Sonet and P2P

Sonet

- Synchronous Optical NETwork (SONET)
    - ANSI standard
- ITU sets SONET standard in 1989
    - Called Synchronous Digital Hierarchy

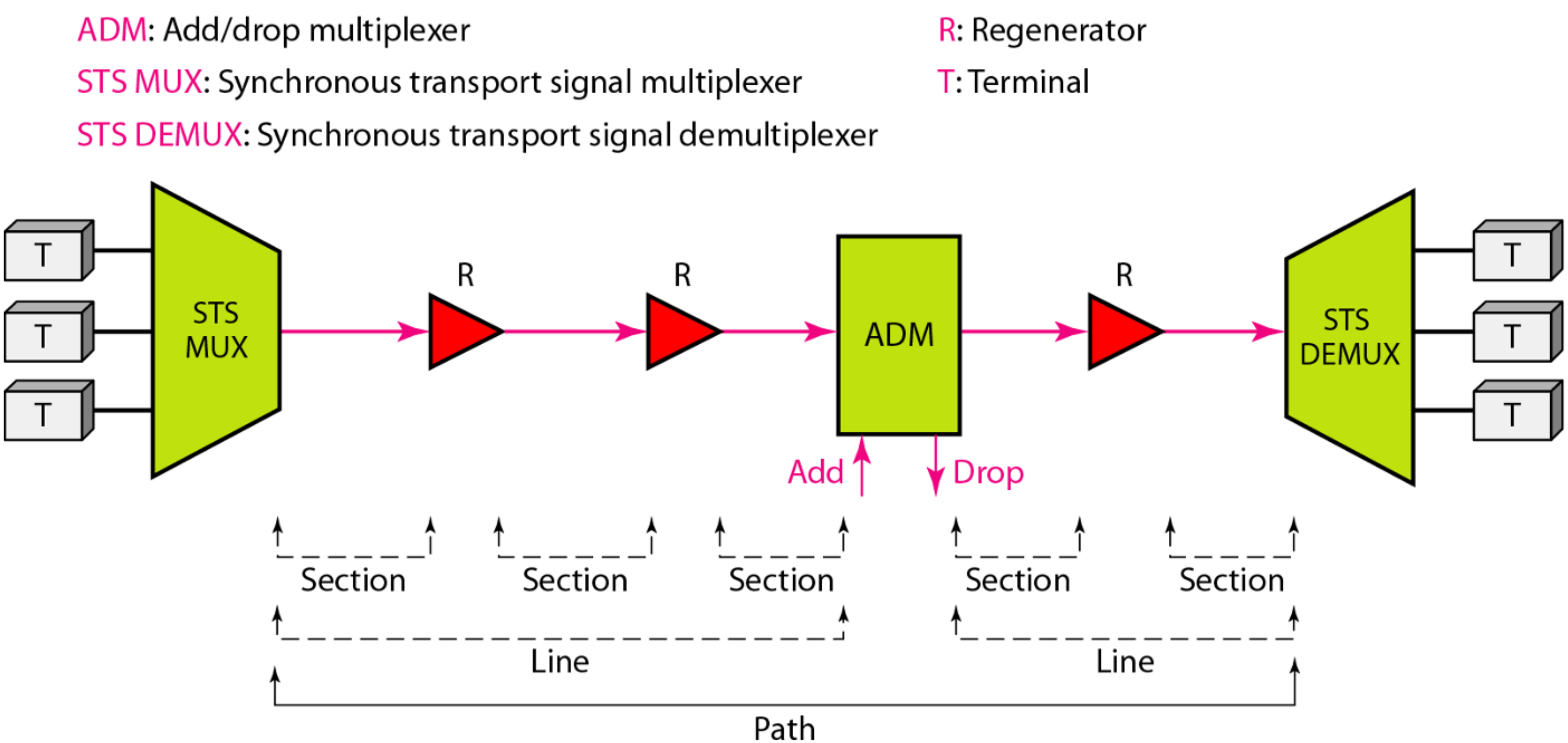
Sonet

- Hierarchy of Electrical Signaling levels / Optical Carriers
  - Synchronous transport signals (SST)

STS	*OC*	*Rate (Mbps)*	*STM*
STS-1	OC-1	51.840	
STS-3	OC-3	155.520	**STM-1**
STS-9	OC-9	466.560	**STM-3**
STS-12	OC-12	622.080	**STM-4**
STS-18	OC-18	933.120	**STM-6**
STS-24	OC-24	1244.160	**STM-8**
STS-36	OC-36	1866.230	**STM-12**
STS-48	OC-48	2488.320	**STM-16**
STS-96	OC-96	4976.640	**STM-32**
STS-192	OC-192	9953.280	**STM-64**

Sonet

- Sonet uses: STS MUX/DEMUX, Regenerators, add/drop MUX

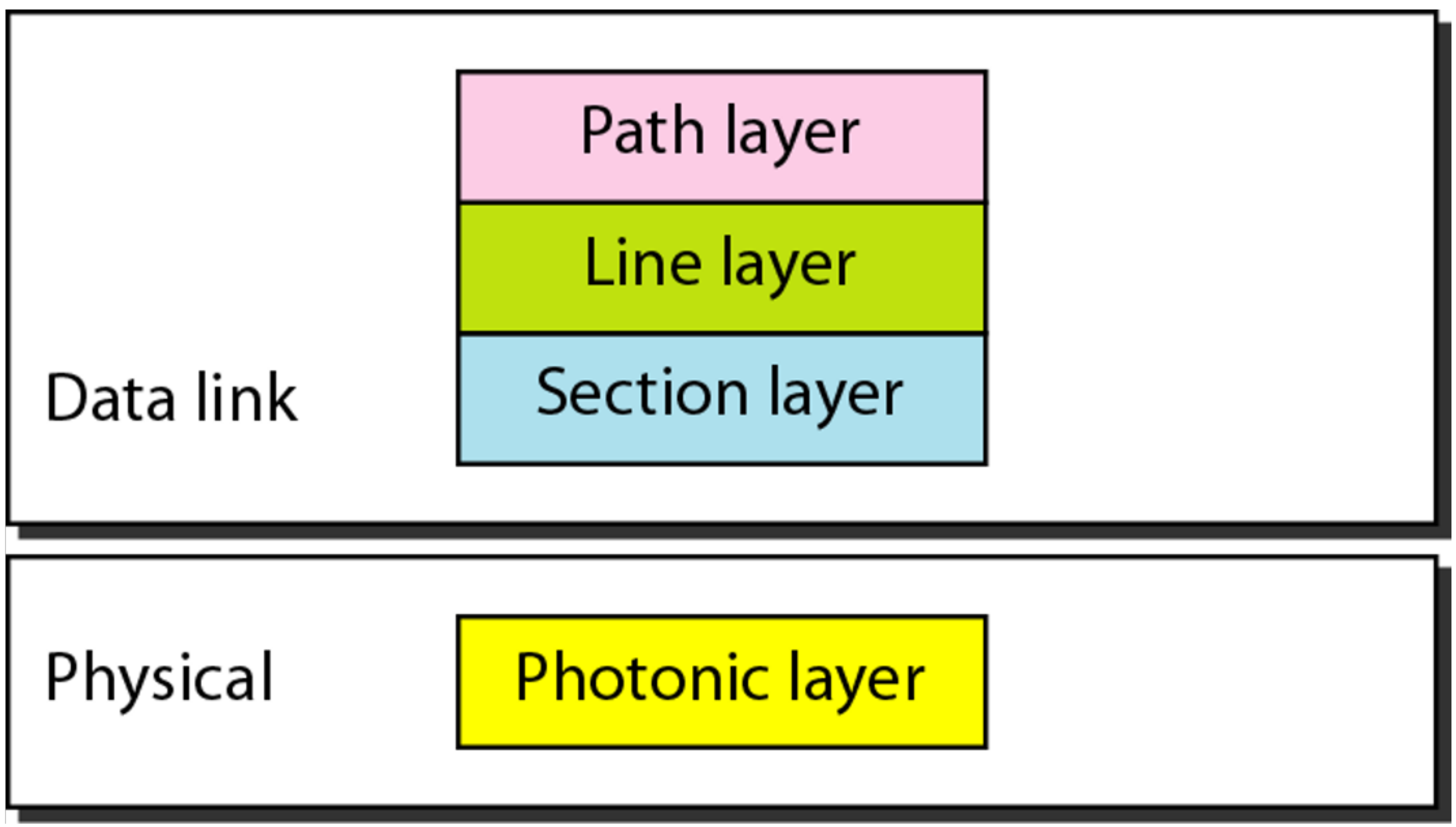


Sonet

- STS Multiplexer / Demultiplexer
    - Begin and end points of a SONET link
    - Converts to / from optical signal
- Regenerator
    - Repeater that takes an optical signal (OC-*n)*
    - demodulates to electrical signal (STS-*n*)
    - regenerates the electrical signal
    - modulates back to an optical signal (OC-*n*)
- Add / Drop Multiplexer
    - Reorganizes signals

Sonet

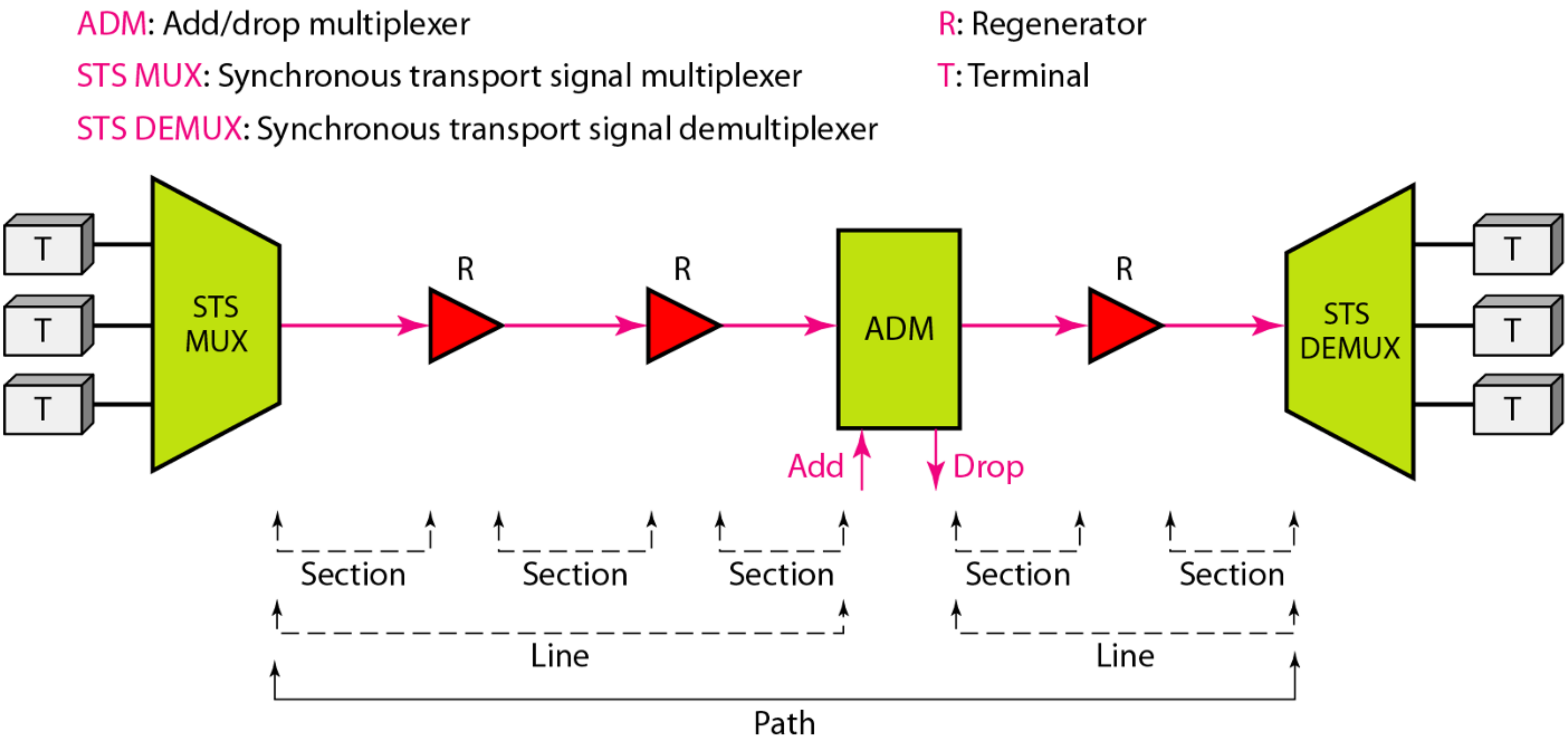
- Sonet Layer:



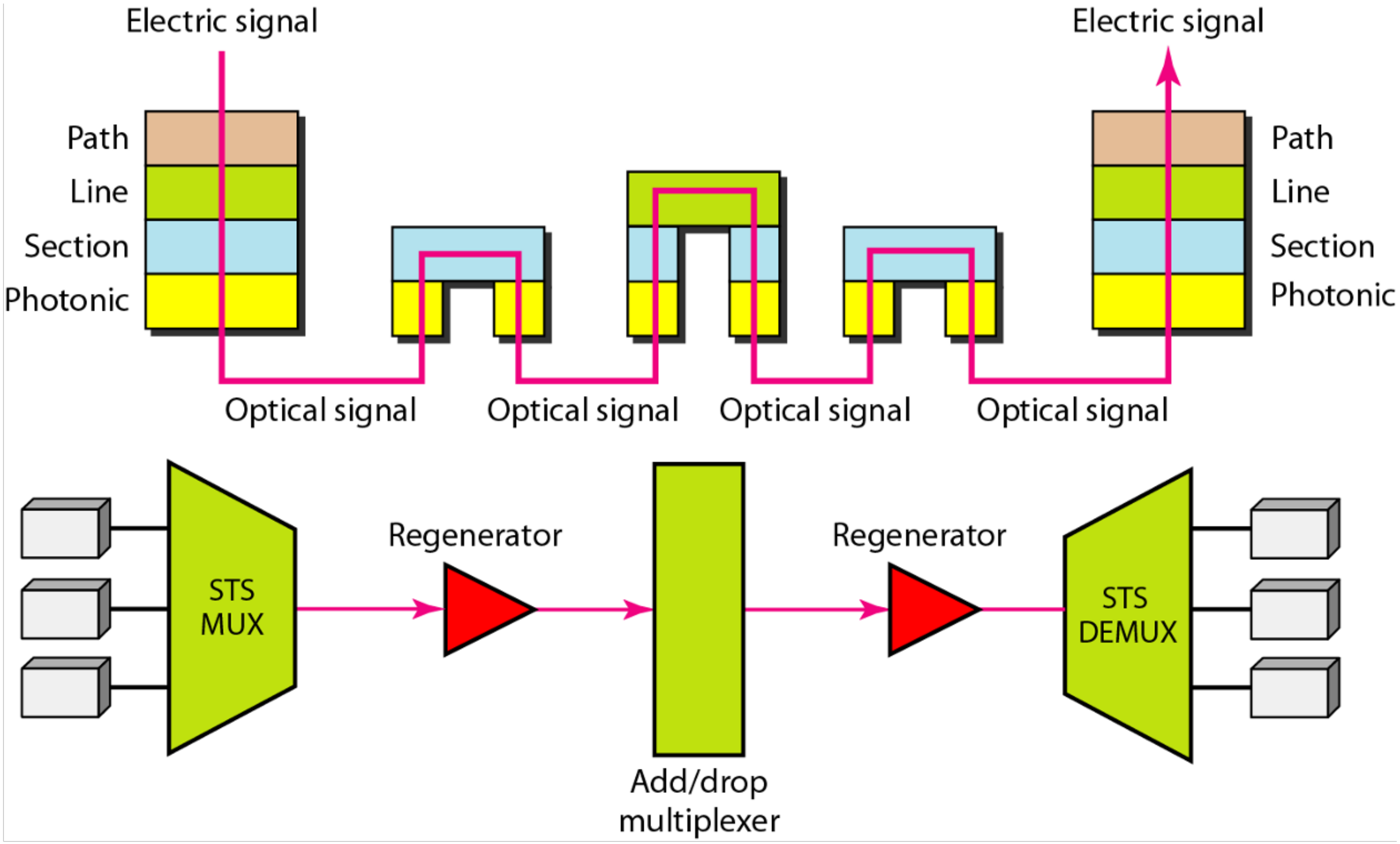
Sonet

- Path layer:
  - Moves signal from optical source to optical destination
  - Provided by STS multiplexers
- Line layer:
  - Moves signal across a physical line
- Section layer:
  - Moves signal across a physical section

Sonet


ADM: Add/drop multiplexer
STS MUX: Synchronous transport signal multiplexer
STS DEMUX: Synchronous transport signal demultiplexer
R: Regenerator
T: Terminal
T
T
T
STS MUX
R
R
ADM
R
STS DEMUX
T
T
T
Add
Drop
Section
Section
Section
Section
Section
Line
Line
Path

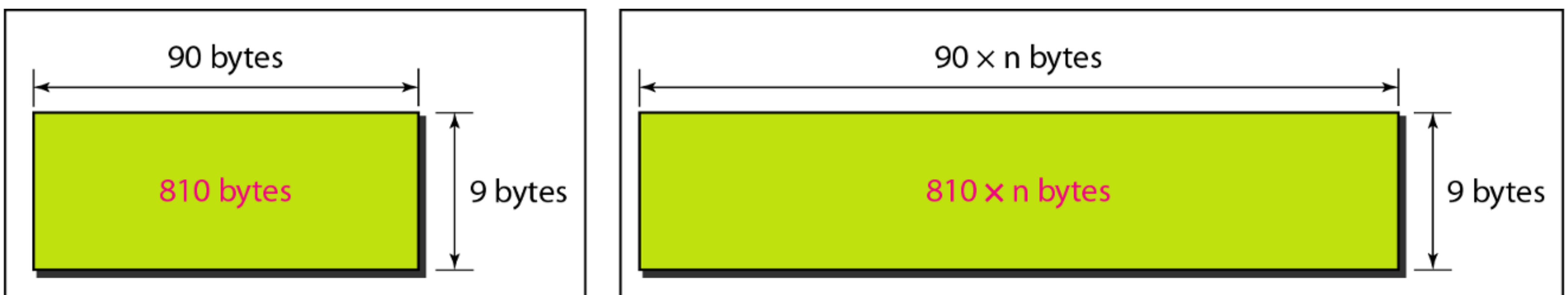
Sonet



Electric signal
Electric signal
Path
Line
Section
Photonic
Path
Line
Section
Photonic
Optical signal
Optical signal
Optical signal
Optical signal
STS
MUX
Regenerator
Regenerator
STS
DEMUX
Add/drop
multiplexer

Sonet

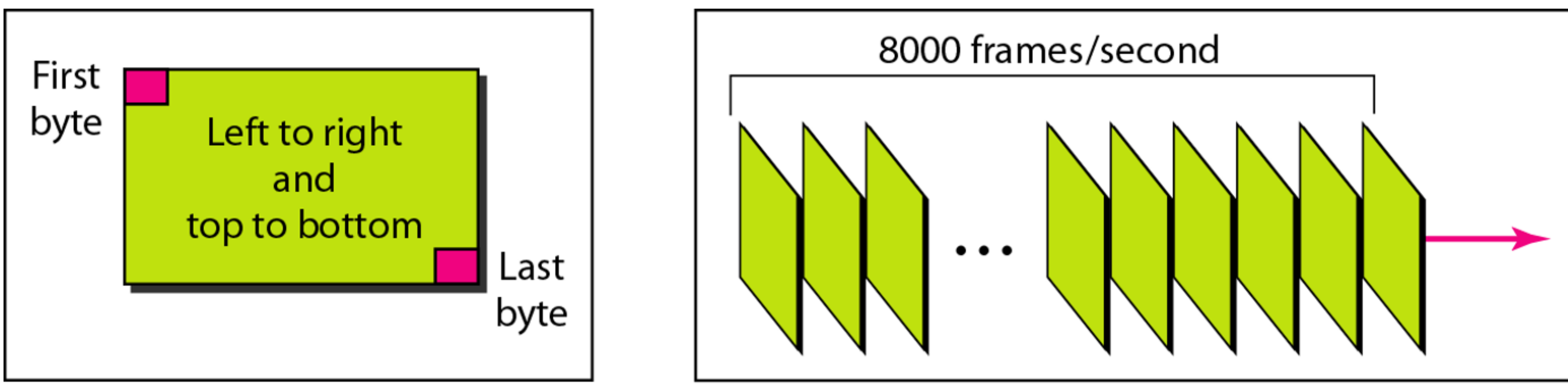
- Each STS-*n* consists of 8000 frames
- Each frame is a matrix with 9 rows and $90 \times n$ columns



a. STS-1 frame b. STS-n frame

Sonet

- Each STS-*n* signal is transmitted at a ***fixed*** rate of 8000 frames per second
    - Example: Voice is digitized at rate 8000 / sec
    - Each byte in a SONET frame can carry a telephone call



a. Byte transmission b. Frame transmission

Sonet

- Quiz:
  - What is the duration (time on line) of a SONET frame
- Answer:
  - 1/8000 sec = 125 μsec

Sonet

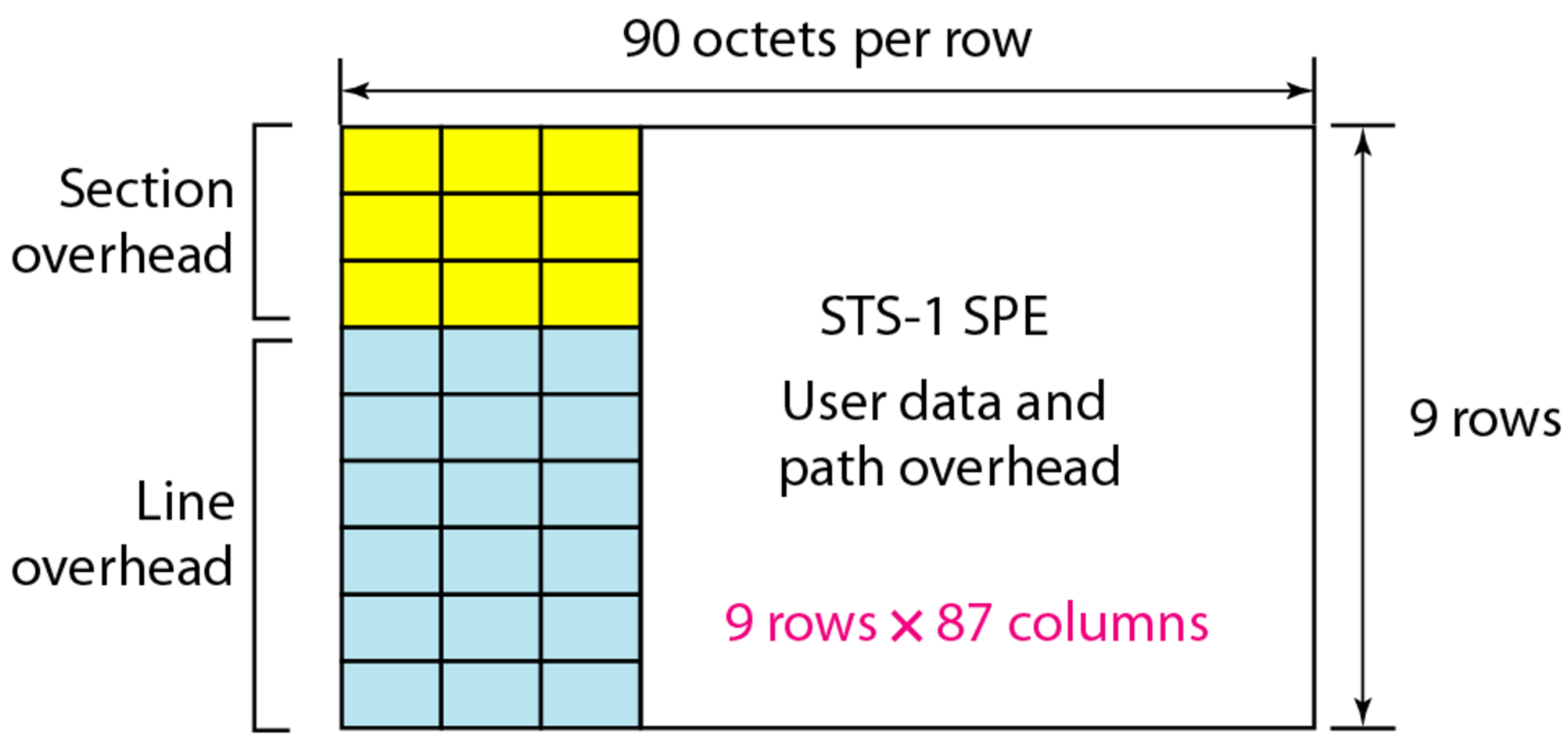
- Quiz:
  - What is the data rate for STS-1
- Answer:
  - $8000 \times (9 \times (1 \times 90))$ Bps $= 6.480$ MBps $= 51.840$ Mbps

Sonet

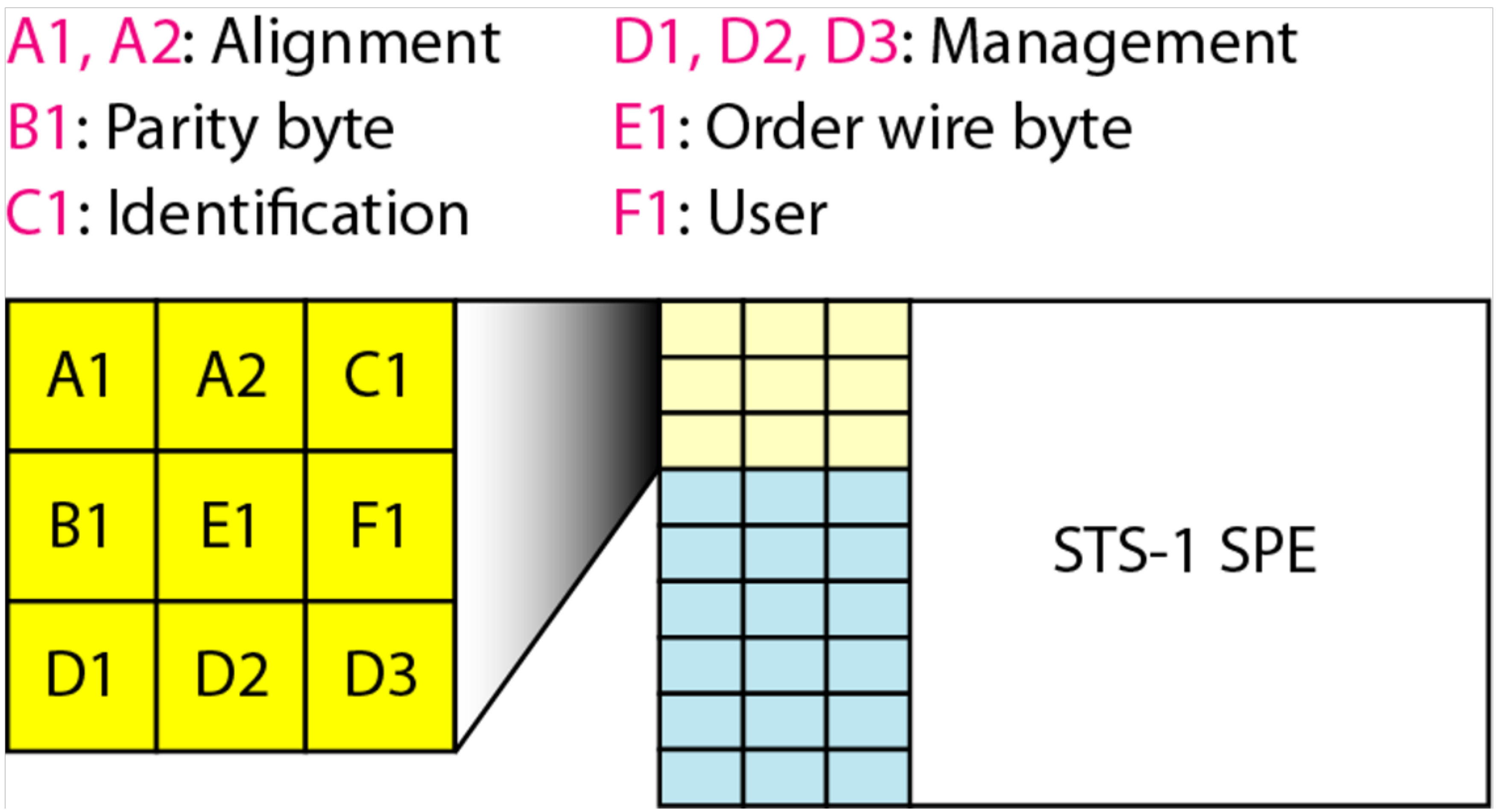
- Quiz:
  - What is the data rate of an STS-3
- Answer
  - $8000 \times (9 \times 3 \times 90 \times 8) = 155.52$ Mbps

Sonet

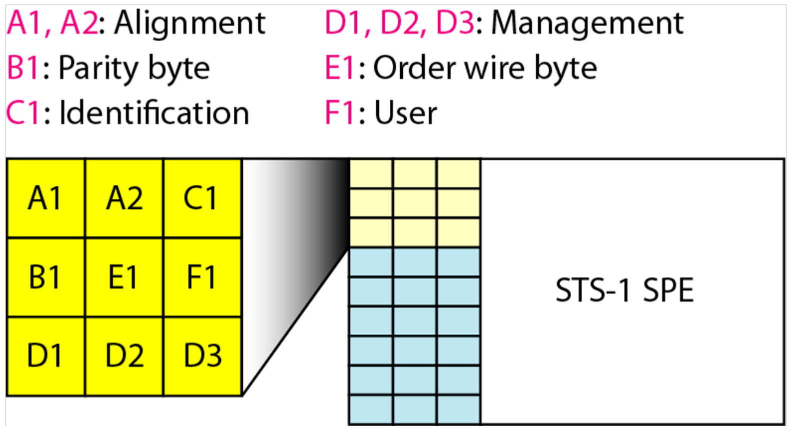
- First three columns are used for section and line overhead



Sonet

- Frame metadata
- 

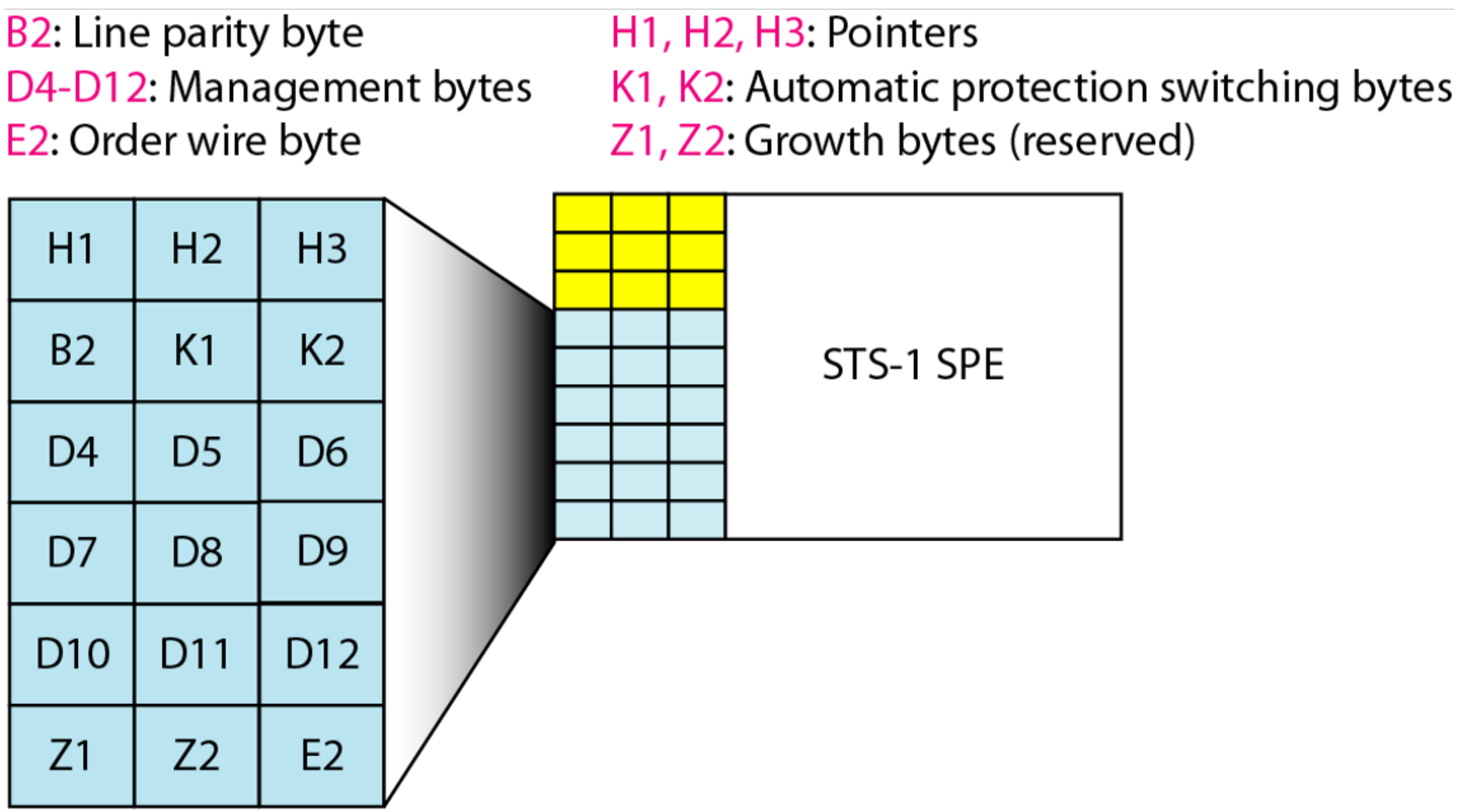
Sonet



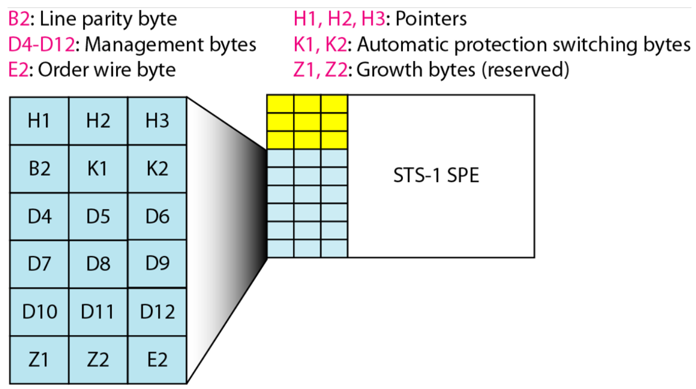
- Frame metadata
  - A1, A2 for framing and synchronization
  - Section Parity Byte: interleaved parity of previous frame STS-1 frame
  - Identification Byte:
    - Identifies STS-1 frame needed when multiple STS-1 are multiplexed to create a higher rate STS (STS-3, STS-9, STS-12)
  - Management bytes:
    - forms a $3 \times 8000 \times 8 = 192$ kbps *data*
    - *communication channel* for operation, administration, maintenance
  - Order wire byte: 64 kbps channel to communicate between regenerators
  - User byte: 64 kbps channel reserved for the section level

Sonet

- Line Overhead



Sonet

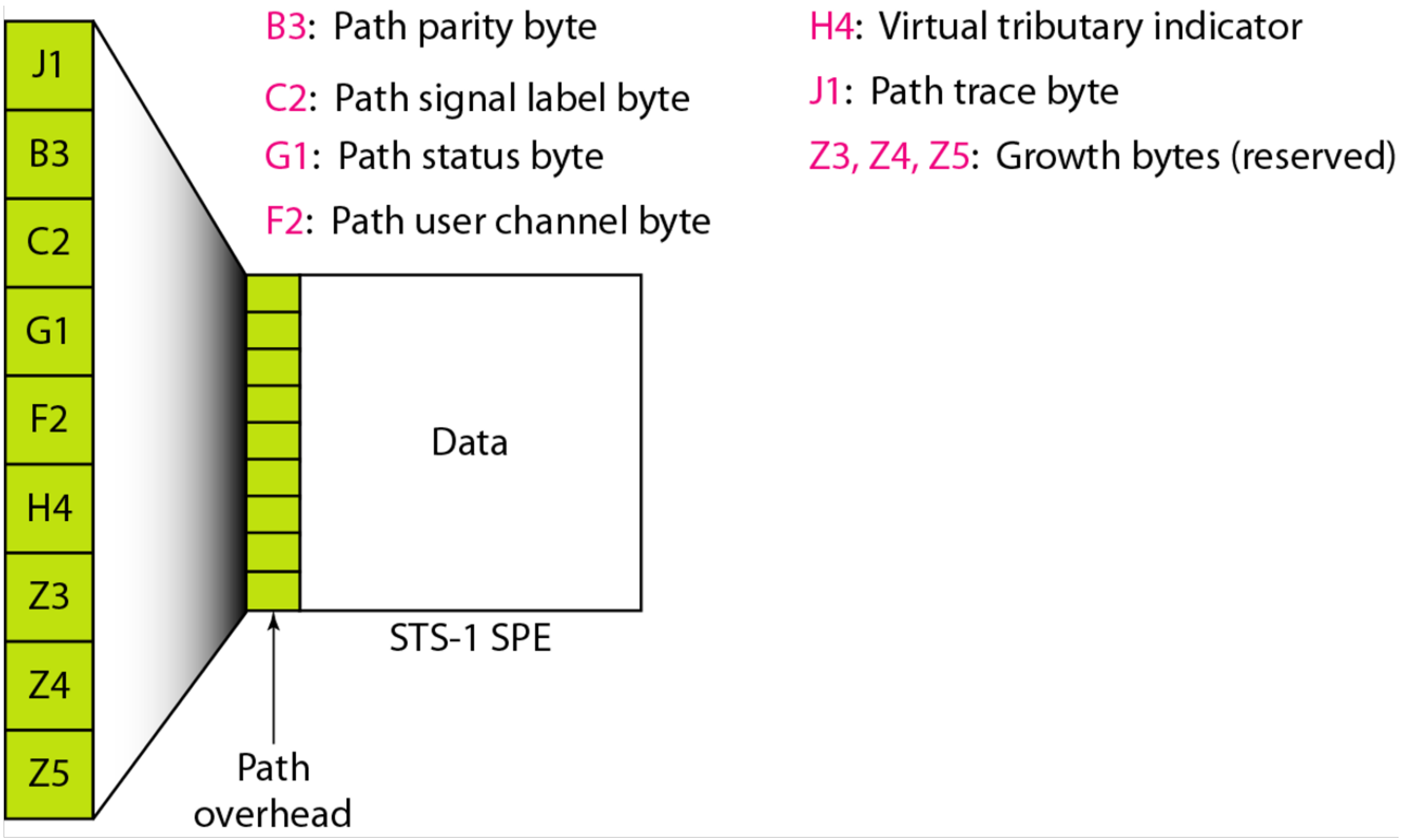


- Line Overhead
  - Line parity byte: Error checking for frame over a line
  - Data communication channel 576 kbps
  - Order wire byte: line level 64 kbps channel
  - Pointer bytes:
    - H1, H2 offset of the SPE in the frame
    - H3 justification
  - Automatic protection switching bytes
    - 128 kbps channel for automatic detection of problems in line terminating equipment
  - Growth bytes: reserved for future use

Sonet

- Synchronous Payload Envelope (SPE)
    - Contains the user data and the overhead related to user data
    - SPE does not necessarily fit into a STS-1 frame, but split between two
    - Path overhead (9 bytes)

Sonet



B3: Path parity byte
C2: Path signal label byte
G1: Path status byte
F2: Path user channel byte
H4: Virtual tributary indicator
J1: Path trace byte
Z3, Z4, Z5: Growth bytes (reserved)
J1
B3
C2
G1
F2
H4
Z3
Z4
Z5
Data
STS-1 SPE
Path overhead

Sonet

- Path overhead
  - Parity byte B3
  - Path signal label byte: Identifies different protocols such as IP or ATM that are carried in a SPE
  - Path user channel byte: 64kbps for user needs at the path level
  - Path status byte: Allows the receiver to communicate its status to the sender
  - Multiframe indicator: Indicates payloads that cannot fit into a single frame
    - E.g. Virtual tributaries can be combined to be divided into different frames
  - Path trace byte: 64kbps channel to verify connection.
    - Continuous 64B stream of the same byte selected by application program
  - Growth byte: Reserved for future use

Sonet

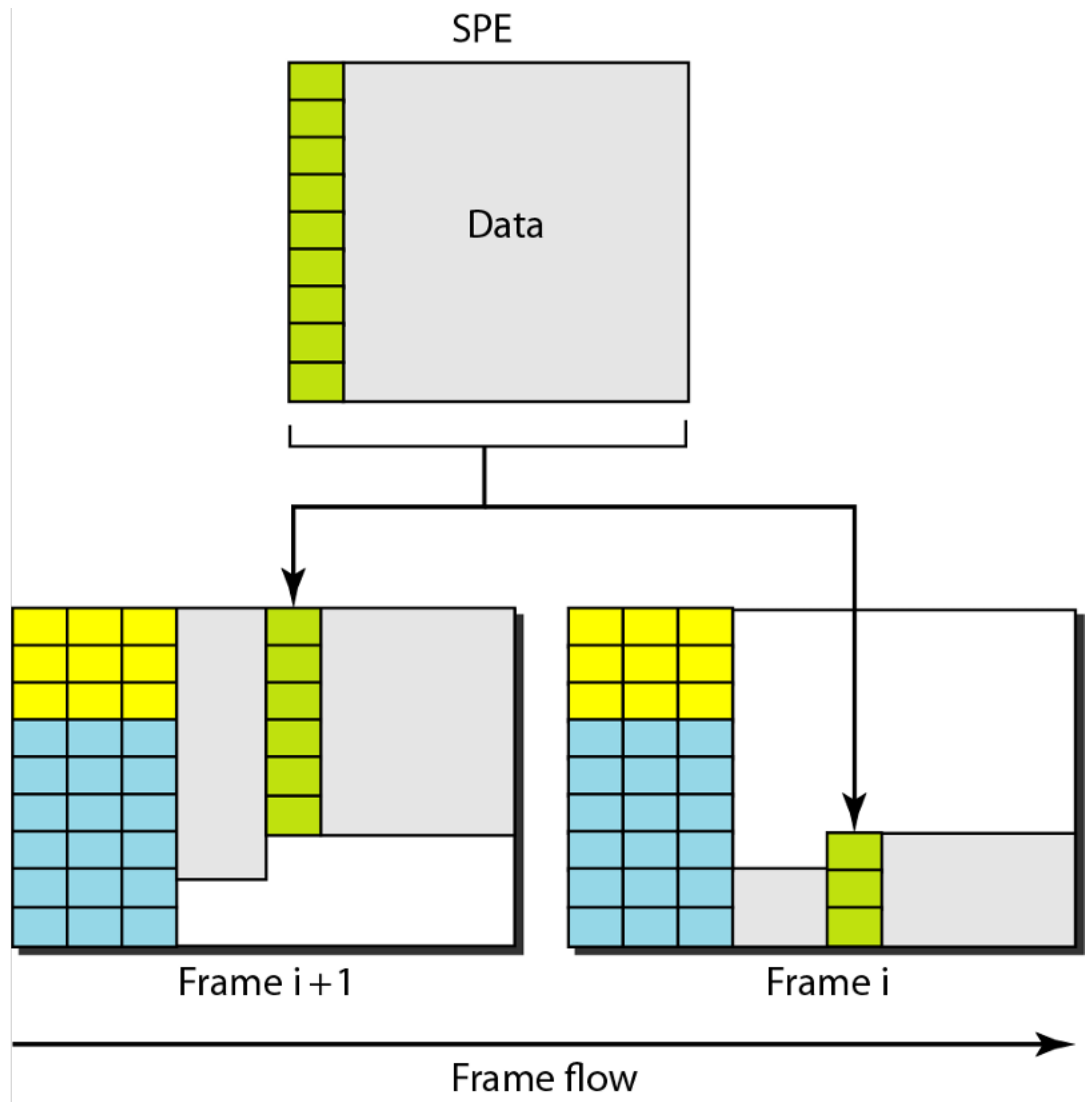
Byte Function	*Section*	*Line*	*Path*
Alignment	A1, A2		
Parity	B1	B2	B3
Identifier	C1		C2
OA&M	D1–D3	D4–D12	
Order wire	E1		
User	F1		F2
Status			G1
Pointers		H1– H3	H4
Trace			J1
Failure tolerance		K1, K2	
Growth (reserved for future)		Z1, Z2	Z3–Z5

Sonet

- Quiz:
  - What is the user data rate of an STS-1 frame without overheads
- Answers:
  - User data makes up 9 rows and 86 columns
- Data rate is
  - $8000 \times 9 \times 86 \times 8 = 49.536$ Mbps

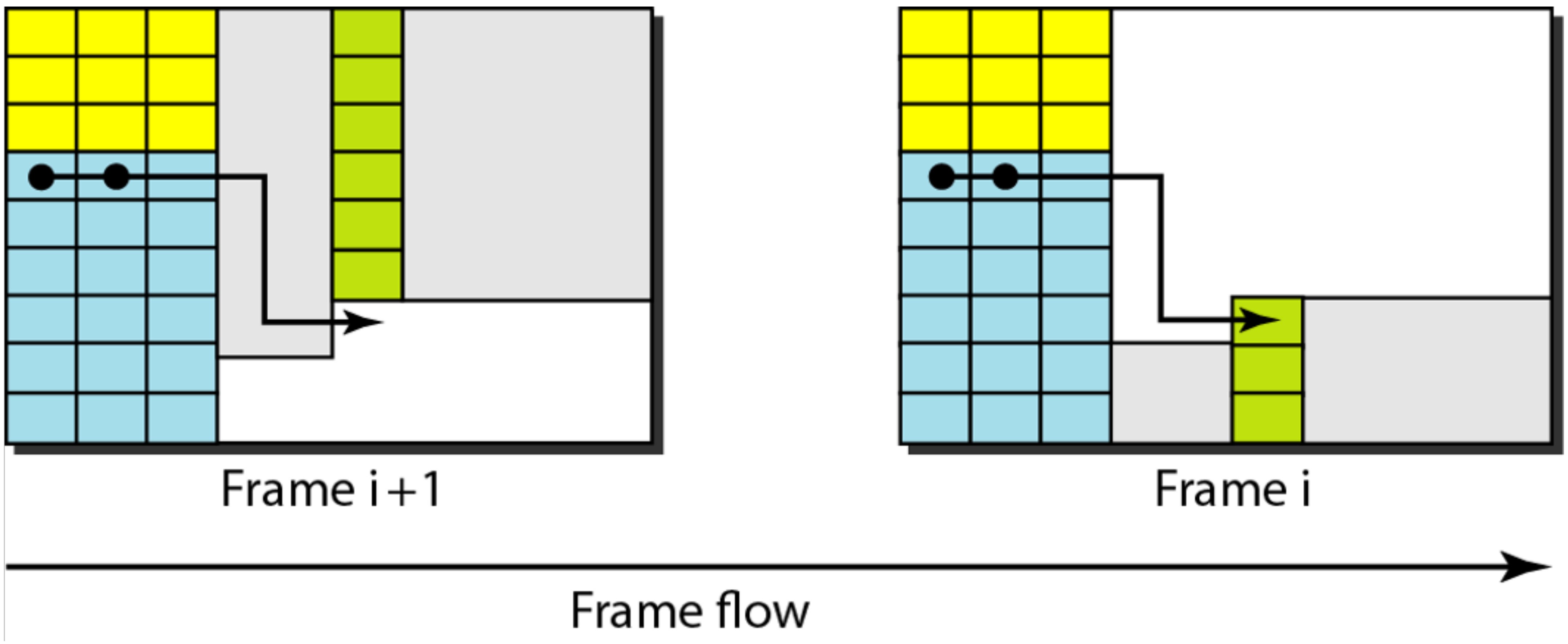
Sonet

- Offsetting:
  - SPE can span two frames



Sonet

- H1 and H2 pointers show start of an SPE in a frame

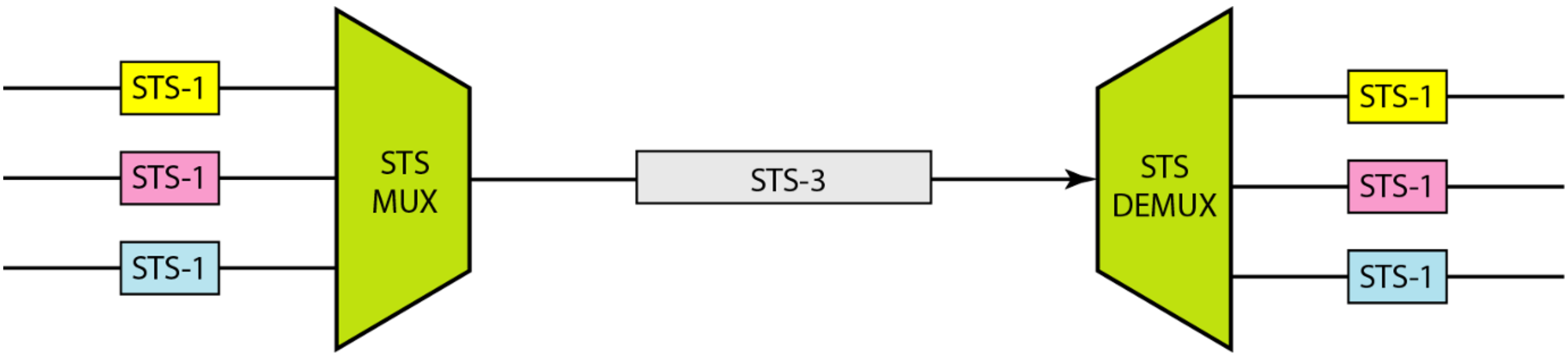


Sonet

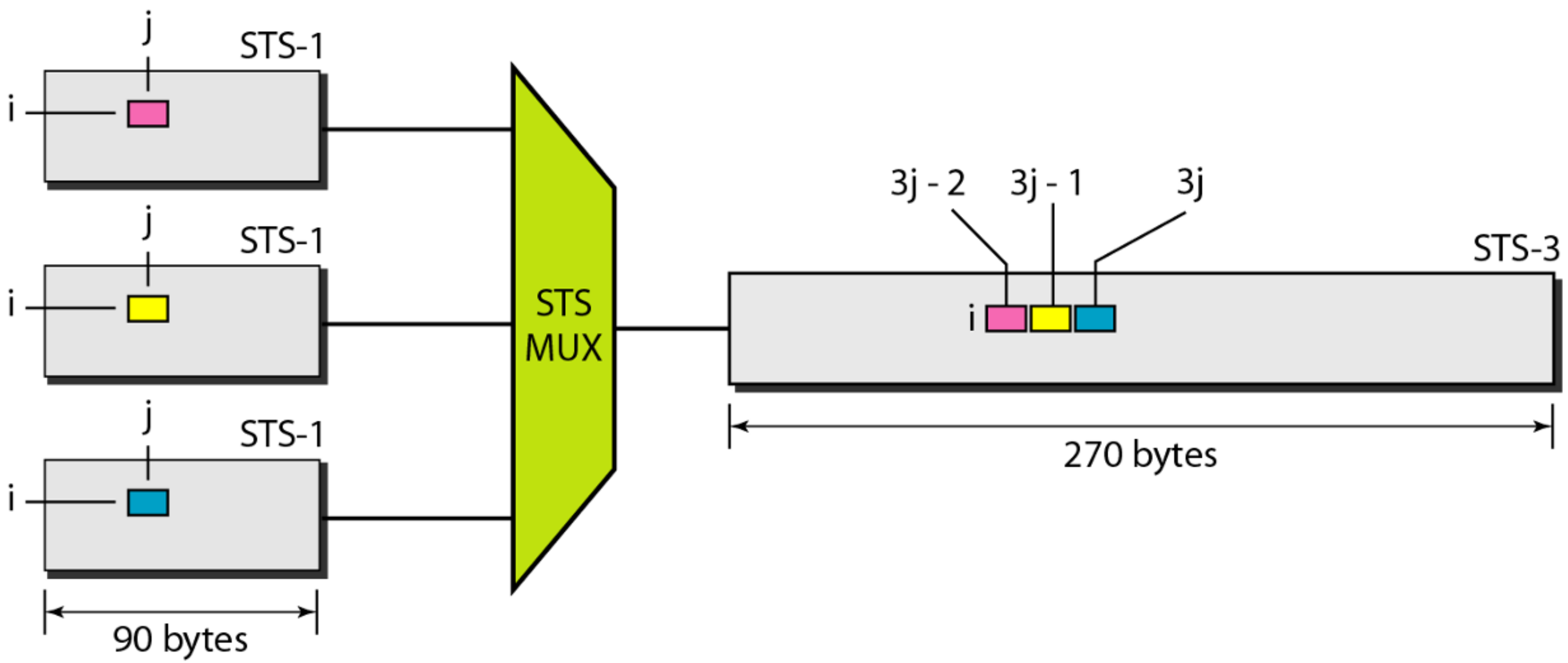
- Quiz:
  - An SPE starts at byte 450
  - What are the H1 and H2 values?
- Answer:
  - $450_{10} = 0x01c2$
  - H1 value is 0x01
  - H2 value is 0xc2

Sonet

- STS multiplexing
  - Use synchronous Time Division Multiplexing
  - Clocks in network are synchronized to master clock



Sonet



j
STS-1
i
j
STS-1
i
j
STS-1
i
90 bytes
STS
MUX
3j - 2
3j - 1
3j
STS-3
i
270 bytes

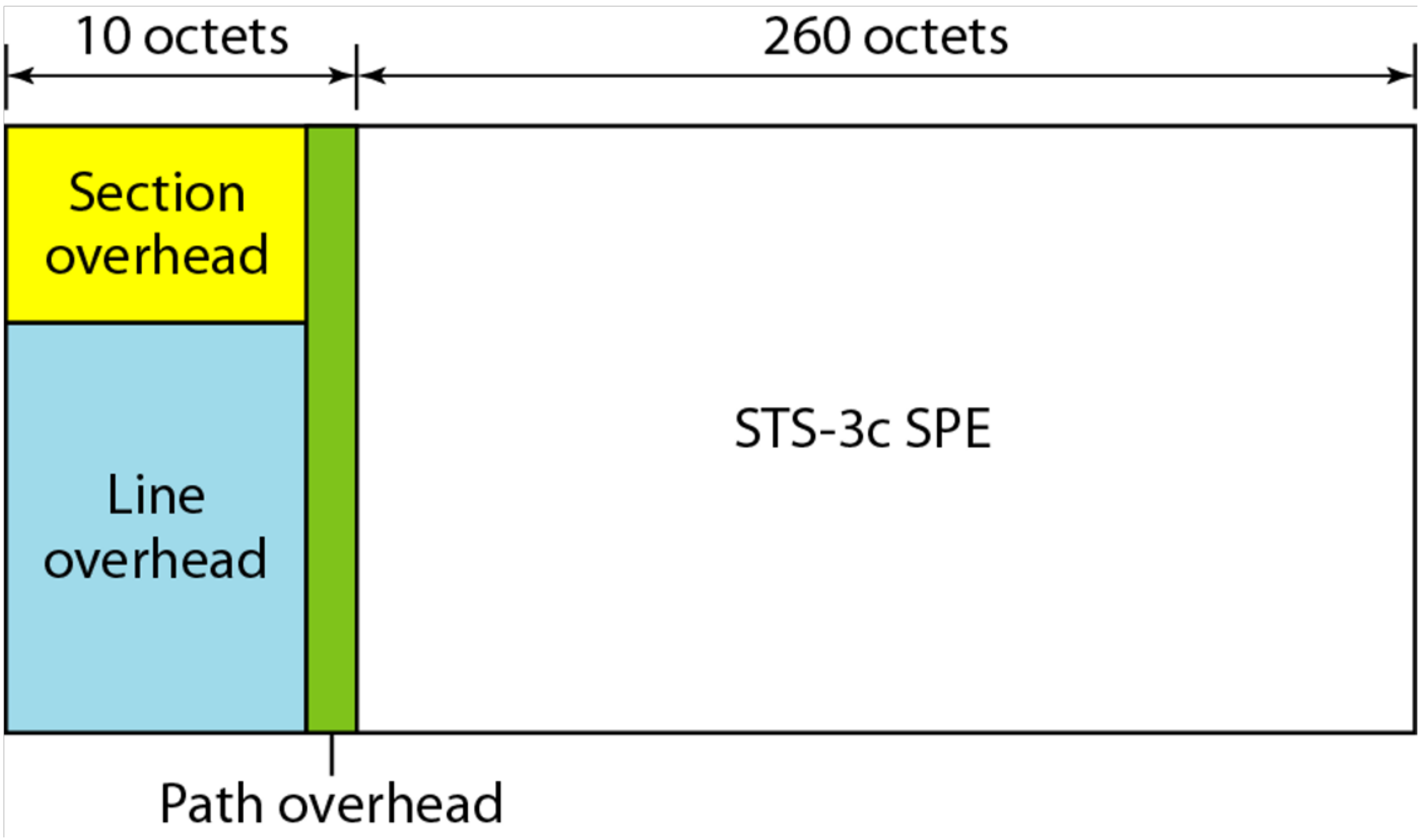
Sonet


9 bytes
261 bytes
Section overhead
A1 A1 A1 A2 A2 A2 C1 C1 C1
B1 B1 B1 E1 E1 E1 F1 F1 F1
D1 D1 D1 D2 D2 D2 D3 D3 D3
Line overhead
H1 H1 H1 H2 H2 H2 H3 H3 H3
B2 B2 B2 K1 K1 K1 K2 K2 K2
D4 D4 D4 D5 D5 D5 D6 D6 D6
D7 D7 D7 D8 D8 D8 D9 D9 D9
D10 D10 D10 D11 D11 D11 D12 D12 D12
Z1 Z1 Z1 Z2 Z2 Z2 E2 E2 E2
STS-3 SPE
Interleaving
bytes of three SPEs

Sonet

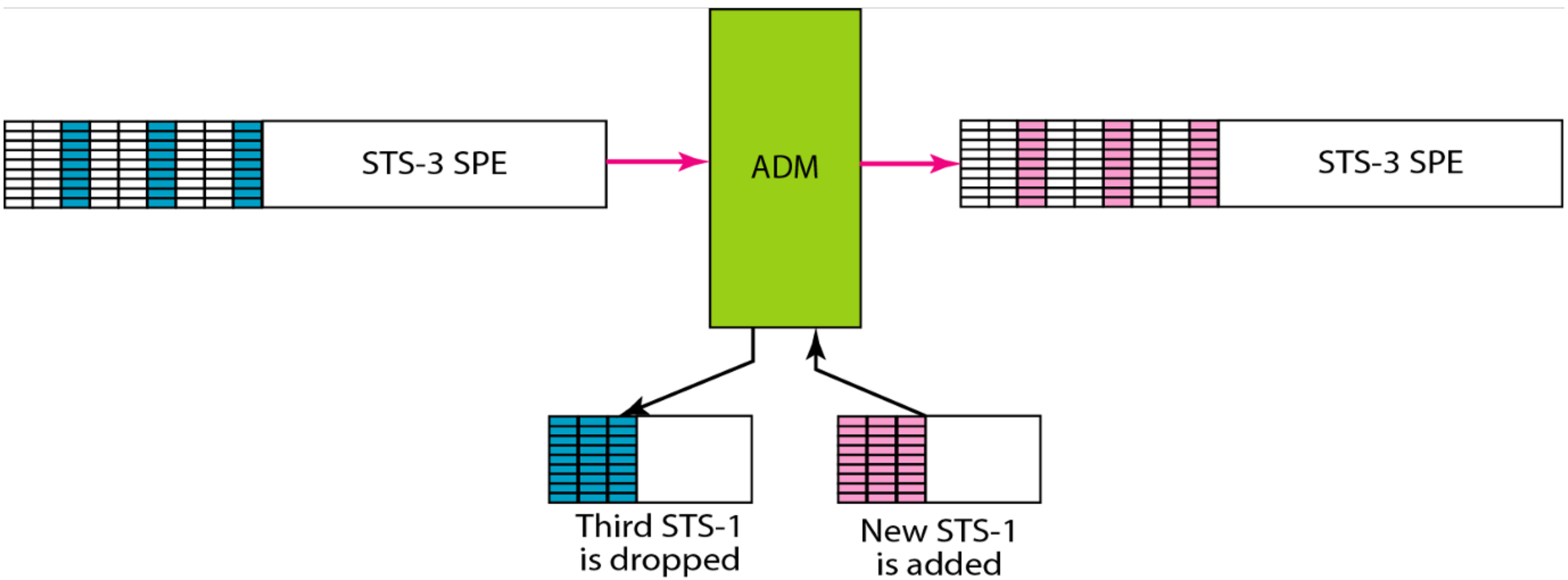
- ATM is a cell network with 53B cells
- SPE of a STS-3c signal can carry ATM cells
  - SPE carries 9×260 = 2340 B
  - Can accommodate 44 ATM cells

Sonet


10 octets
260 octets
Section overhead
Line overhead
STS-3c SPE
Path overhead

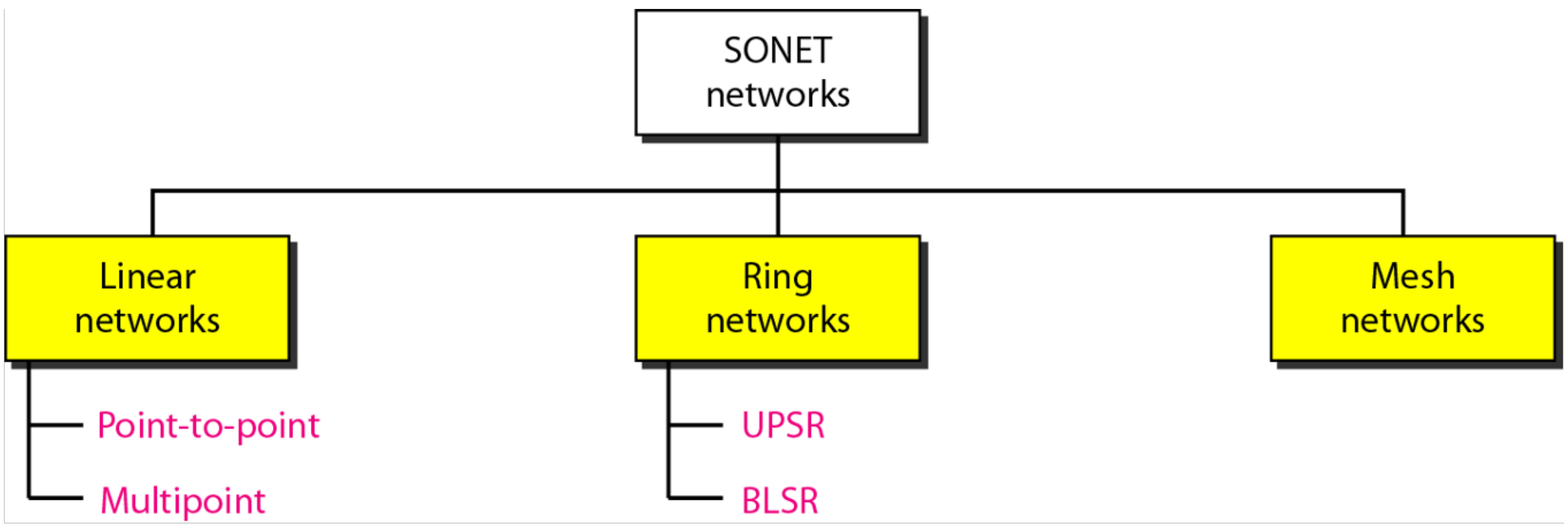
Sonet

- Add Drop Multiplexer allow us to exchange one STS-1 for another



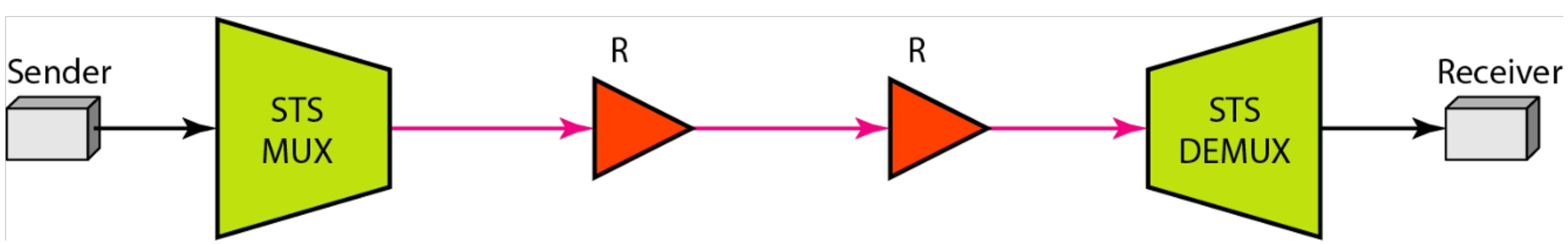
Sonet Networks

- Use SONET equipment to build high-speed backbones
  - to carry loads from ATM, IP, …
-



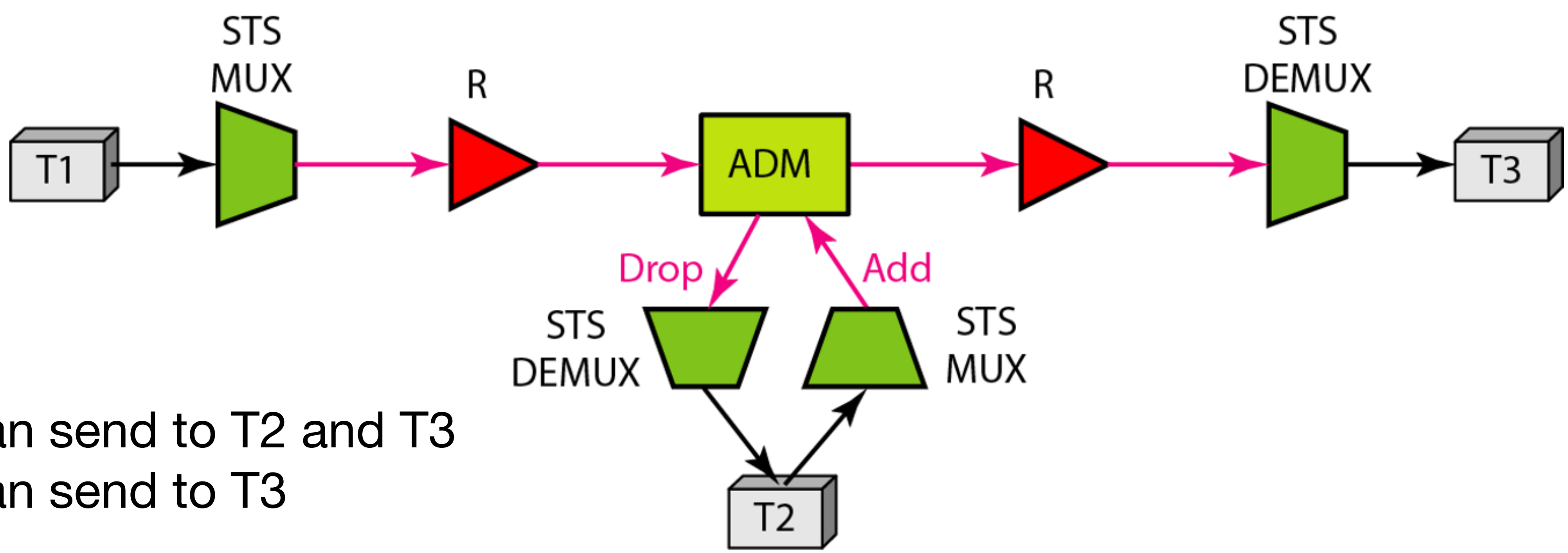
Sonet Networks

- P2P network:
  - Uses an STS multiplexer, an STS demultiplexer, and zero or more regenerators
  - Flow can be unidirectional (shown) or biderectional



Sonet Networks

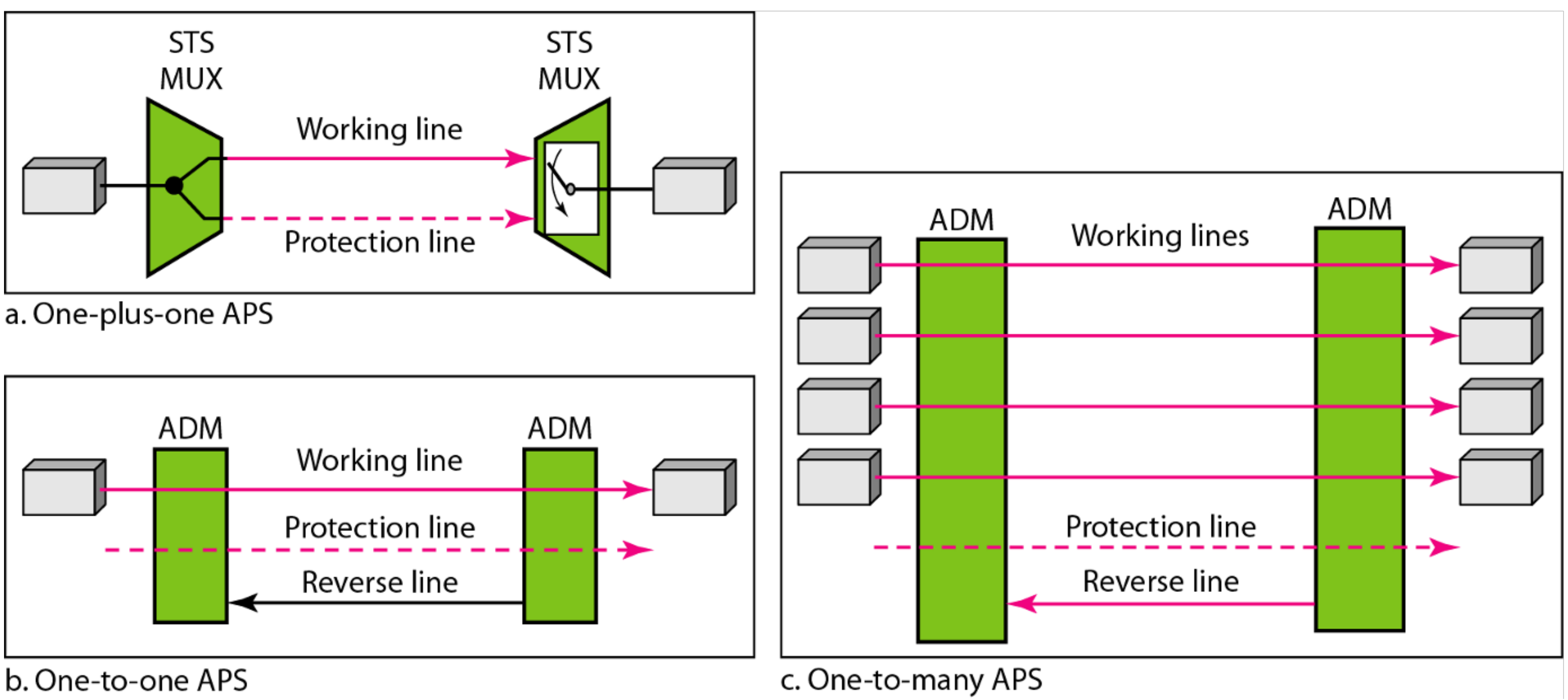
- Multipoint networks
  - Use ADM to remove signal to terminal connected to and add new signal
  - Can be unidirectional (shown) or bidirectional



T1 can send to T2 and T3
T2 can send to T3

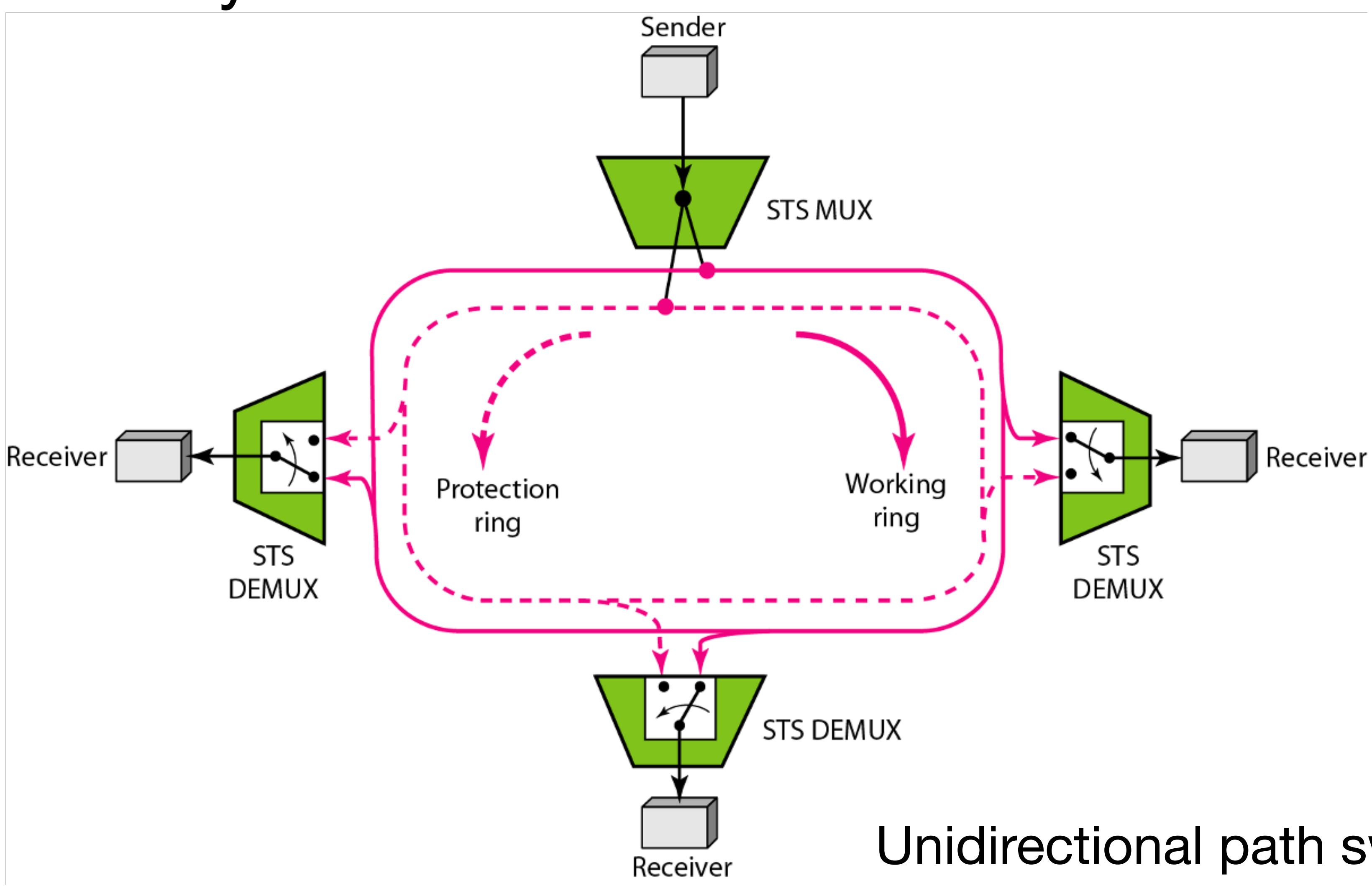
Sonet Networks

- Automatic protection switching
  - A redundant line (at the line layer) to replace a failed main line



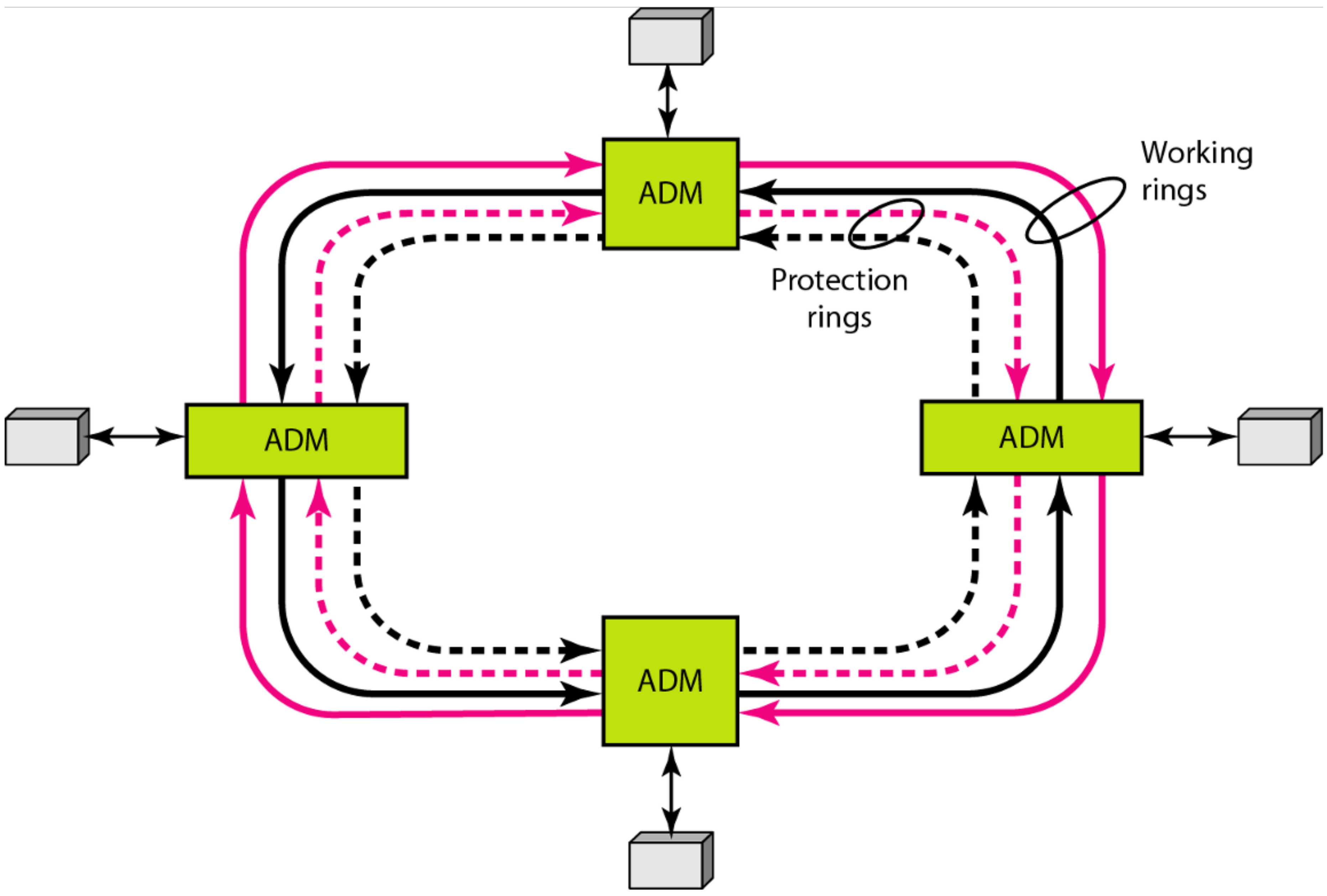
Sonet Networks

- Ring networks
  - Use one or two rings, add additional rings for redundancy



Unidirectional path switching ring

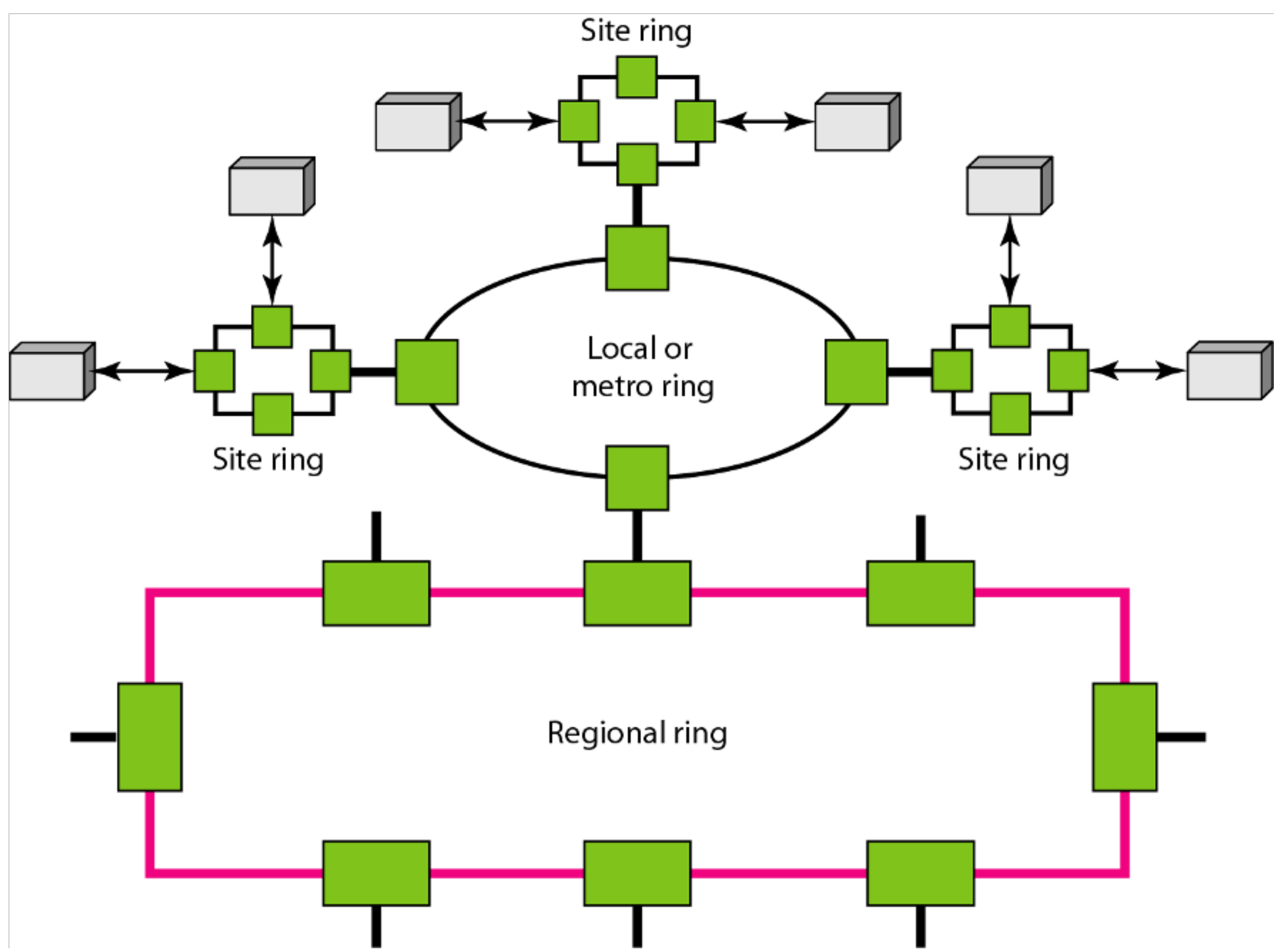
Sonet Networks



Bidirectional line switching ring

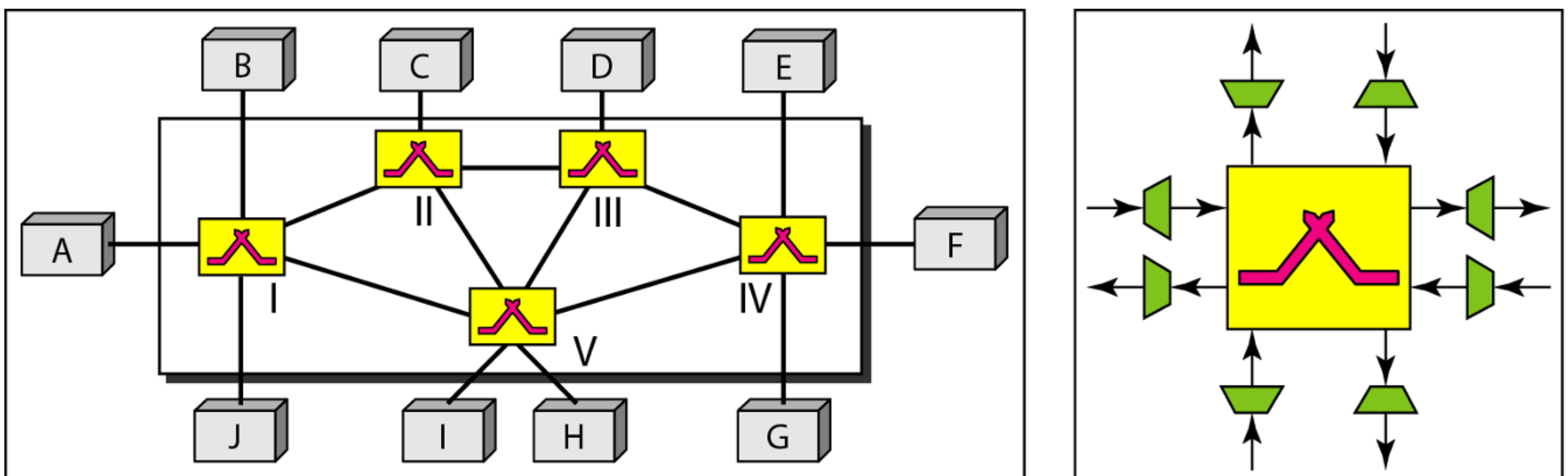
Sonet Networks

- Rings have poor scalability
- Combining rings



Sonet Networks

- Meshes
  - Combining rings with switches for wide are service



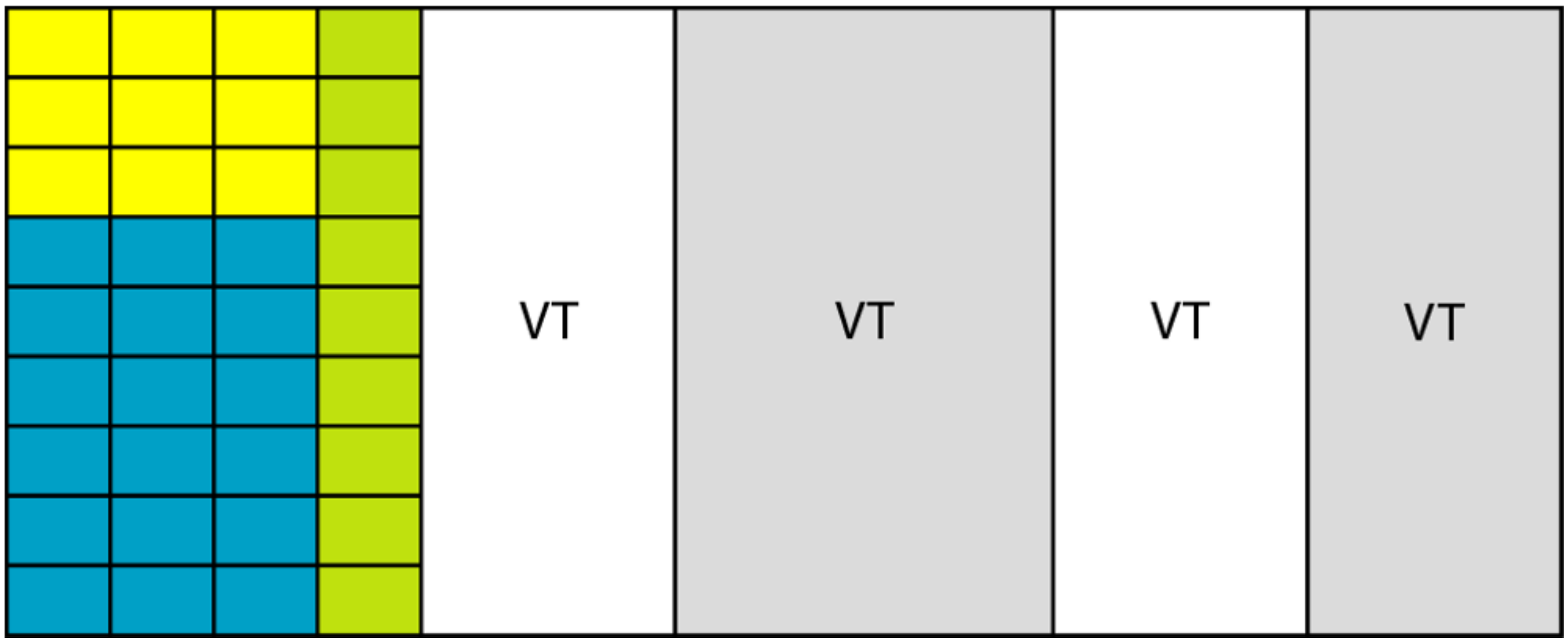
a. SONET mesh network
b. Cross-connect switch

Sonet Virtual Tributaries

- SONET has higher data rates than previous technologies
- Use Virtual Tributaries to carry broadband payloads (DS1-DS3)
  - Partial payload combined with other payloads to be inserted into a STS-1
-

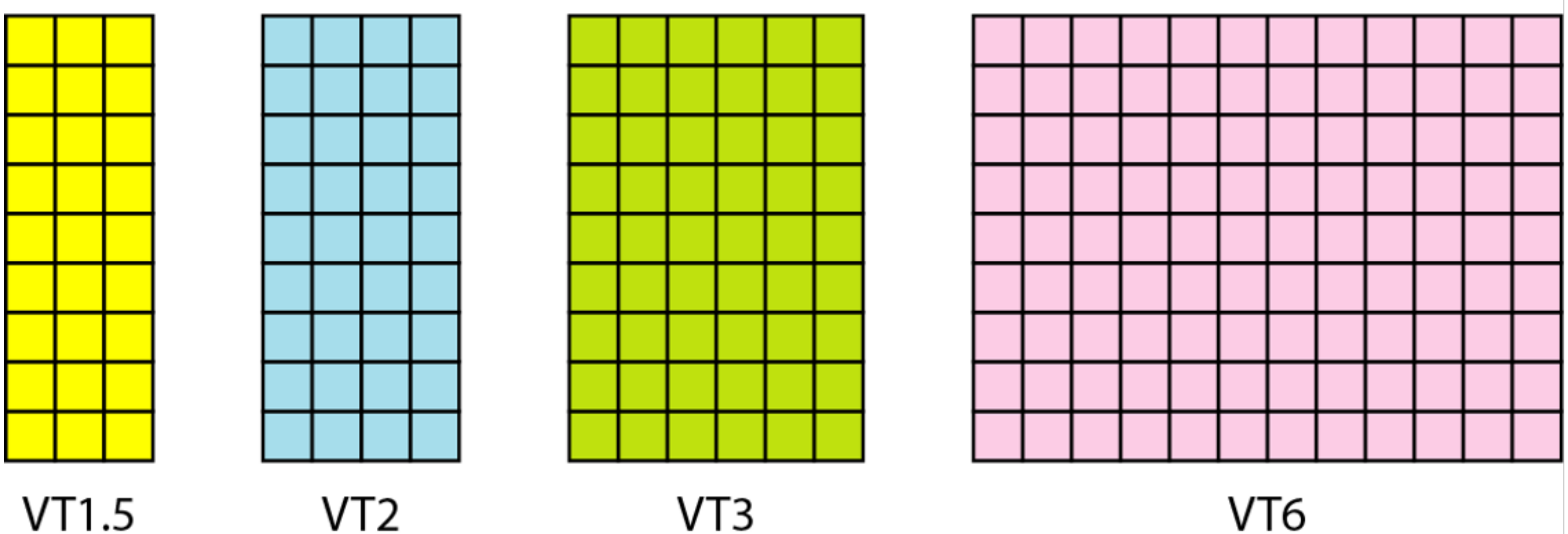
VT1.5	DS-1	(1.544 Mbps)
VT2	CEPT-1	(2.048 Mbps)
VT3	DS-1C	(3.152 Mbps)
VT6	DS-2	(6.312 Mbps)

Sonet Virtual Tributaries



Sonet Virtual Tributaries

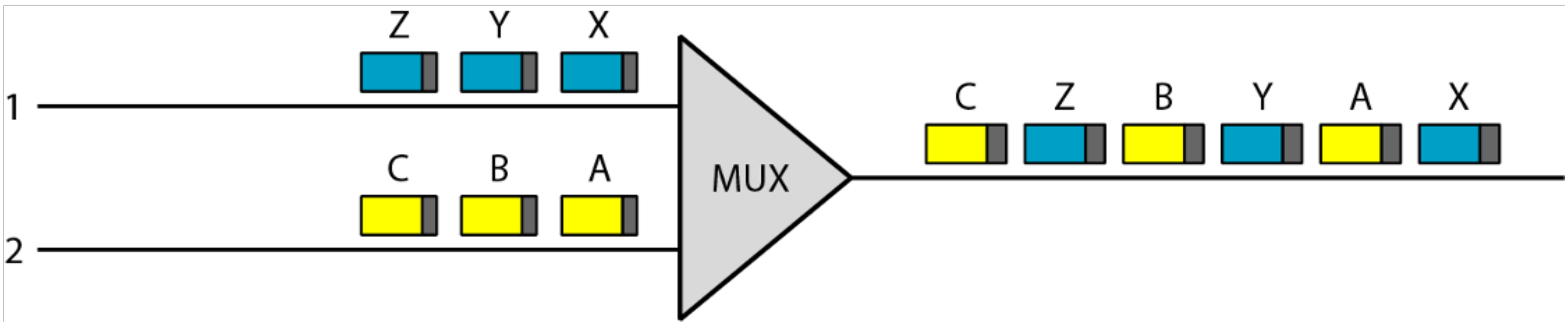
VT1.5	= 8000 frames/s	3 columns	9 rows	8 bits	=	1.728 Mbps
VT2	= 8000 frames/s	4 columns	9 rows	8 bits	=	2.304 Mbps
VT3	= 8000 frames/s	6 columns	9 rows	8 bits	=	3.456 Mbps
VT6	= 8000 frames/s	12 columns	9 rows	8 bits	=	6.912 Mbps



ATM

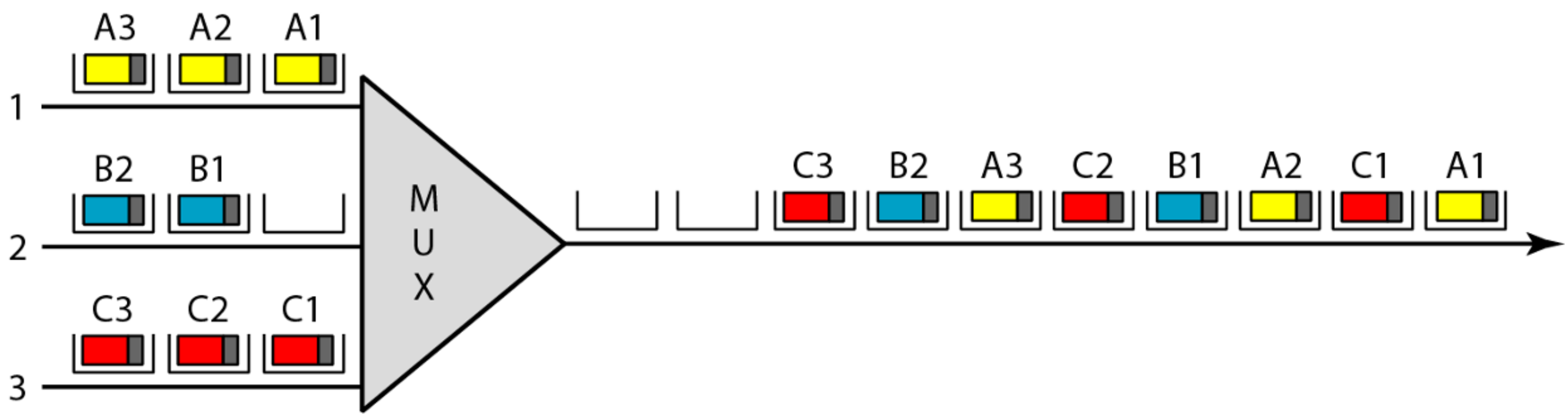
- Asynchronous Transfer Mode
  - Use cell relay protocol
    - **Cell** is a small data unit of fixed size
    - All data is loaded into identical cells
    - Frames of different sizes / formats are split into cells
    - Cells are multiplexed with other cells and routed through the cell network

ATM



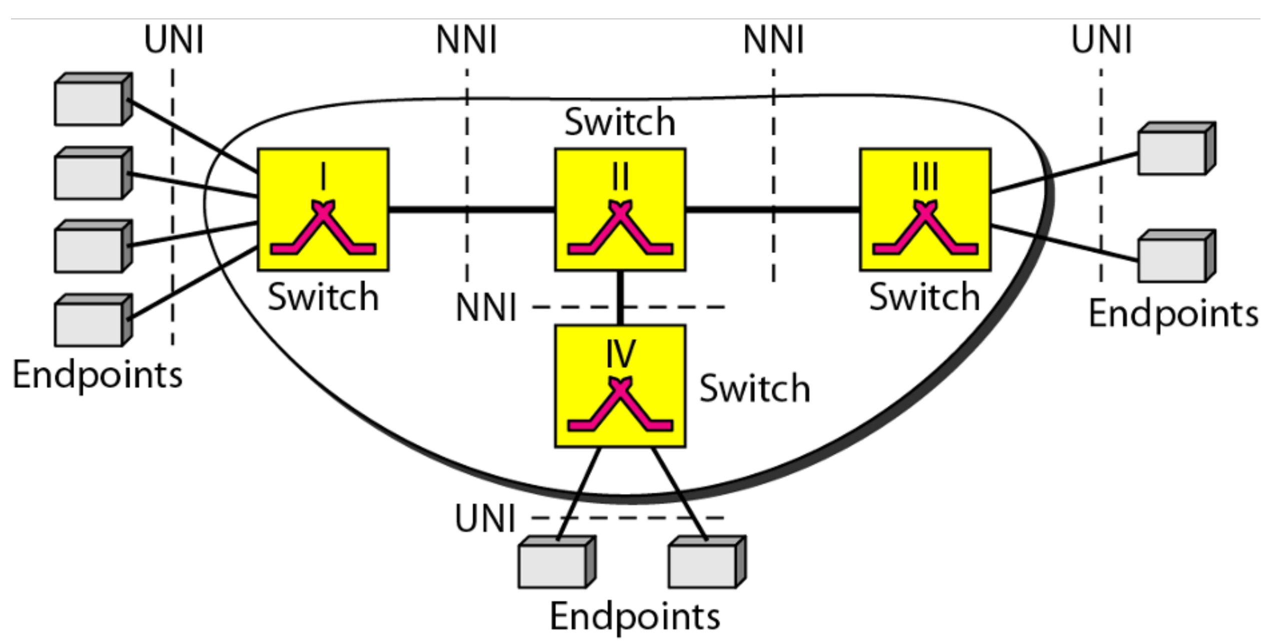
ATM

- ATM uses asynchronous time-division multiplexing
- Emits cells at same rate, but slots can be empty



ATM Architecture

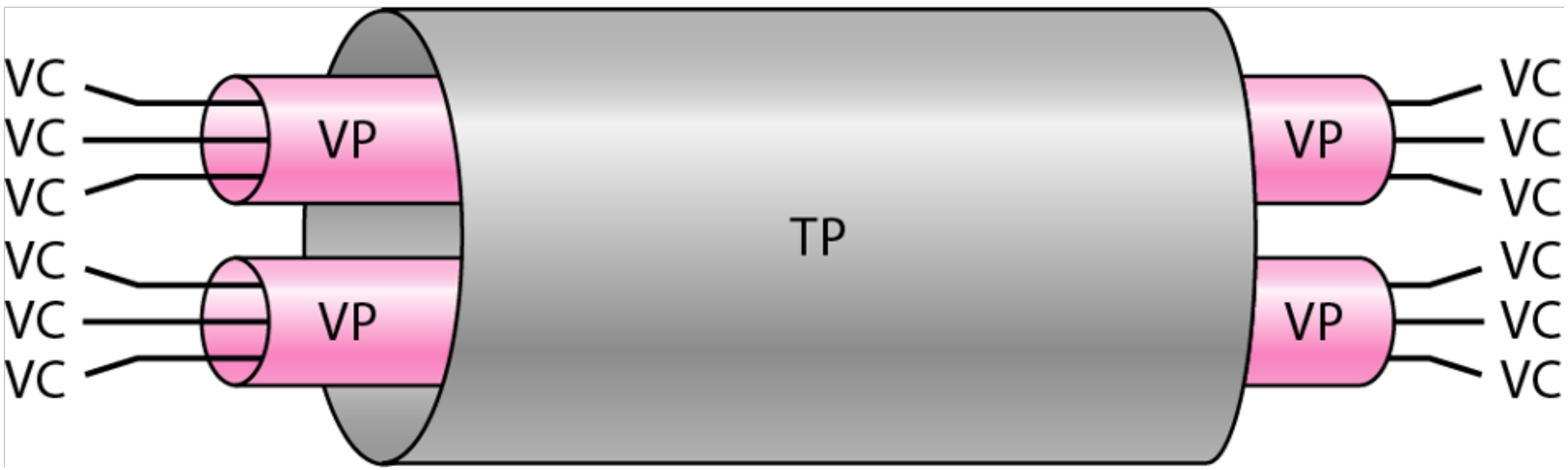
- User access devices (called endpoints)
  - Connected through User to Network Interface (UNI) to switches inside the network
  - Switches are connected through Network to Network Interfaces (NNI)



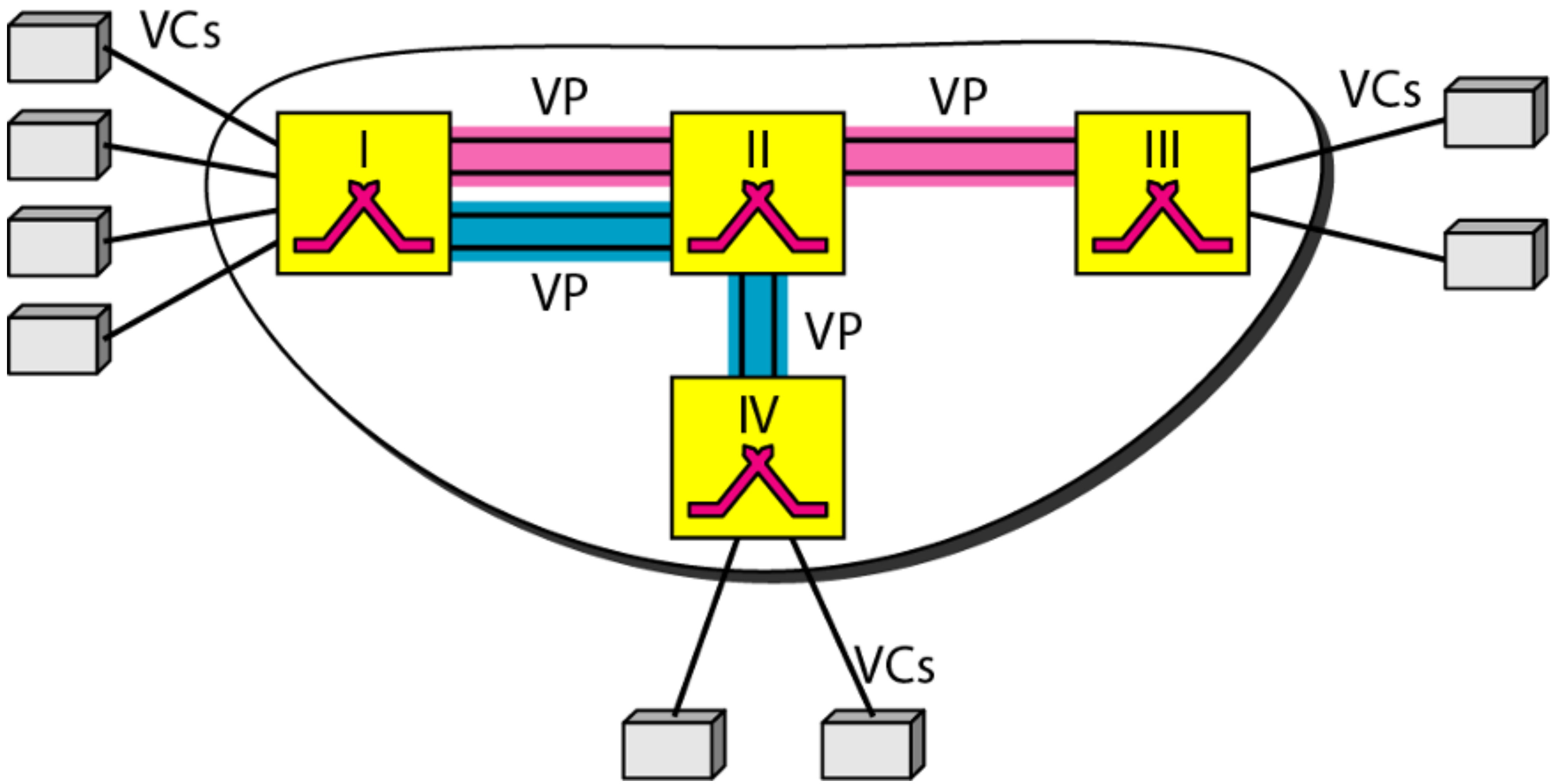
ATM Architecture

- Connection between two endpoints
  - Transmission paths
    - Physical connection
  - Virtual paths
    - Abstraction of a part of a transmission path
  - Virtual circuits
    - Cells belonging to a single message follow the same virtual circuit and remain in their original order

ATM Architecture



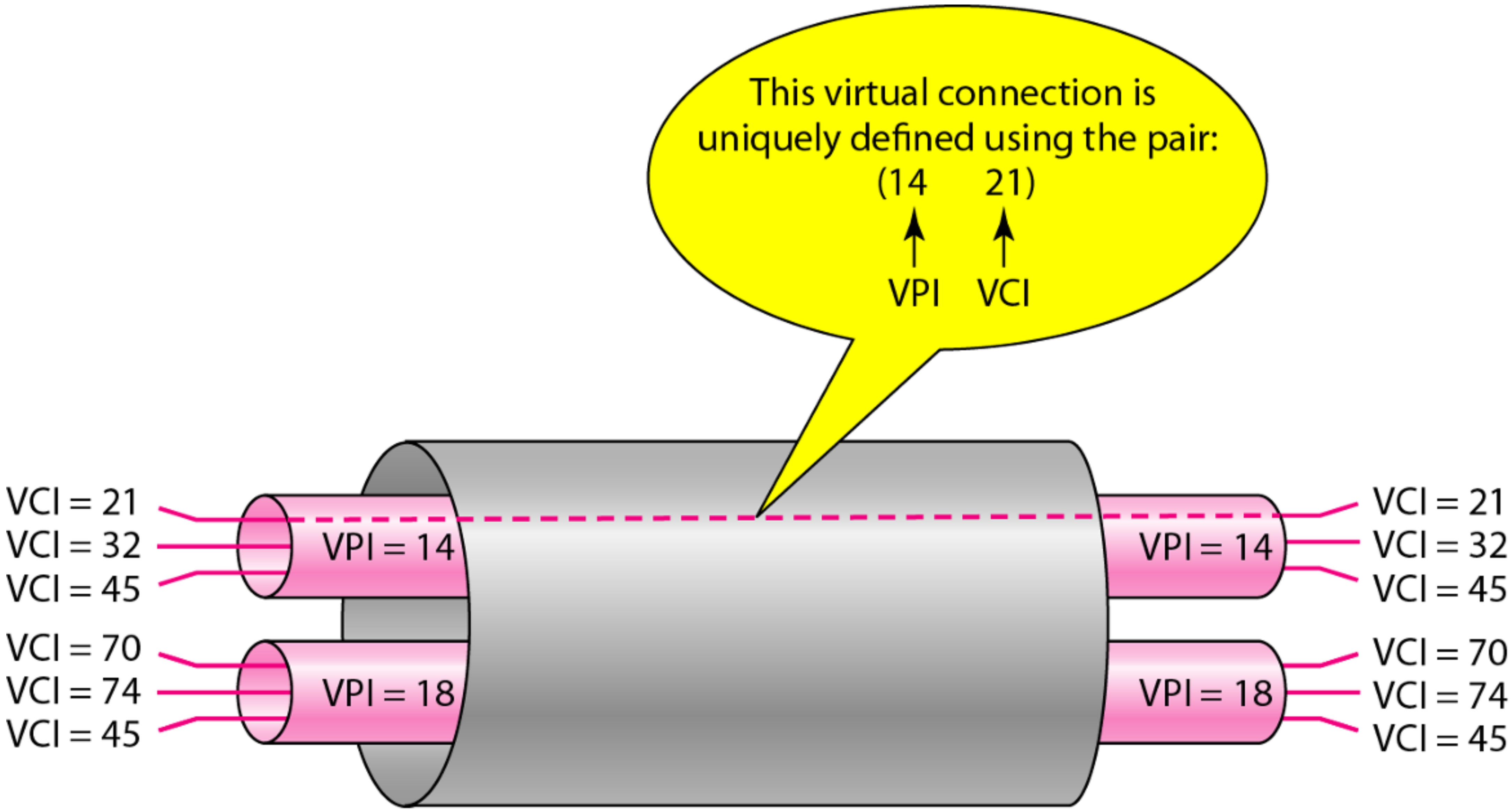
ATM Architecture



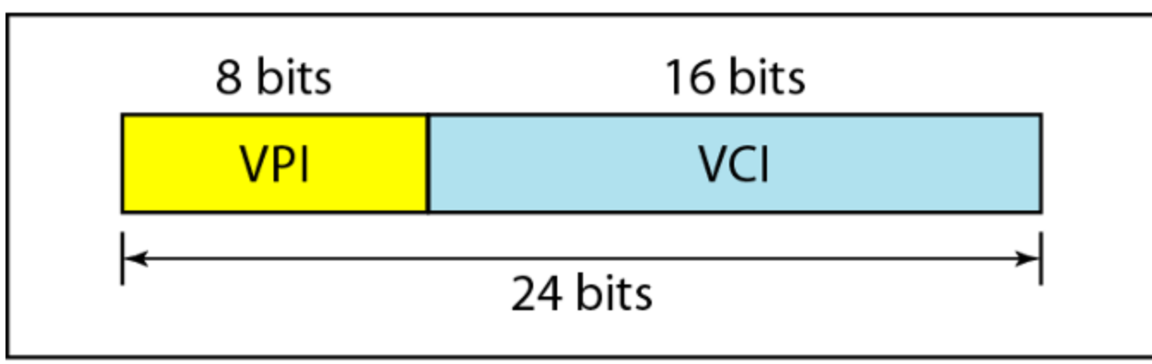
ATM Architecture

- For routing:
  - Identify the virtual connection:
    - Two layers:
      - Virtual Path Identifier (VPI)
      - Virtual Circuit Identifier (VCI)

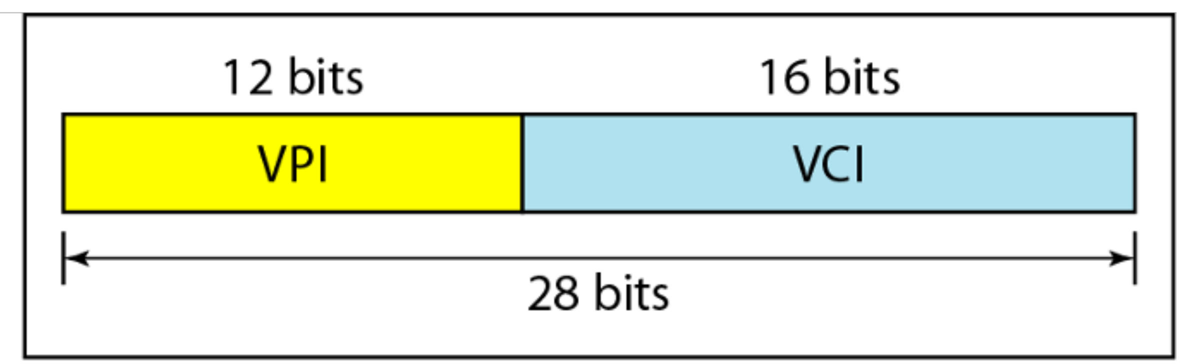
ATM Architecture



ATM Architecture



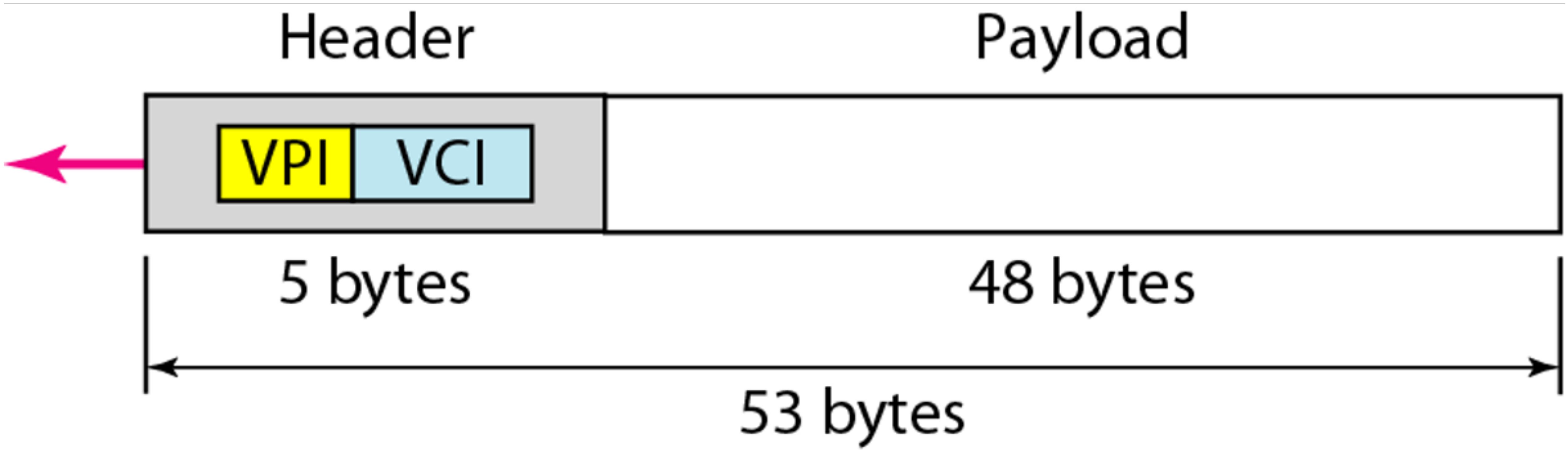
a. VPI and VCI in a UNI



b. VPI and VCI in an NNI

ATM Architecture

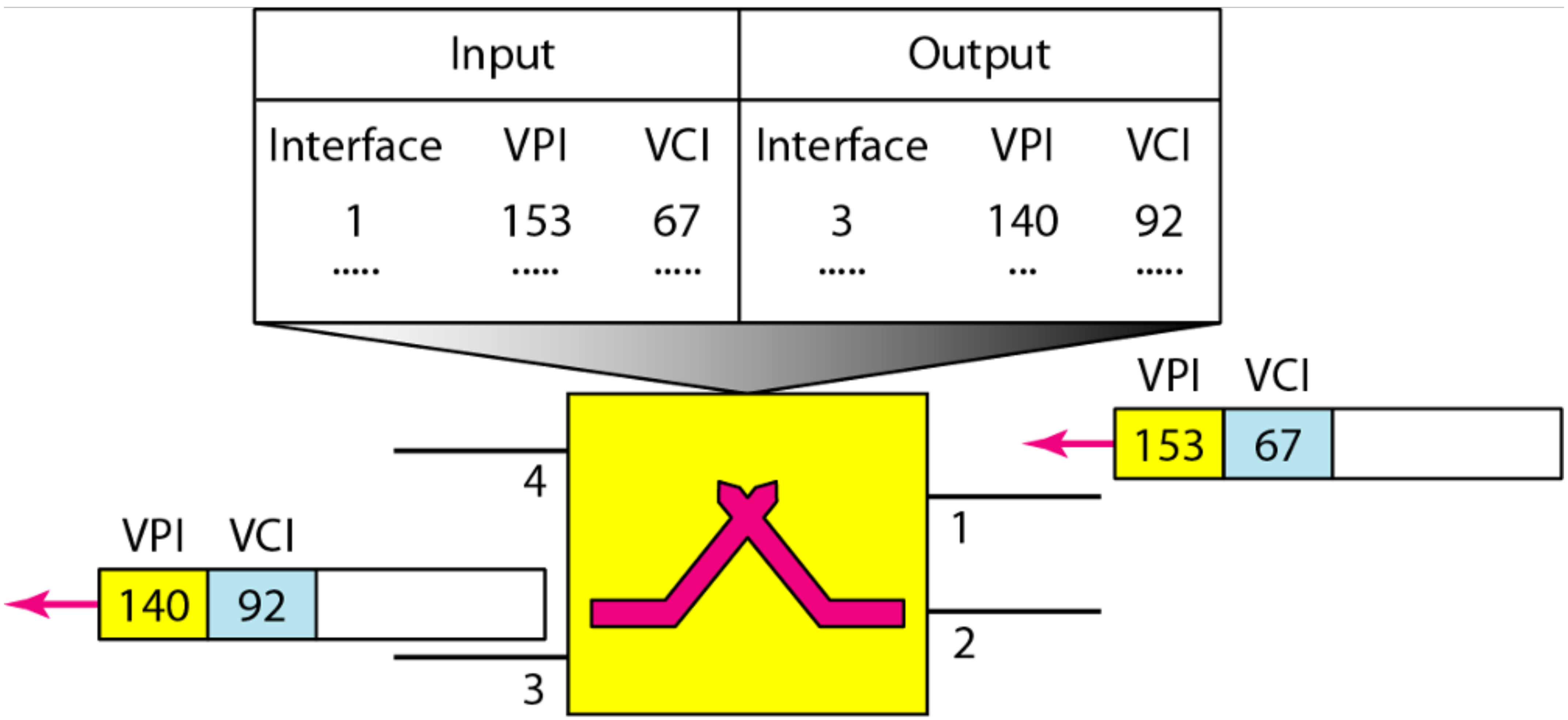
- Cell makeup



ATM Architecture

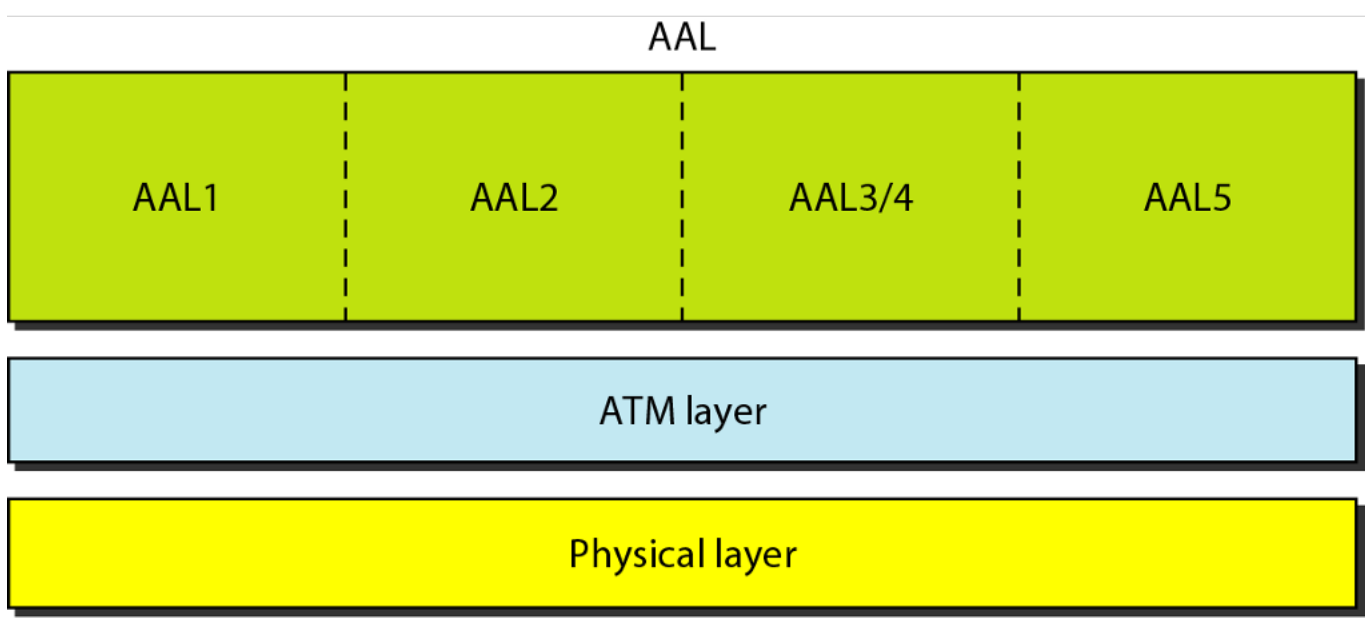
- ATM uses
  - Permanent virtual-circuit connections
  - Switched virtual-circuit connections
    - Connection needs to be established first
    - Network layer defines the actual protocol
- Switches use the complete header

ATM Architecture

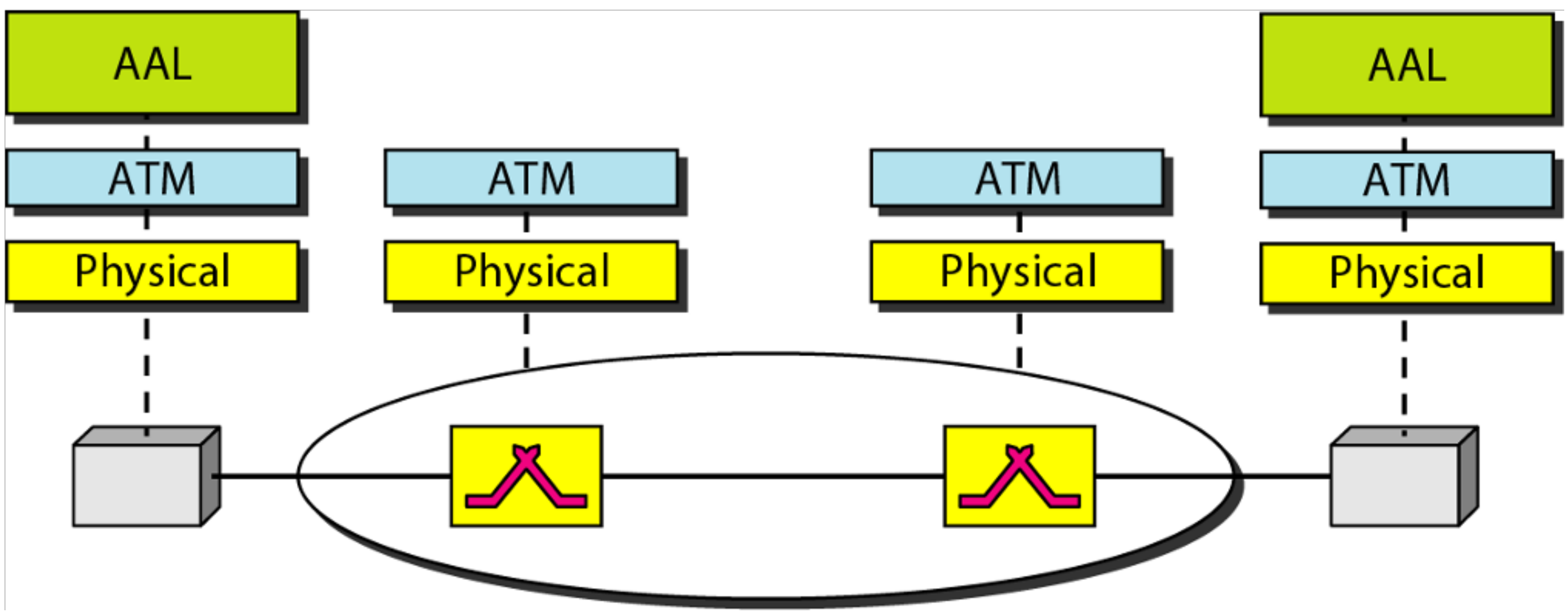


ATM Layers

- Application adaption layer (AAL)
- ATM layer
- Physical layer



ATM Layers

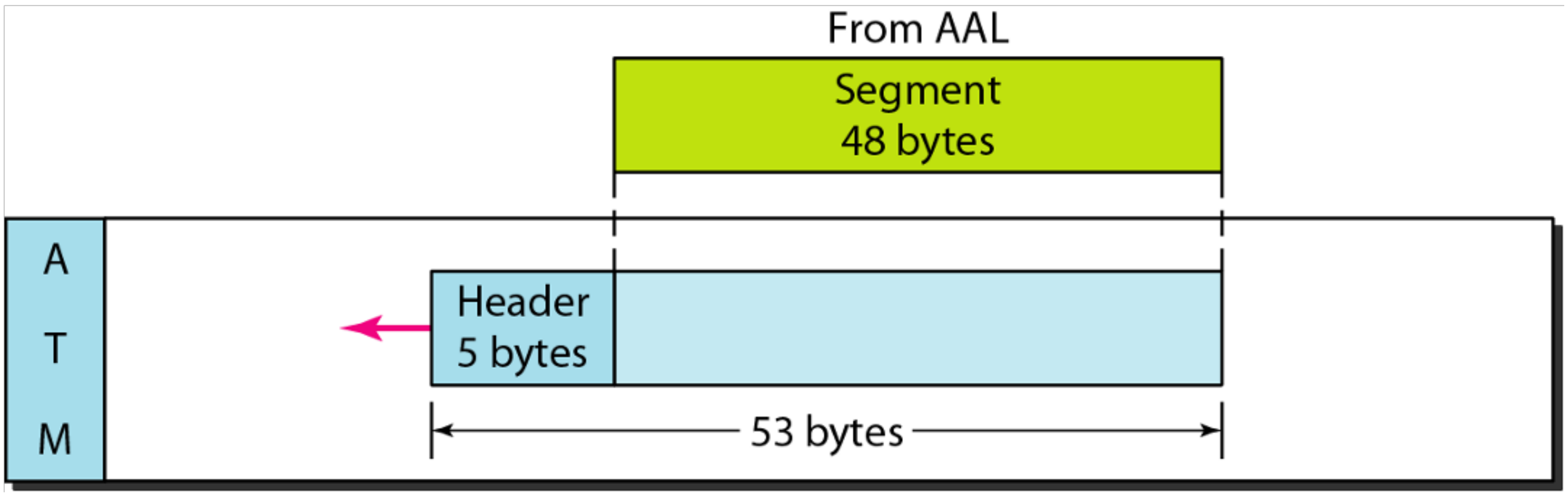


AAL
ATM
Physical
ATM
Physical
ATM
Physical
AAL
ATM
Physical

ATM Layers

- ATM needs to accept all payloads
  - Frames
  - Continuous bit-streams
- Segmentation and Reassembly Layer divides payload into cells and reassembles them at the destination
- Convergence Sublayer assures integrity of data

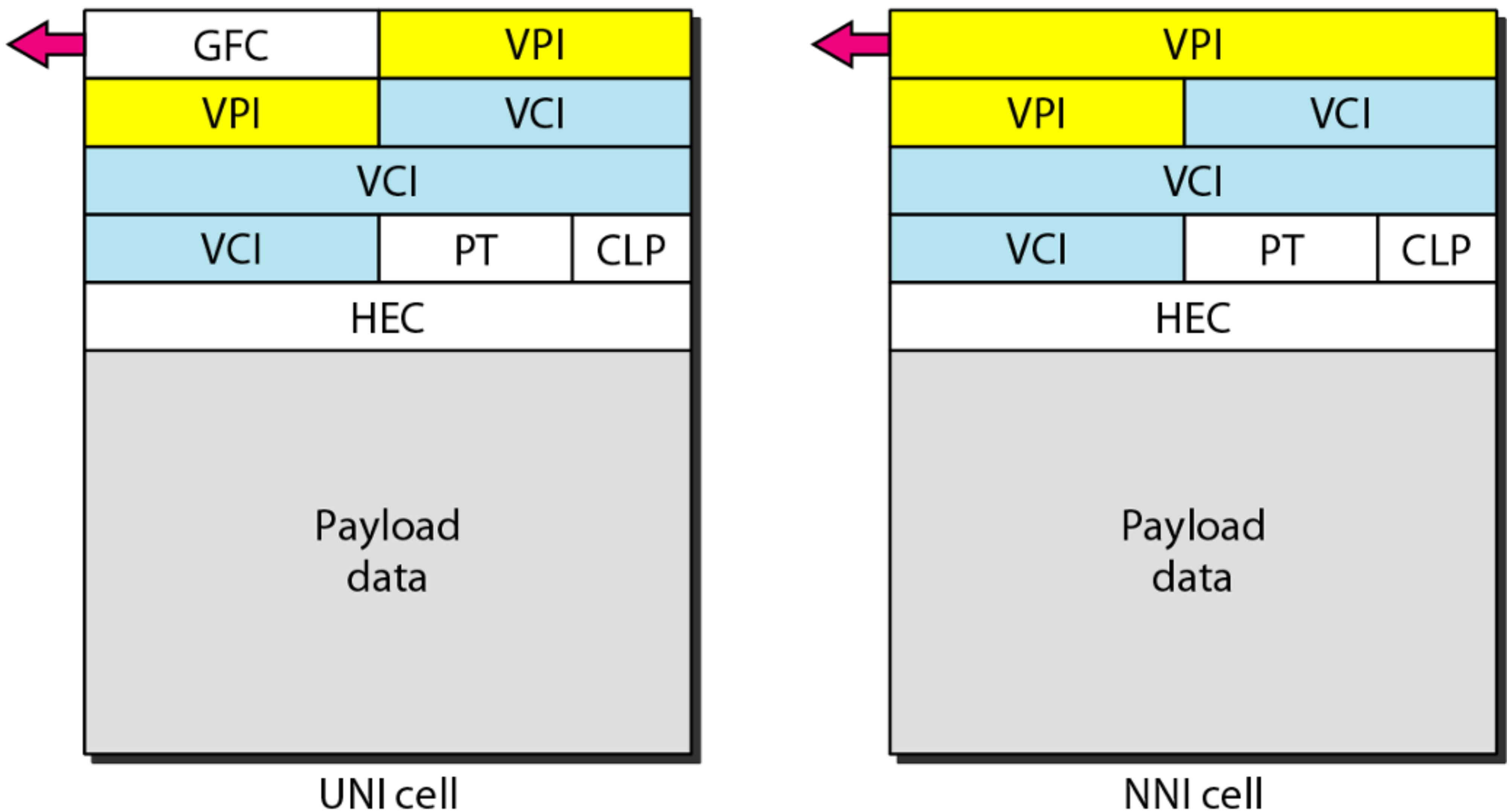
ATM Layers



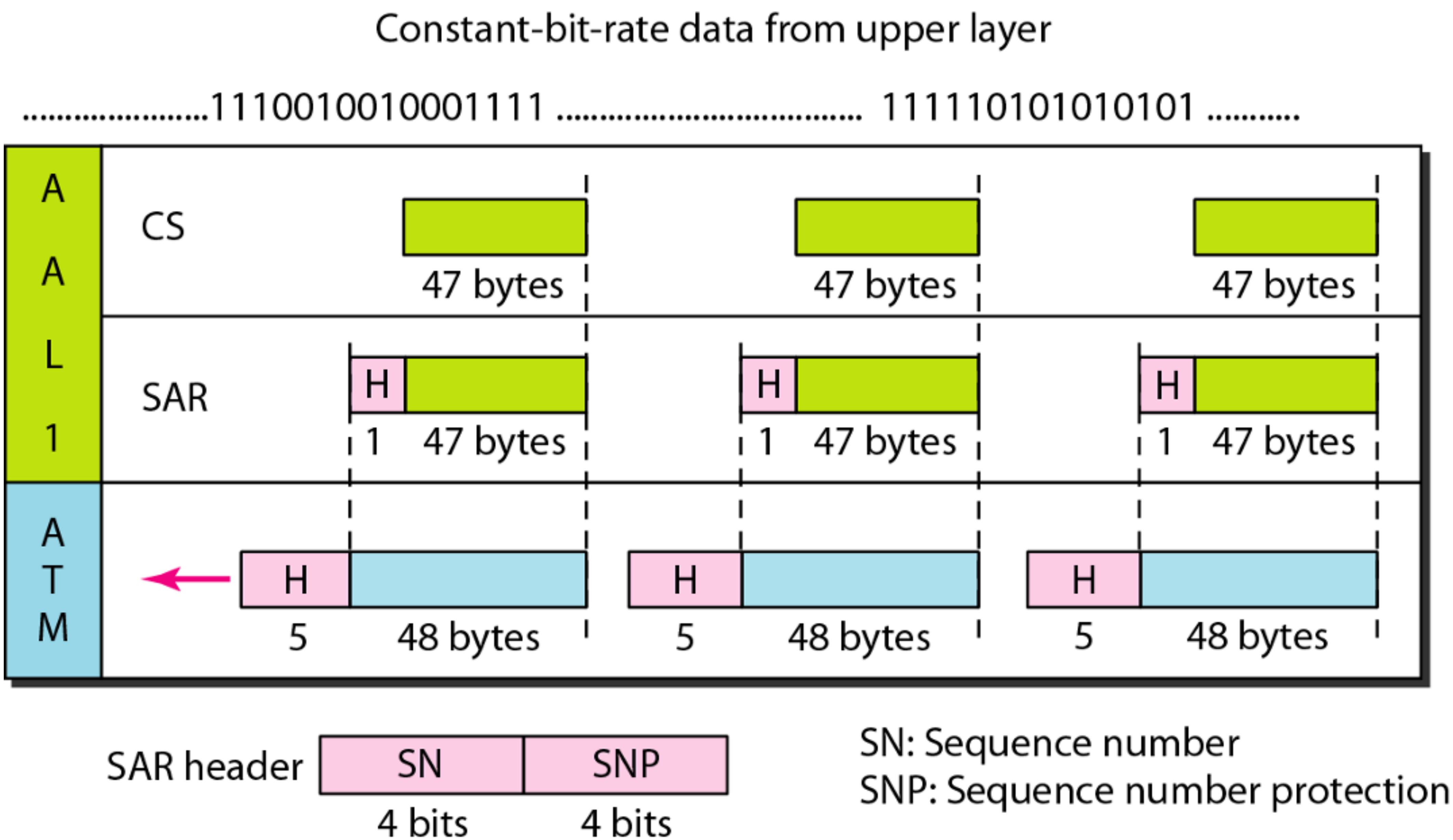
ATM Layers

GFC: Generic flow control
VPI: Virtual path identifier
VCI: Virtual circuit identifier

PT: Payload type
CLP: Cell loss priority
HEC: Header error control

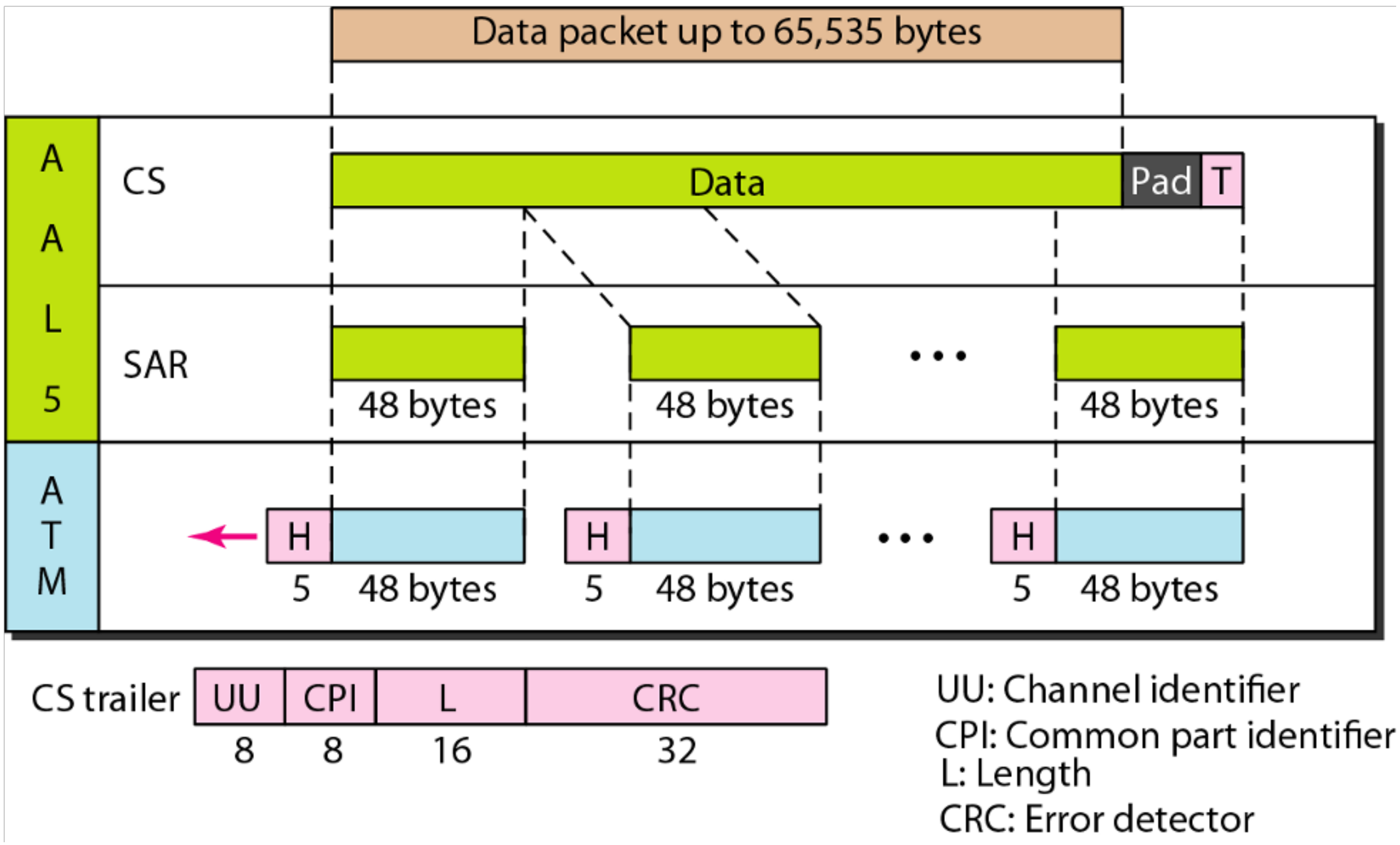


ATM Layers



Constant-bit-rate data from upper layer
......................11100100100011111 .... 111110101010101 ....
A A L 1
CS
47 bytes
47 bytes
47 bytes
SAR
H
1
47 bytes
H
1
47 bytes
H
1
47 bytes
A T M
H
5
48 bytes
H
5
48 bytes
H
5
48 bytes
SAR header
SN
SNP
4 bits
4 bits
SN: Sequence number
SNP: Sequence number protection

ATM Layers



Data packet up to 65,535 bytes
A A L 5
CS
Data
Pad
T
SAR
48 bytes
48 bytes
48 bytes
A T M
H
5
48 bytes
H
5
48 bytes
H
5
48 bytes
CS trailer
UU
CPI
L
CRC
8
8
16
32
UU: Channel identifier
CPI: Common part identifier
L: Length
CRC: Error detector

Serial Line Internet Protocol

SLIP

- Created informally in early 1980s
- Became a standard

  RFC 1055 (1988) A Non-standard for Transmission of IP Datagrams over Serial Lines : SLIP
- Just provides framing
  - SLIP *END character* of a frame is 0xC0 = b11000000
  - Minor enhancement: precede the datagram with a SLIP end character
  - Uses *SLIP escape character* 0xDB = b11011011
  - Maximum frame size is 1006B, but can change between implementations

Point-to-Point Protocol (PPP)

PPP Overview

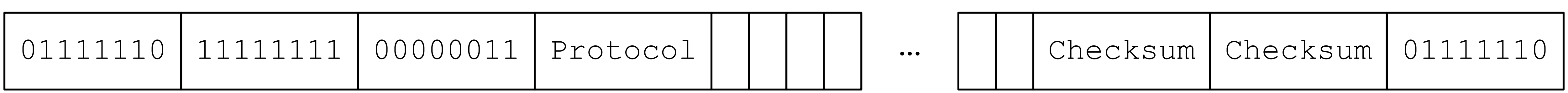
- RFC 1134 (1989) —> RFC 1171 (1990): the PPP standard
- Uses the ISO High Level Data Link Control (HLDLC) protocol by IBM
- PPP provides:
  - More comprehensive framing
  - Allows multiple layer 3 protocols to be multiplexed on a single link
  - Uses error detection via CRC
  - Negotiates link parameters, including maximum frame size
  - Testing links before and during transmission
  - Support for authentication
  - Support for compression, encryption, and link aggregation
    - Link aggregation - two physical links can be used as one

PPP Overview

- **Usually** used only for connectionless unacknowledged service
  - Called "unnumbered mode"

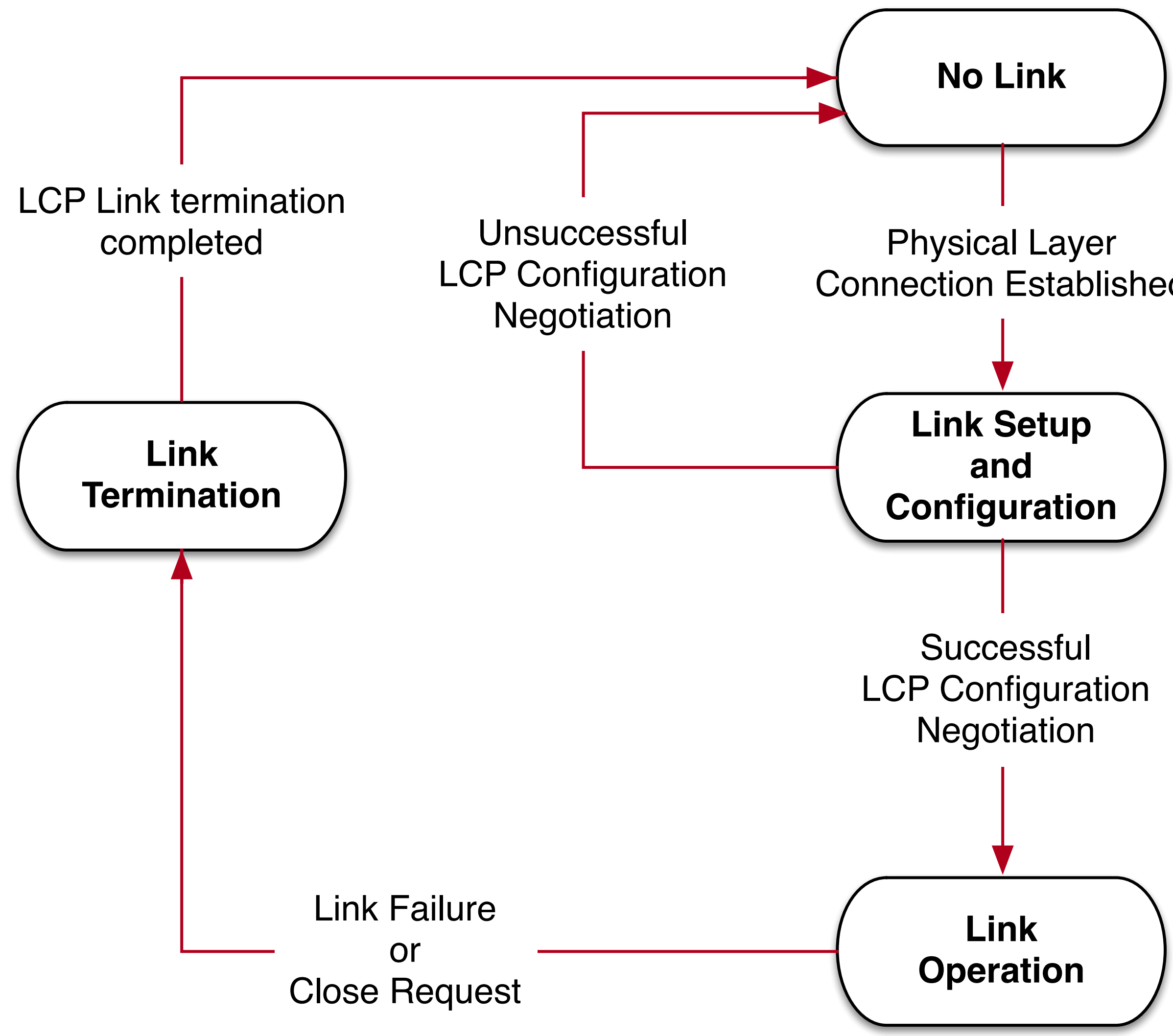
PPP Full Frame

- Flag — always 01111110
- Address — always 11111111 (for everyone)
- Control — always 00000011
- Protocol — 1 or 2 B: type of packet in the payload
- Payload — up to a maximum of typically 1500 B
- Checksum — 2 or 4 B calculated with CRC
- Flag



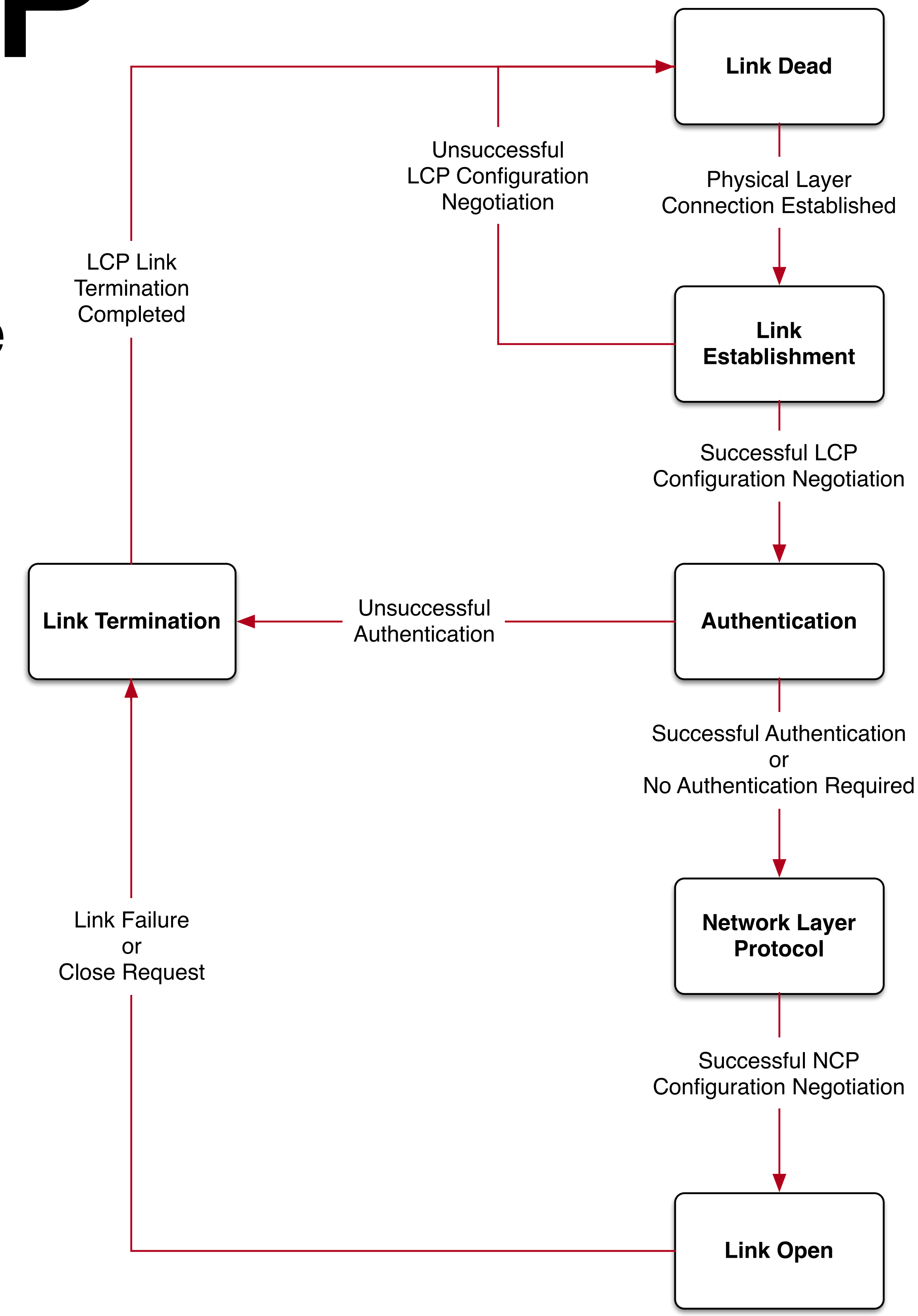
PPP

1. Devices make contact and set up a link
   - Agree on all parameters
   - Network Control Protocol (NCP) is selected according to layer 3 traffic
2. Link operation
3. Link termination
   - by either device



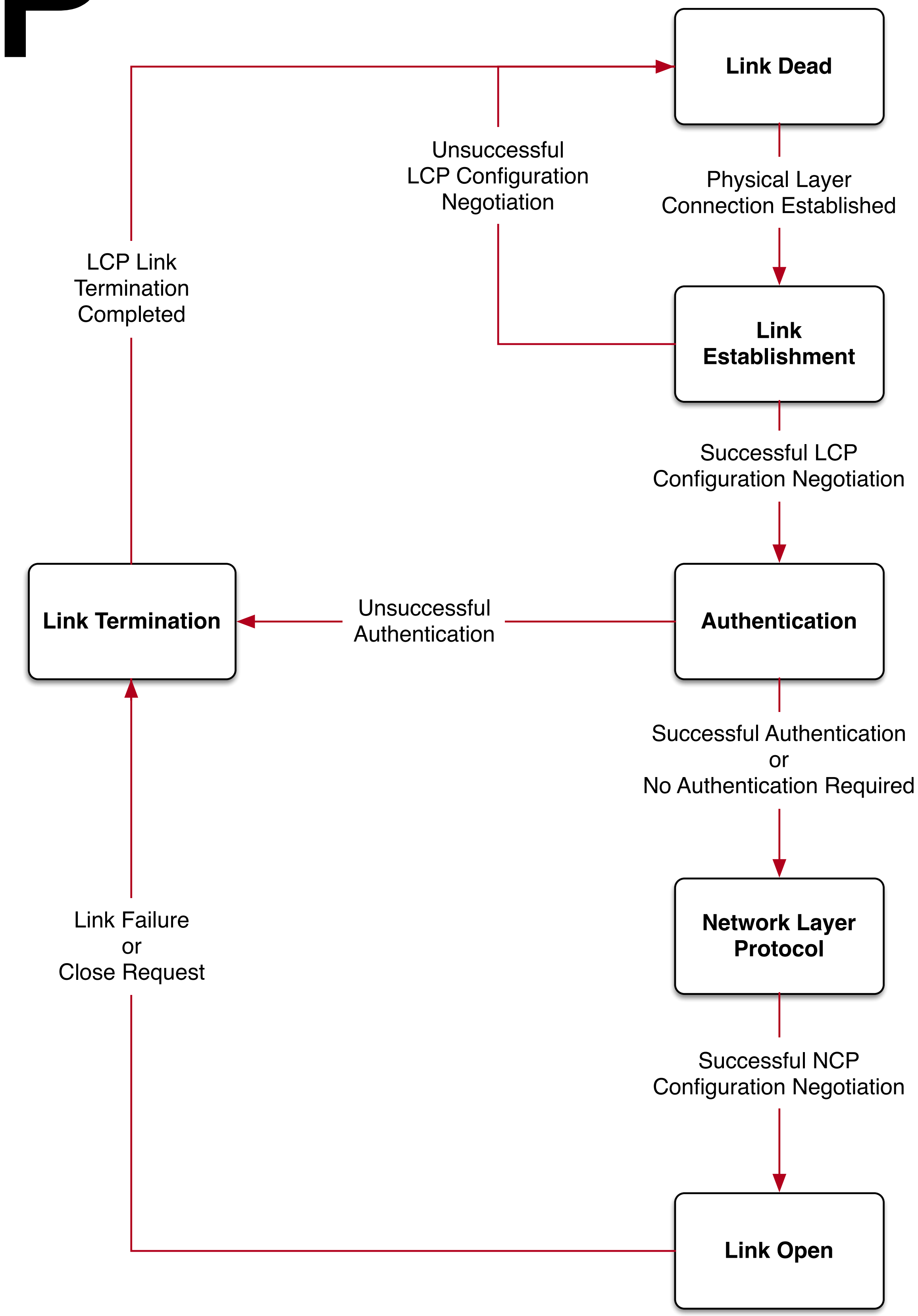
PPP

- Link Control Protocol used to set up link so that PPP can be used
- Links start out in the Link Dead phase
- When devices detect connection, they start establishment



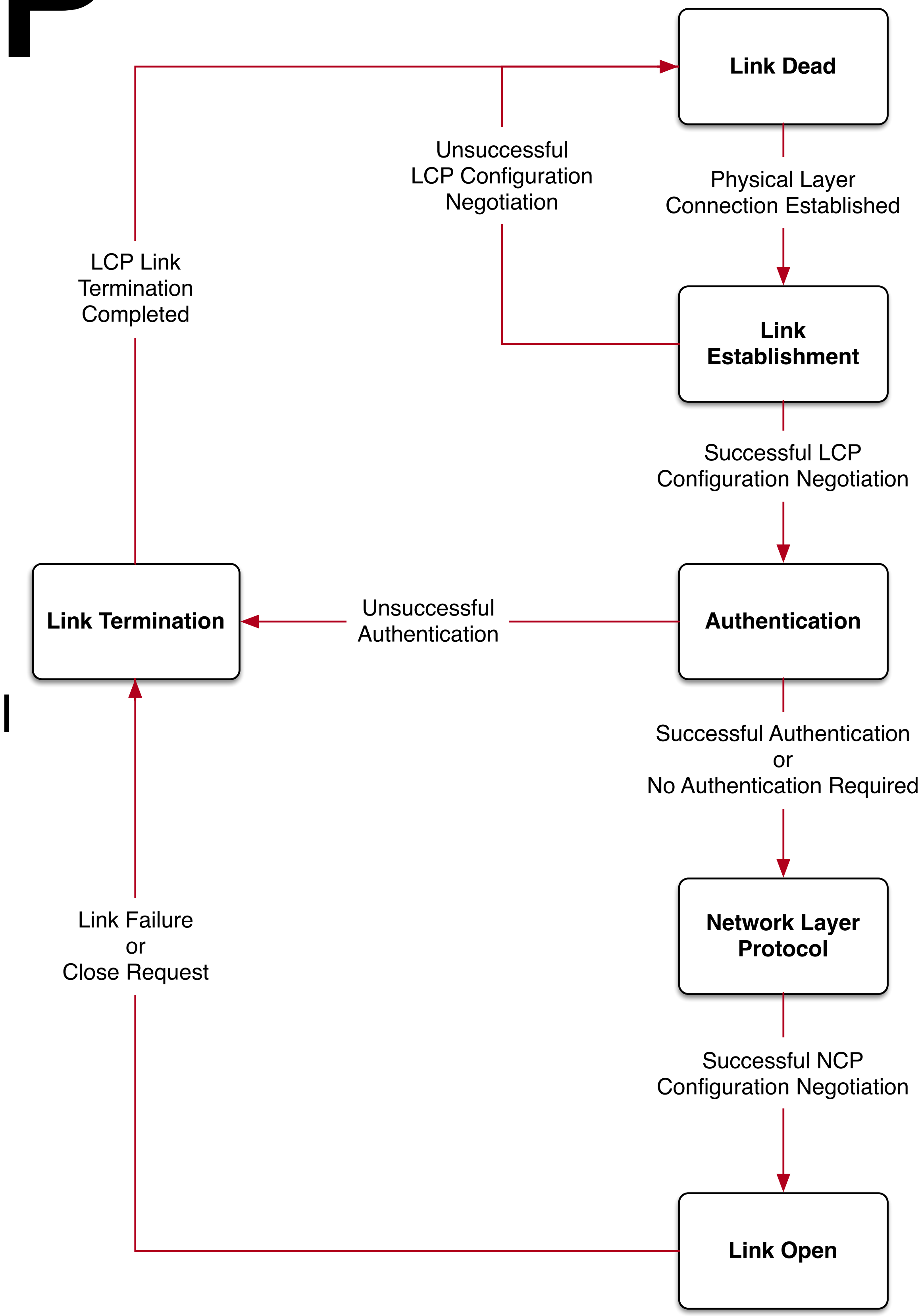
PPP

- Device A sends LCP configuration request to Device B
- Device B checks parameters
- If they work, send Ack
  - Successful negotiation
- If they do not work, send Nack
  - Unsuccessful negotiation



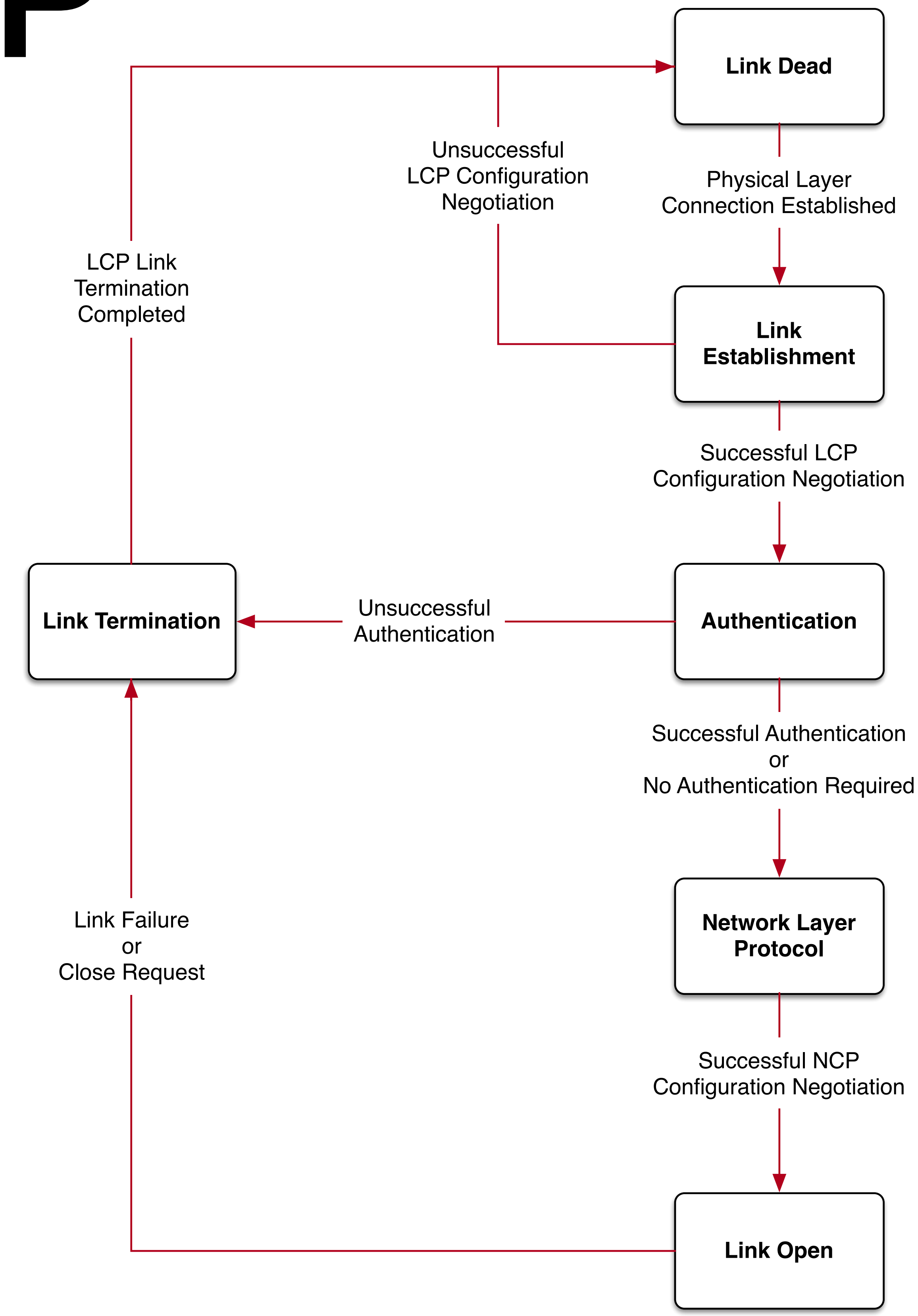
PPP

- LCP link configuration
  - Initiator sends a configure-request frame
    - Options for MRU, and Authentication & Quality protocols, Magic Number (in order to detect loopbacks), Protocol field compression in PPP frames, Address and Control field compression in PPP frames
  - Responder either agrees or disagrees with the proposal
    - Configure-Nack makes counter-proposals
    - Configure-Reject just rejects



PPP

- After link establishment, proceed to authentication phase
  - Needed for example for dial-up connections
  - Uses CHAP or PAP

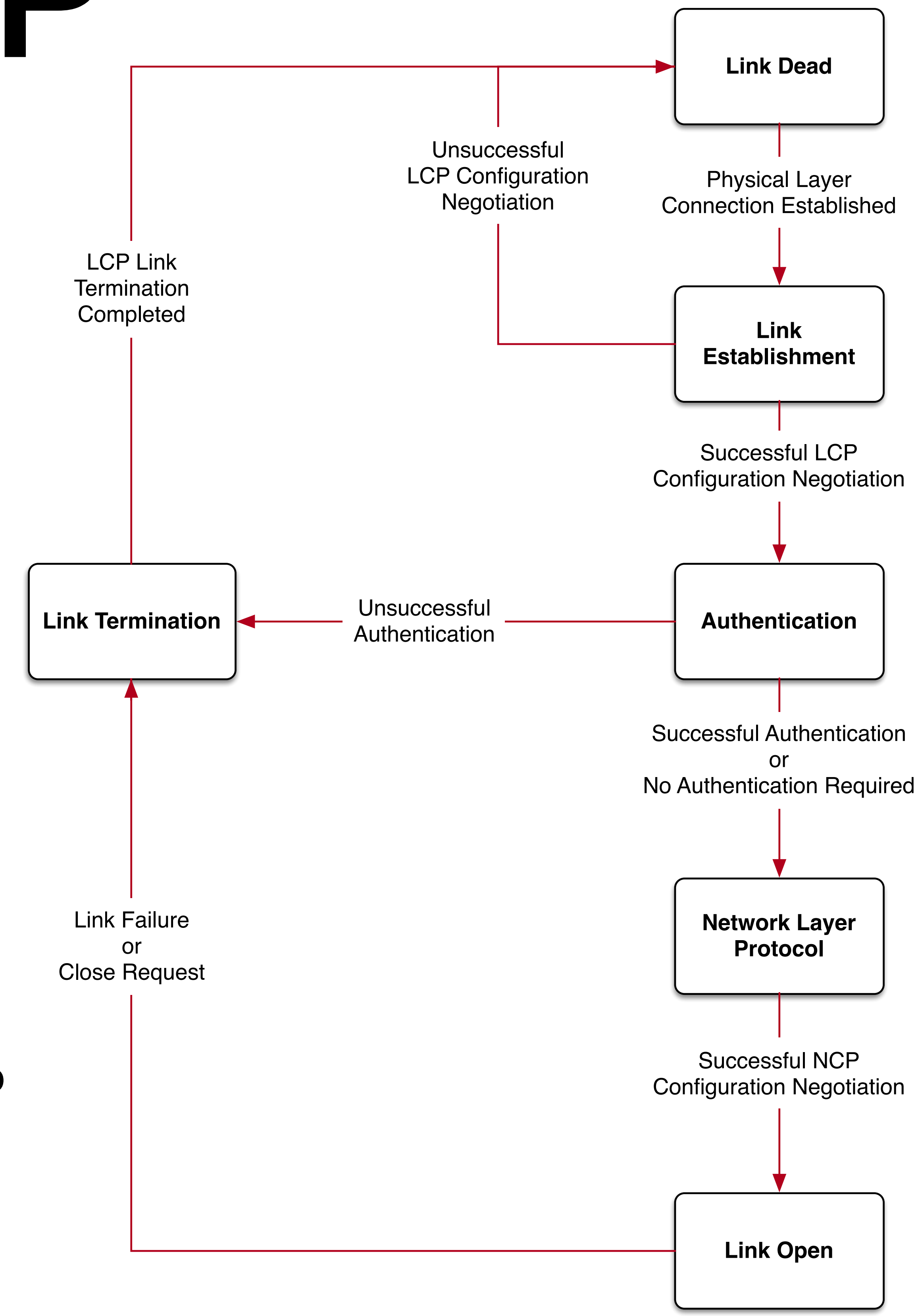


PAP & CHAP

- PAP
  - Initiator sends a password and name in an Authentication Request
  - Responder decides whether to accept
- PAP is insecure
- CHAP
  - Uses three-way hand-shake:
    - Responder sends a challenge
    - Initiator encrypts challenge with shared key
    - Responder checks and indicates success or failure to initiator

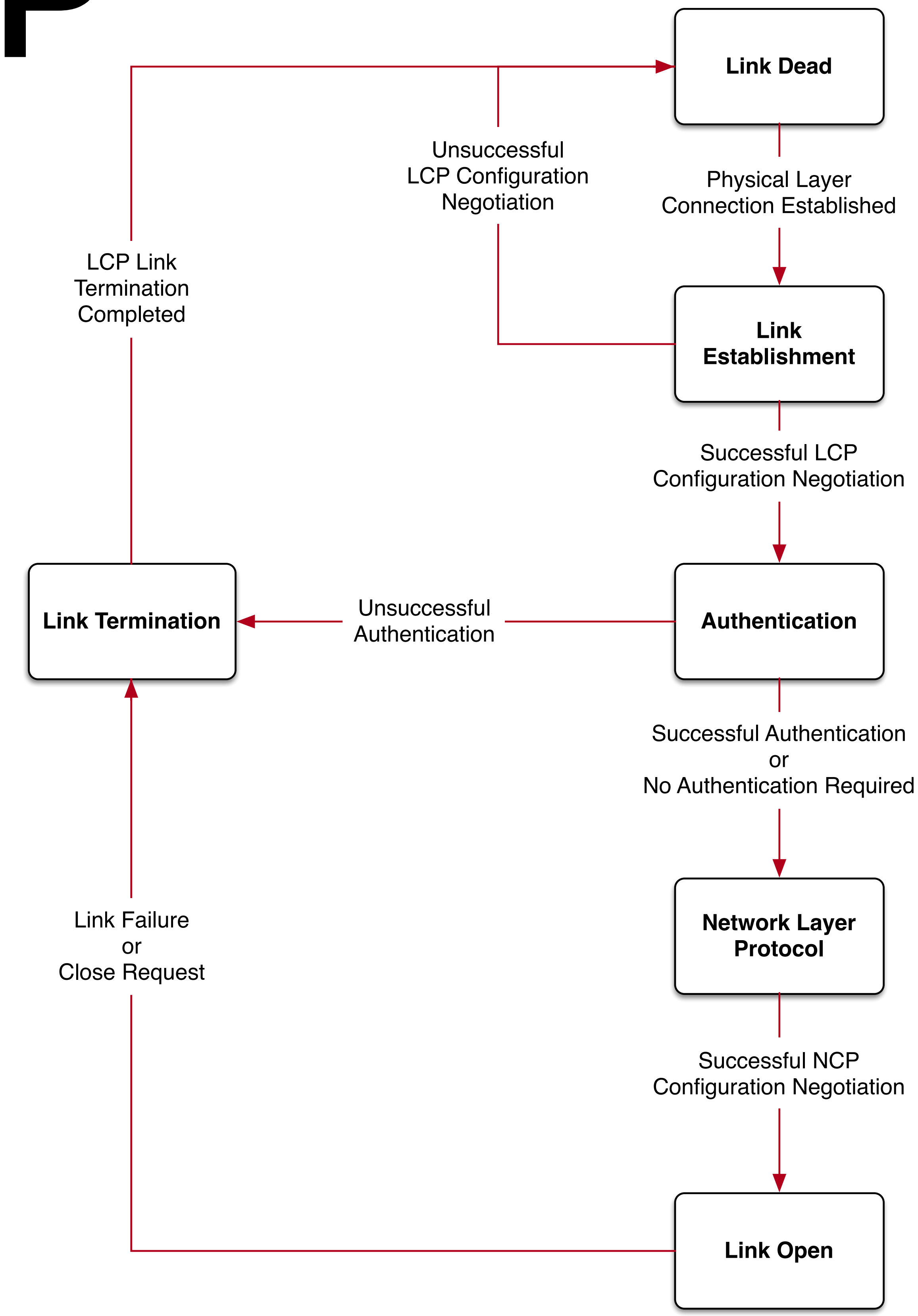
PPP

- Network Control Protocol
  - Lightweight version of LCP
  - Optimizes according to Layer 3 traffic
    - Originally, PPP was for IP only
    - Special protocol versions for:
      - IPv4, IPv6, IPX (Novell NetWare suite), NetBios, AppleTalk
  - There can be more than one NCP connection over the same link



PPP

- NCP uses Configure-Request, Configure-Ack, Configure-Nack, ConfigureReject to establish parameters
- Example IPv4:
    - Van Jacobson TCP/IP header compression
    - Specify IP address
    - Request other device supplies IP address (for dial up)
- NCP connection can be closed without closing the LCP connection



PPP

- PPP Link Quality Monitoring and Reporting (LQM / LQR)
- Can periodically create statistics
  - Number of frames
  - Number of bytes
  - Number of errors
  - Number of discarded frames
- Devices can use LQR to react to changes in the quality of the link

PPP

- PPP Compression Control Protocol (PPP CCP)
  - Sets up one of several compression algorithms for data
- PPP Encryption Control Protocol (PPP ECP)
  - Sets up one of several encryption protocols
- PPP Multilink Protocol
  - Optional feature of PPP implementations
  - Example: Used to combine several physical channels defined on the same physical medium
  - Each frame is divided into fragments that are sent over the different channels

PPP

- Link maintenance
  - Any device can use echo-requests to test the link
- Link termination
  - Any device can send a terminate-request message
  - Other device sends terminate-ack message