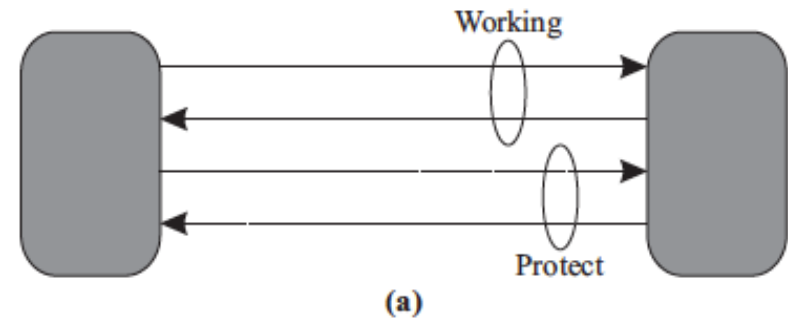
Protection Switching

- Automatic Protection Switching (ASP)

- Unidirectional
  - ASP Required
  - Signaling is required

- Bidirectional
  - No ASP is required

Case b: Only affected direction is switched: - Unidirectional Protection switching (RED is working)

Case c: Bidirectional protection
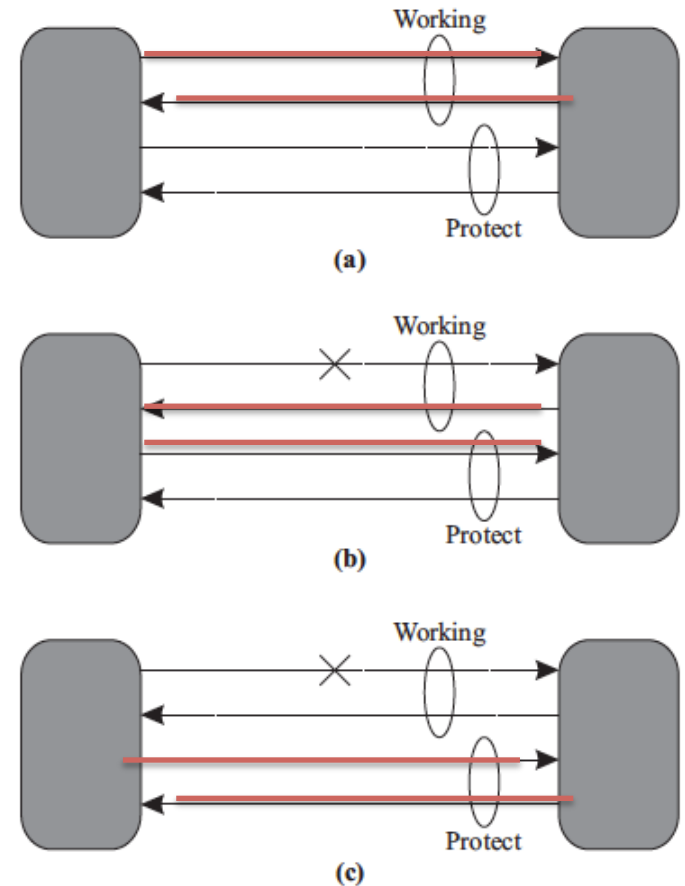
Traffic Routing Due to Protection Switching – how the traffic is being rerouted due to link failure

Connection

(a)

Path Switching

(b)

Span Switching

(c)
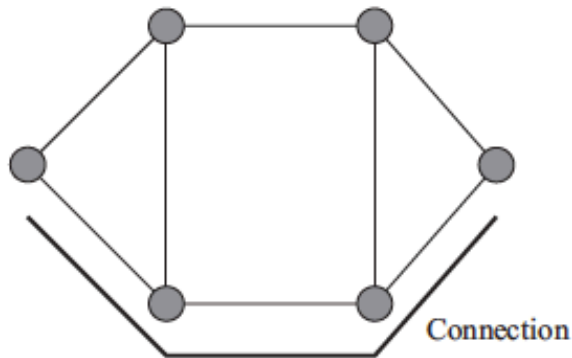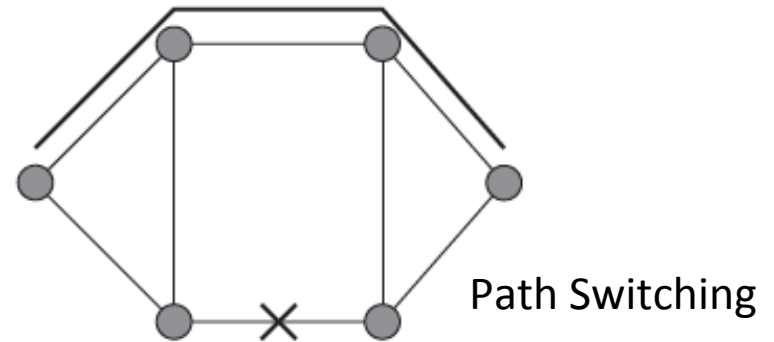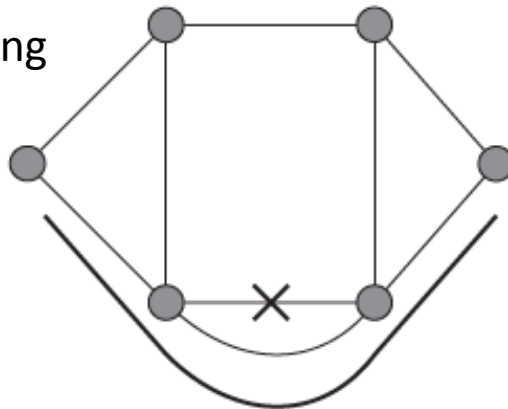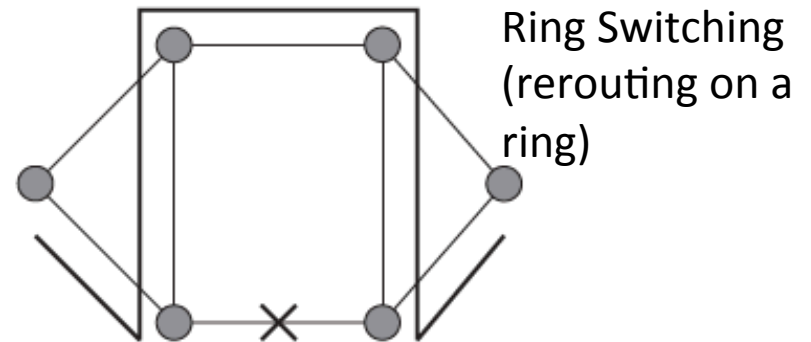
Ring Switching (rerouting on a ring)

(d)

Protection Techniques

1+1 Protection / Simultaneous TX & RX)

(a)

(b)
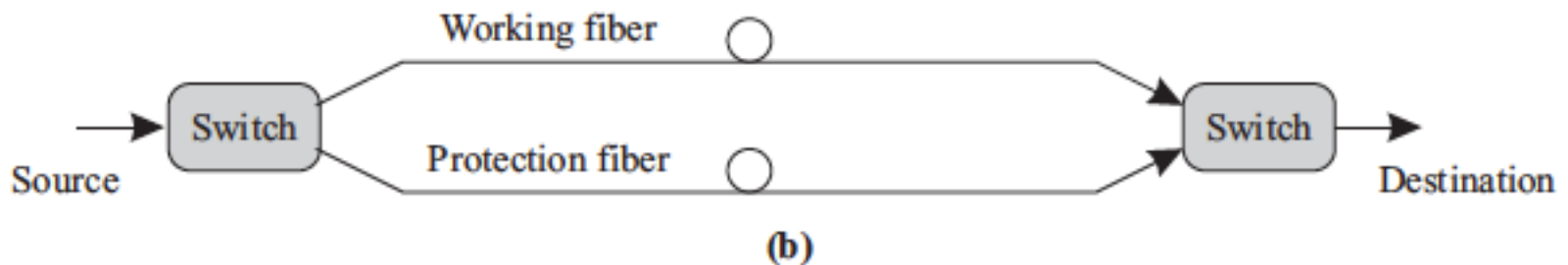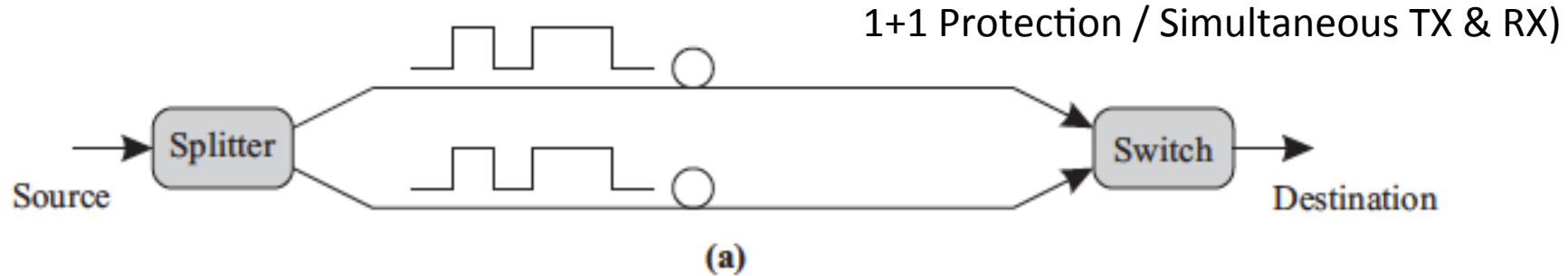
1:1 Protection / Signaling is required
To activate the protection / traffic must be switched /
The protection links can carry EXTRA traffic – low priority

Protection Schemes
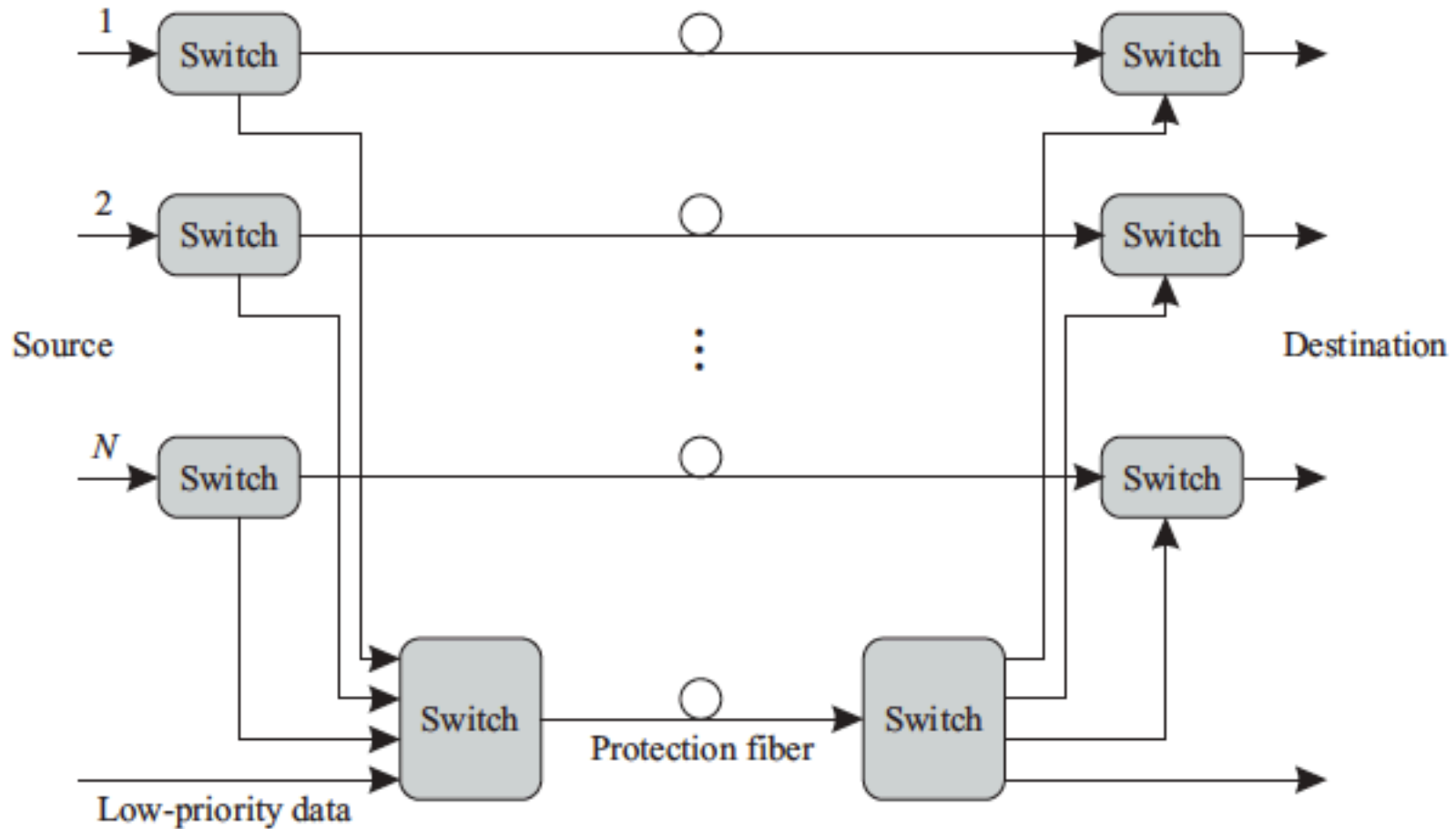
1:N Protection / Shared Protection / Signaling is required / Typically, must be revertive!

SONET Rings and Self-Healing Rings
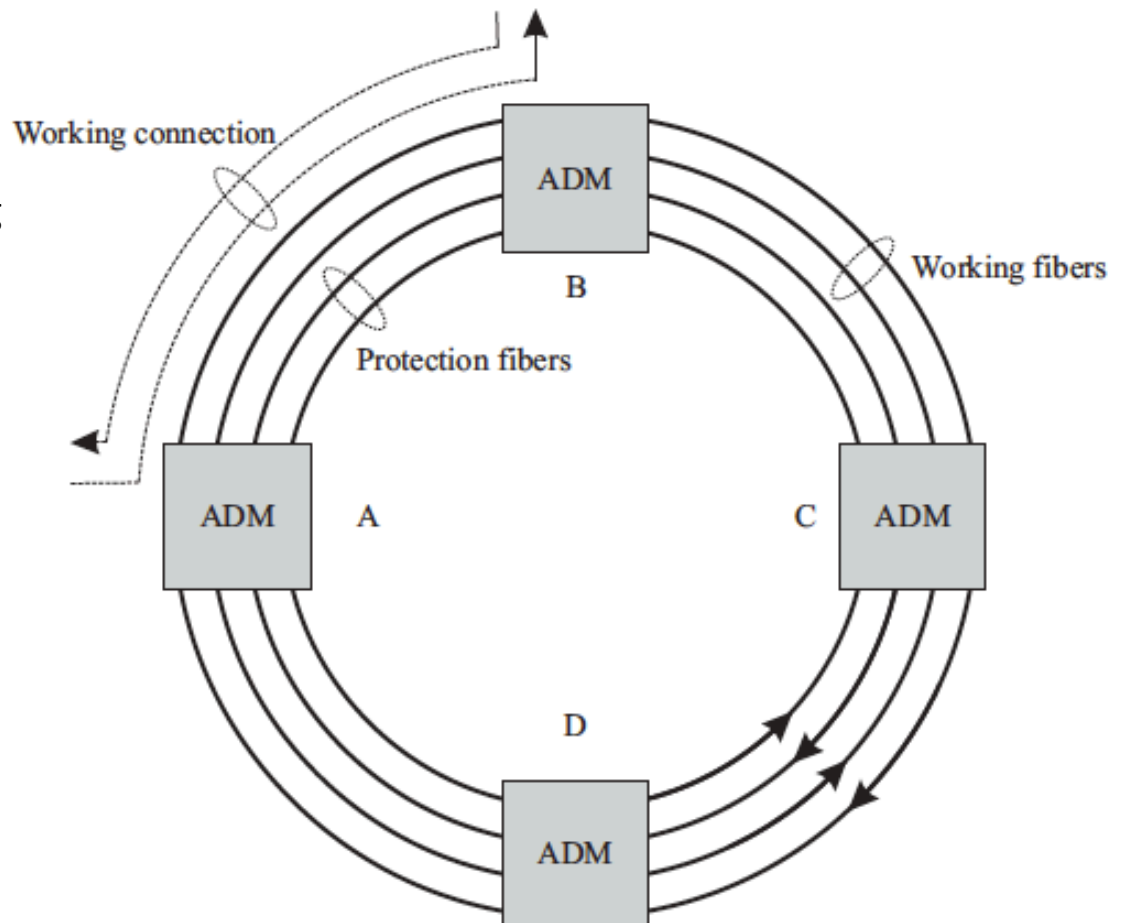
- ## Unidirectional path-switched ring (UPSR)

- 1+1 Protection
- Two Fibers only
- Unidirectional
- Simultaneous traffic (clockwise and counter CW)
- Path Layer Protection
- Simple / requires no signaling
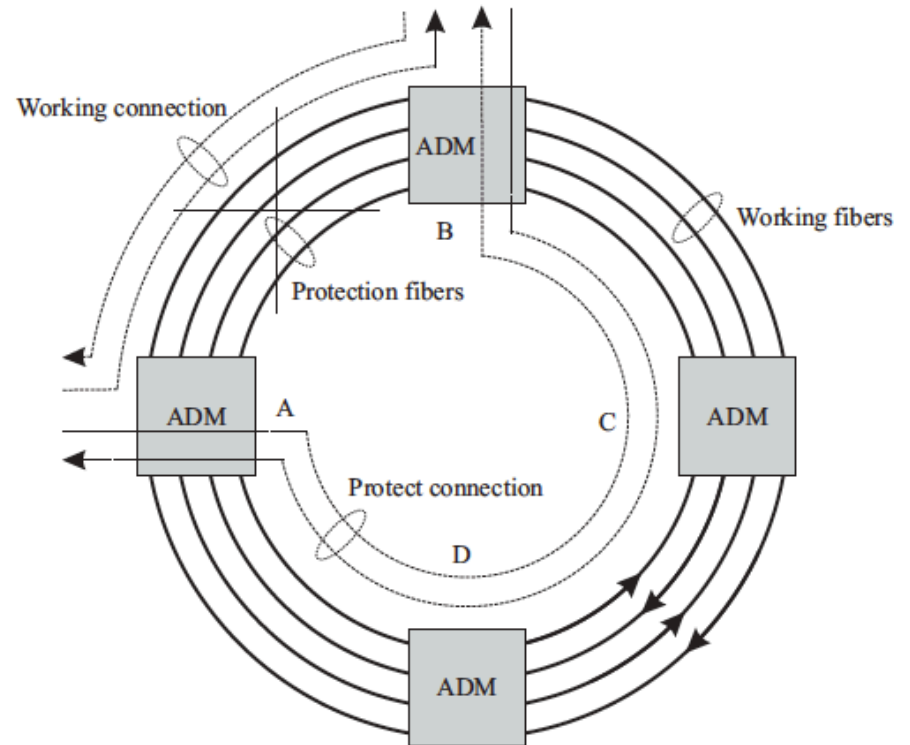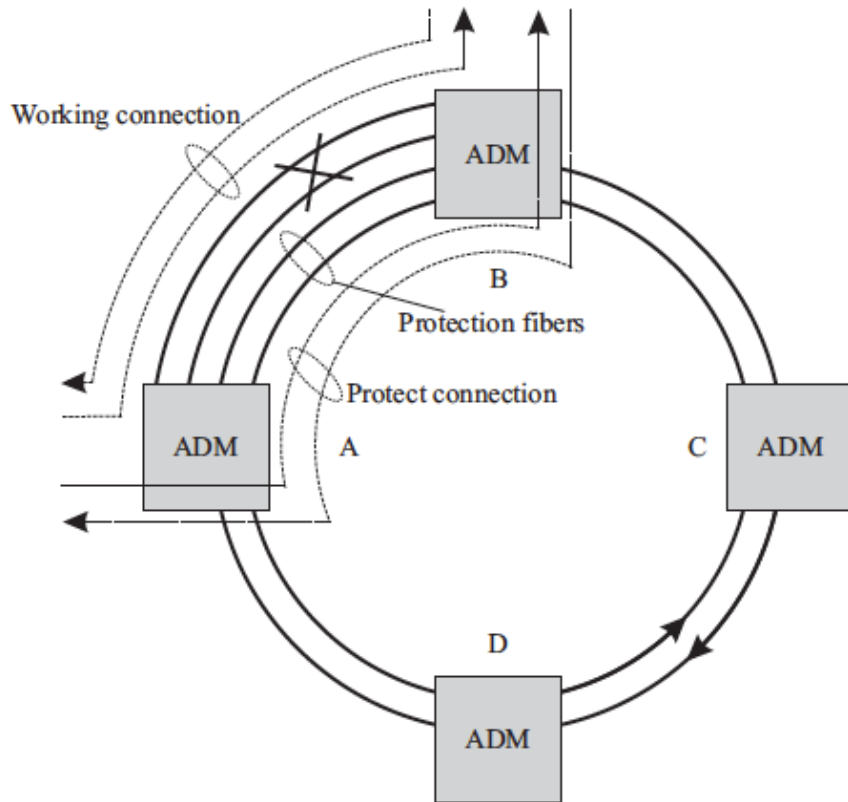- No node limitation / no length limitation
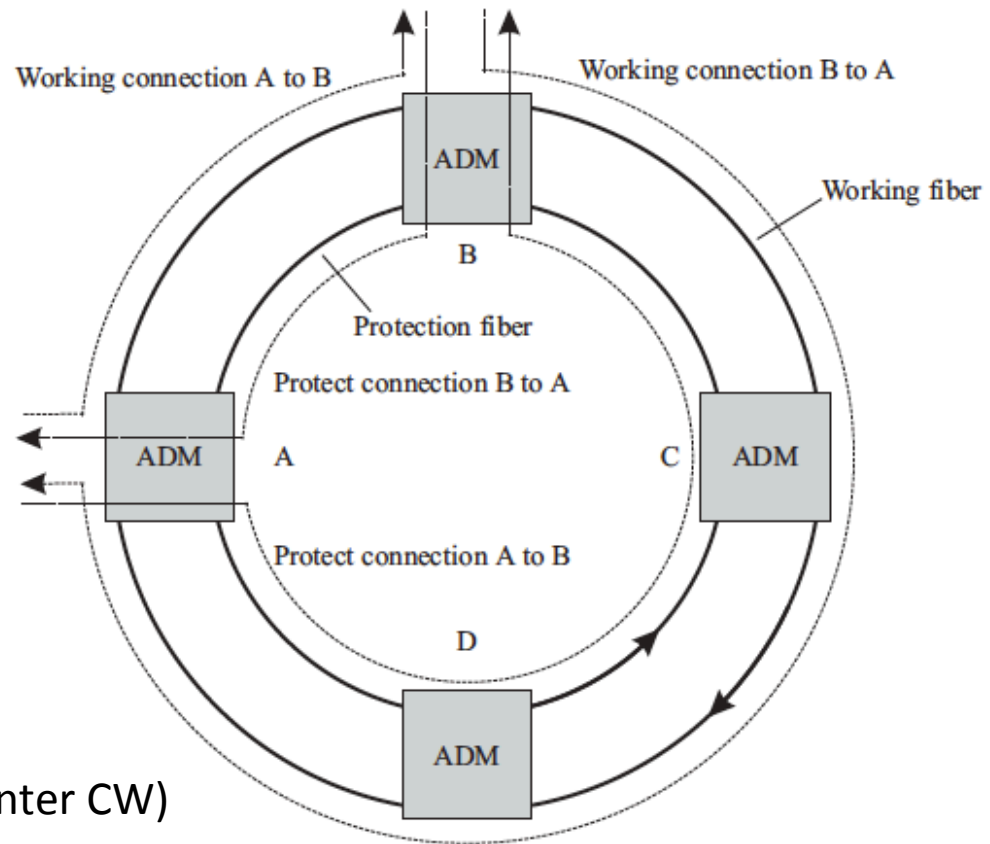
Note: It is important that the traffics are moving in DIFFERENT directions to protect against any node failure

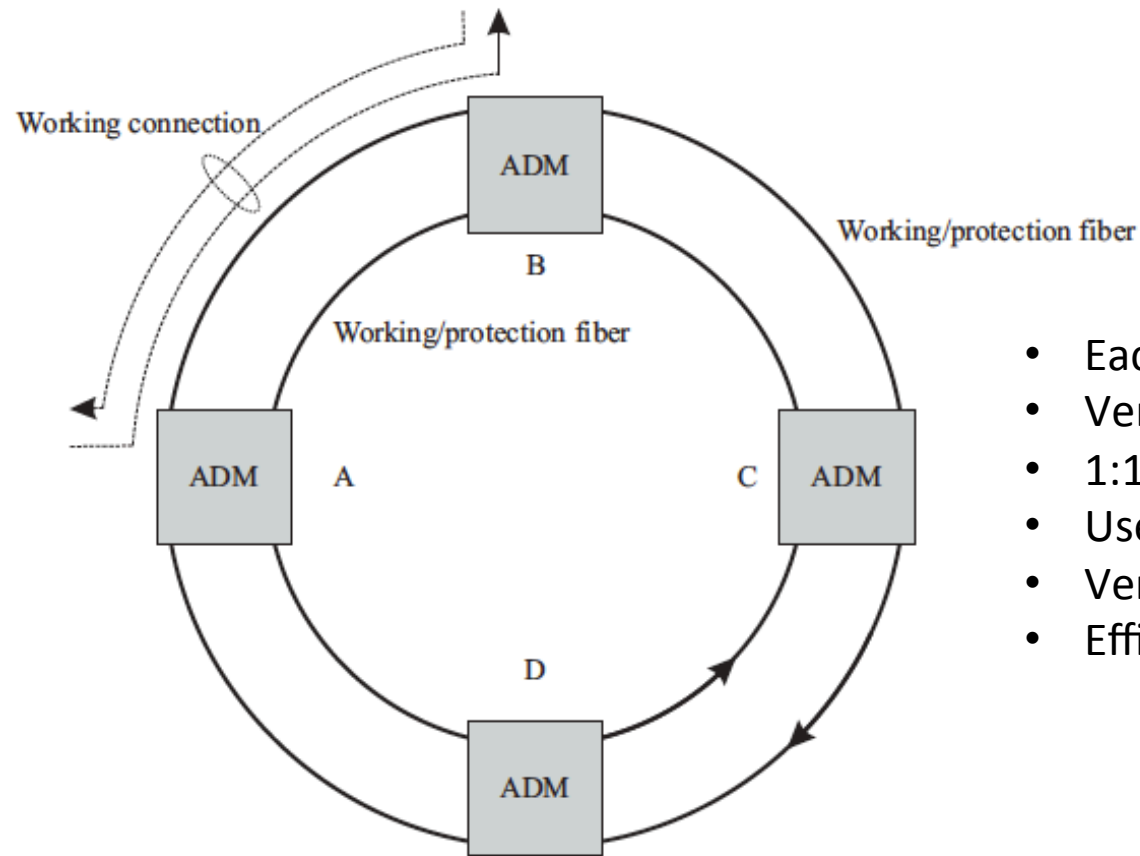# Four Fiber Bidirectional Lines Switched Ring (BLSR/4)

- Mainly, line protection
- Traffic is on both directions
  - CW and CCW
- Max of 16 notes are supported
- Max length is 1600 km
- Supports span switching or ring switching (next slide)

SPAN / RING Switching in BLSR/4

Two-fiber bidirectional line-switched Ring (BLSR/2)

Working connection

Working/protection fiber

ADM

B

Working/protection fiber

ADM   A

C   ADM

D

ADM

- Each link has half BW
- Very complex – uses APS (K1/K2 bytes)
- 1:1 Switching
- Used for long haul
- Very common
- Efficient use of special capacity

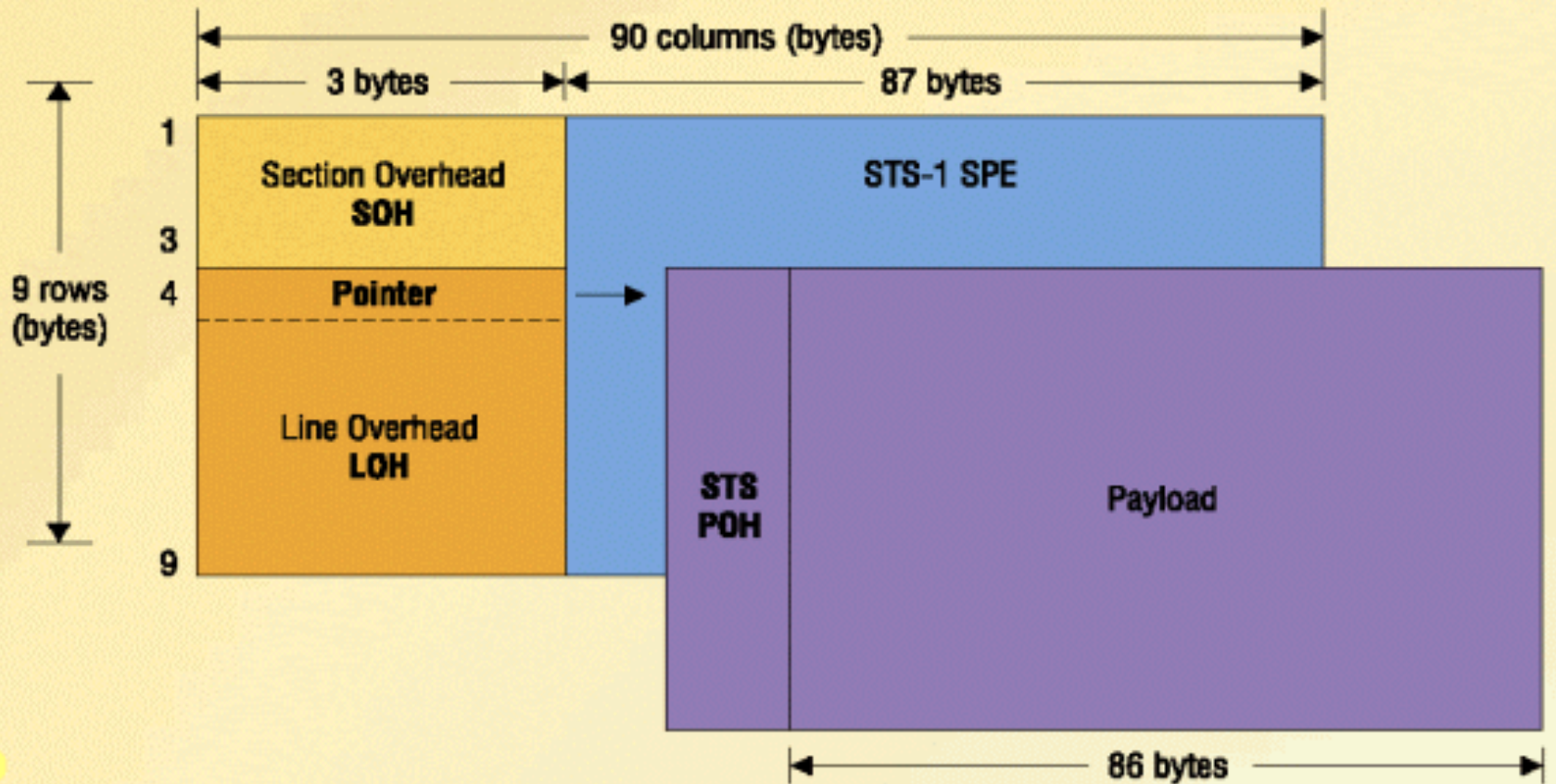# Example: BLSR/2 is much more efficient than UPSR (2 fiber)

Node Failure
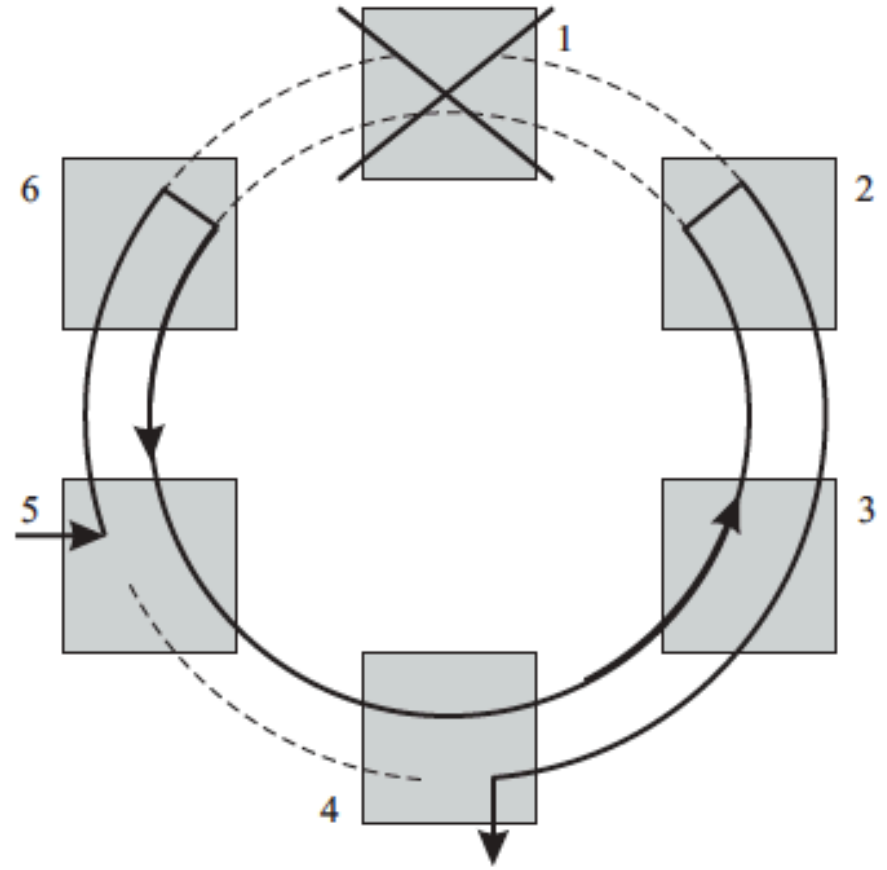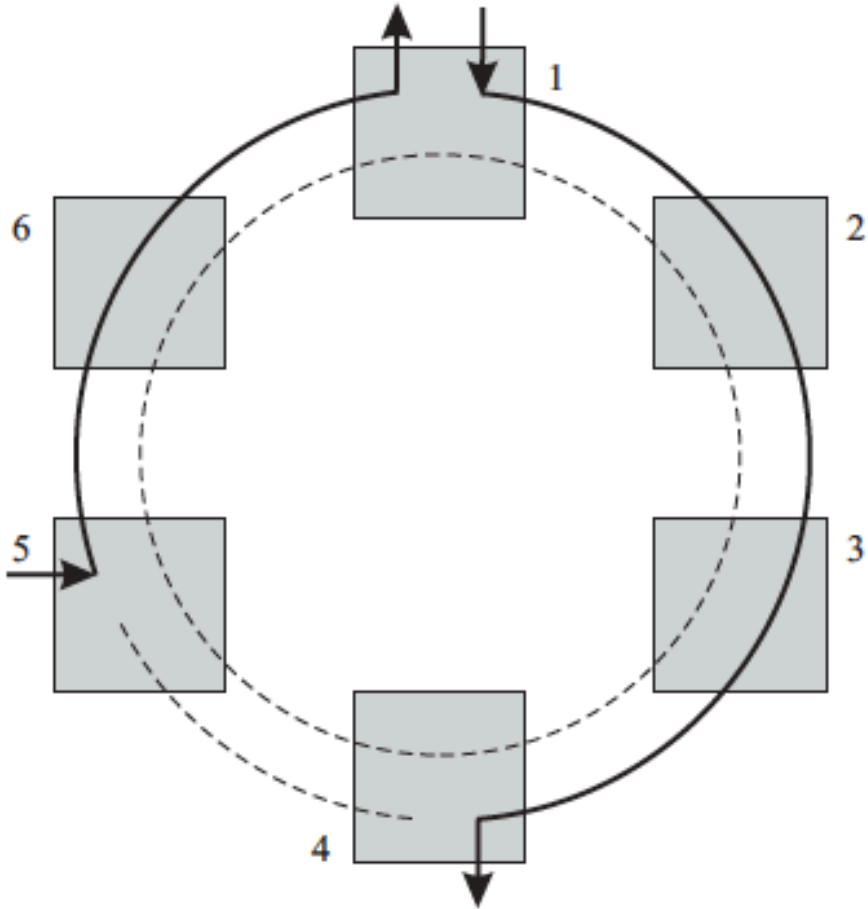
Lab

Framing Review

LAB

SOH Section Overhead

A1, A2: Indicates the beginning of each STS-1 within a STS-n frame. The pattern is Hex F628.

J0: Section trace. It is defined only for STS-1 number 1 of an STS-N signal. Used to transmit a one byte fixed length string or a 16 byte message so that a receiving terminal in a section can verify its continued connection to the intended transmitter.

Z0: Section growth. It is defined in each STS-1 for future growth except for STS-1 number 1 (which is defined as J0).

B1: Section error monitoring. The BIP-8 is calculated over all bits of the previous STS-N frame after scrambling and is placed in the B1 byte of STS-1 number 1 before scrambling. Defined only for STS-1 number 1 of an STS-N signal.

E1: Allocated to be used as local orderwire channels for voice communication between section terminating equipments, hubs and remote terminal locations.

F1: Reserved for user purposes (e.g. temporary data/voice channel connections for special maintenance purposes).

D1 - D3: Data communication channels (DCC). A 192 kbit/s message based channel for alarms, maintenance, control, monitoring, administration and other communication needs.

Framing Bytes

LOH Line Overhead

H1, H2: Pointer bytes. Allocated to a pointer that indicates the offset in bytes between pointer and the first byte of the STS SPE. It is used to align the STS-1 transport overheads in an STS-N signal as well as perform frequency justification.

H3: Pointer action byte. It is used for frequency justification. Depending on the pointer value, this byte is used to adjust the fill input buffers. It only carries valid information in the event of negative justification, otherwise it's not defined.

B2: Line error monitoring. The BIP-8 is used to determine if a transmission error has occurred over a line. It is calculated over all bits of the previous STS-1 frame before scrambling and is placed in the B2 byte of the current frame before scrambling.

K1, K2: Allocated for APS (Automatic Protection Switching) signaling for the protection of the multiplex section.

Connection Setup
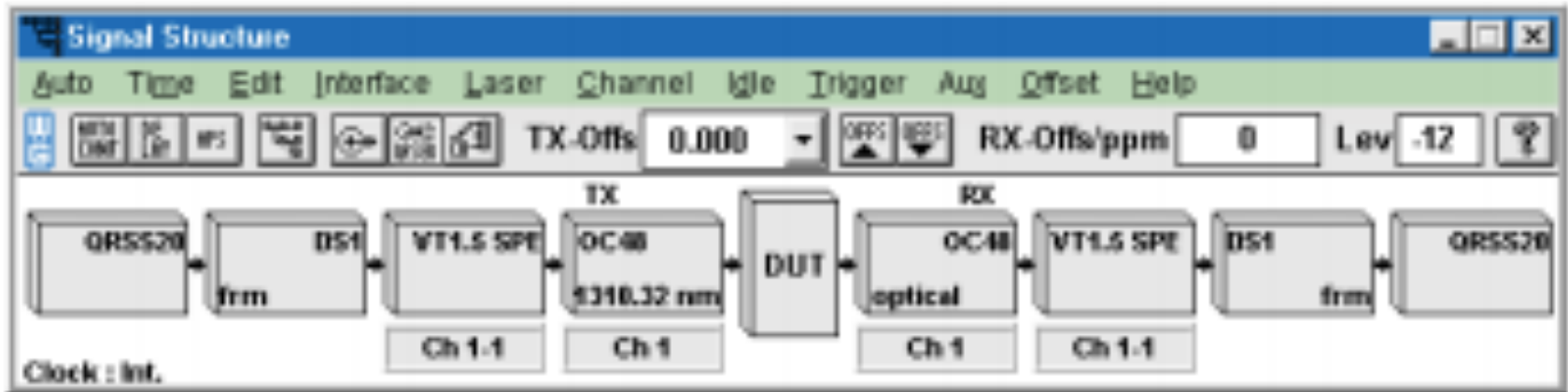
Pseudo-random bit sequences – max 14 consecutive zeros

References

- http://www.cisco.com/en/US/tech/tk482/tk607/technologies_tech_note09186a0080094313.shtml
- http://www.opticus.co.uk/pdf/WhitePaper-Understanding_Error_Checking_Using_Parity_Bytes.pdf