Carrier Networking Technologies

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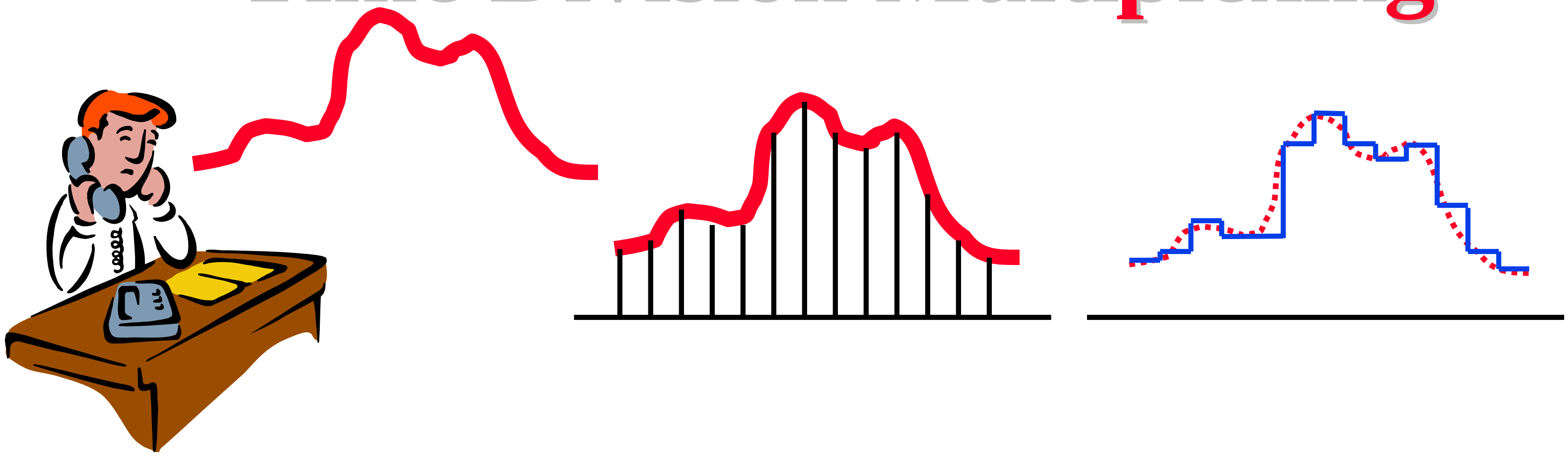
- T1/T3, E1/E3
- SONET: Components, Frame Format
- Multiplexing Hierarchy
- Timing
- Scrambling
- Protection: Rings
- SDH, OTN

Time Division Multiplexing



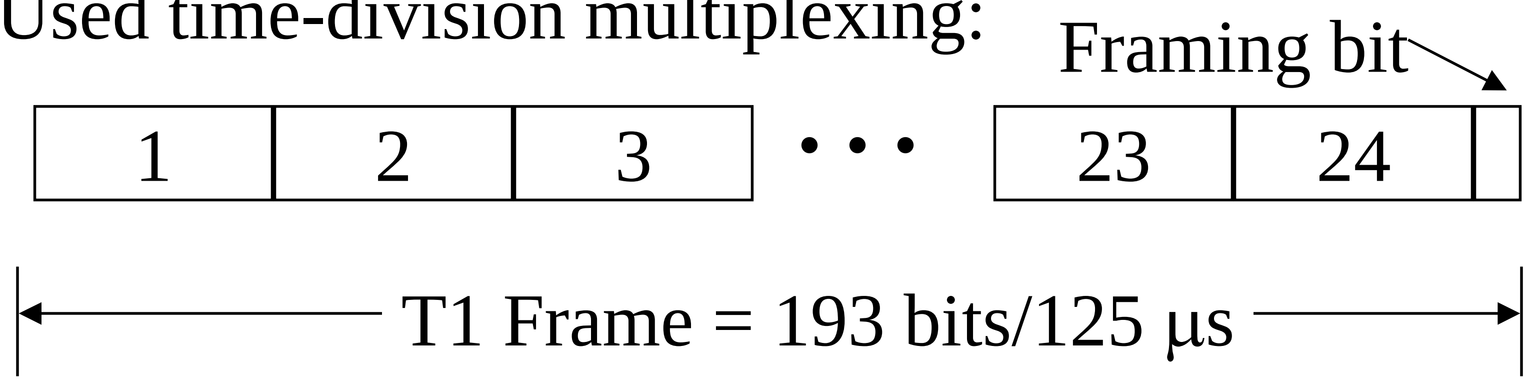
- Acceptable quality voice has a bandwidth of 4 kHz (300 Hz to 3300 Hz is transmitted on phone systems)
- Nyquist sampling theorem:
  Sample at twice the highest signal frequency
  $\Rightarrow$ Sample at 8 kHz $\Rightarrow$ Sample every 125 μsec
- 256 levels $\Rightarrow$ 8 bits per sample $\times$ 8000 samples/sec = 64 kbps

Multiplexing

- Multiple conversations $\Rightarrow$ Multiple frequency bands
  Frequency division multiplexing (FDM)
  Useful for analog signals.
- In 1962, telephone carrier cable between Bell System offices could carry approx 1.5 Mbps over a mile
  = Distance between manholes in large cities
  = Distance between amplifiers
- $1500/64 \approx 24 \Rightarrow$ Can multiplex approx.
  24 voice channels on that carrier
  $\Rightarrow$ Telecommunication-1 carrier or T1 carrier.
  Named after the ANSI committee.

T1 Frame

- T1= 24 voice channels = Digital Service 1 = DS1
- Used time-division multiplexing:



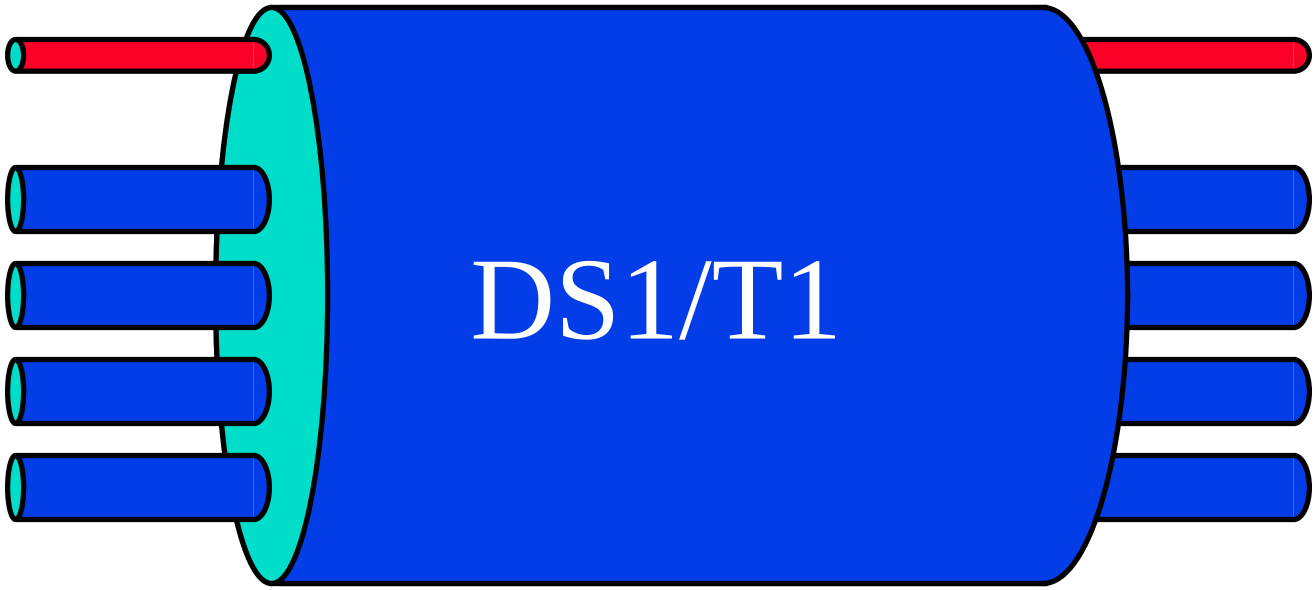
- Simple Framing: Add 101010 (1 bit per frame)

- Any other sequence ⇒ Resynchronize
  Later formats use 193rd bit for framing, CRC and Statistics

T1

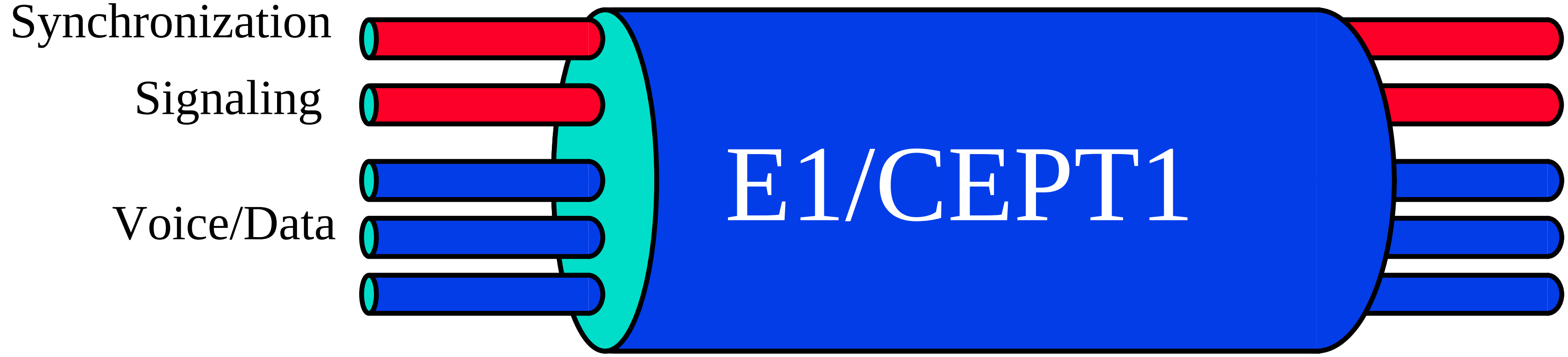
8 kbps for Carrier use

24 64 kbps DS0 Channels



- T1 Rate = 24x64 + 8 = 1536 + 8 = 1544 kbps

European System: E1



- European counter part of American T1
- Designed by Conference of Post and Telecommunications (CEPT)
- 32 bytes per 125 μs frame = 2.048 Mb/s
  30 channels are used for data
  One channel for synchronization
  One channel for signaling

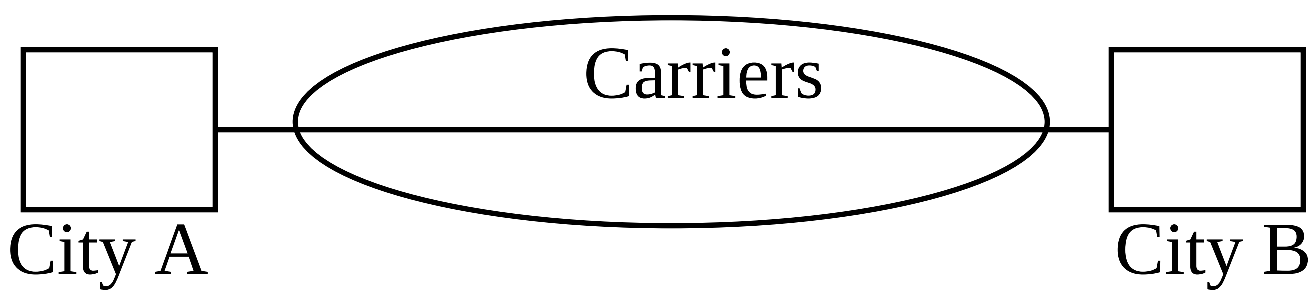
Digital TDM Hierarchy

North America		Europe		Japan	
DS0	64 kbps		64 kbps		64 kbps
DS1	1.544 Mbps	E1	2.048 Mbps	J1	1.544 Mbps
DS2	6.313 Mbps	E2	8.448 Mbps	J2	6.312 Mbps
DS3	44.736 Mbps	E3	34.368 Mbps	J3	32.064 Mbps
DS4	274.176 Mbps	E4	139.264 Mbps	J4	97.728 Mbps
DS1C	3.152 Mbps	E5	565.148 Mbps	J5	397.200 Mbps

SONET

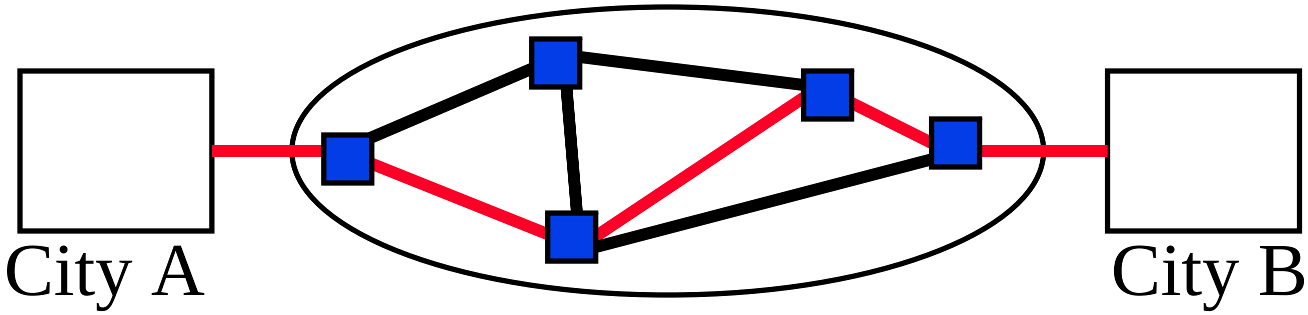
- Synchronous optical network
- Standard for digital optical transmission (bit pipe)
- Developed originally by Bellcore to allow mid-span meet between carriers: MCI and AT&T. Standardized by ANSI and then by ITU

  $\Rightarrow$ Synchronous Digital Hierarchy (SDH)
- You can lease a SONET connection from carriers



SONET Protocols

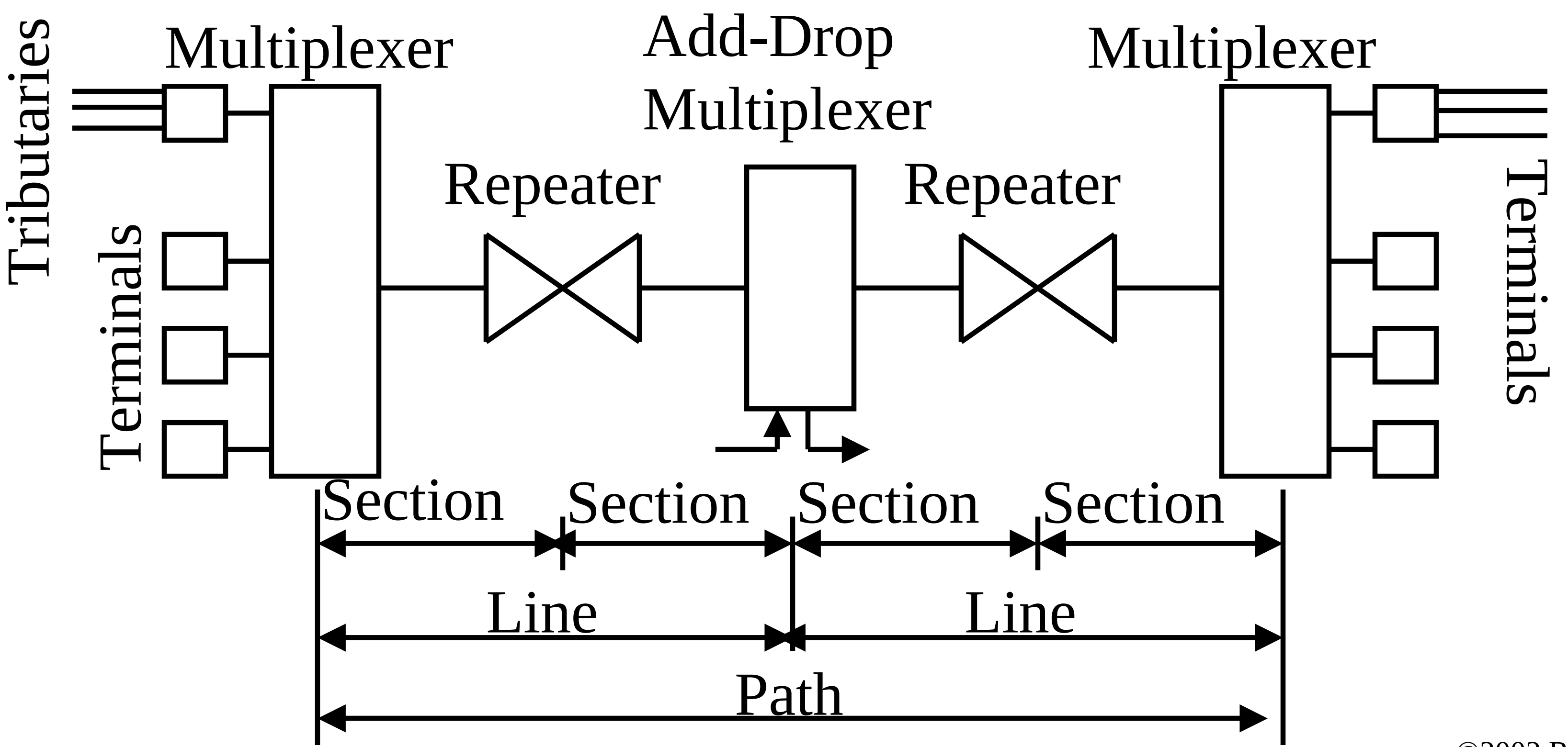
- Synchronous Optical **Network**



Transport	Path
Network	Line
Datalink	Section
Physical	Photonic

Physical Components

- Section = Single run of fiber
- Line = Between multiplexers
- Path = End-to-end



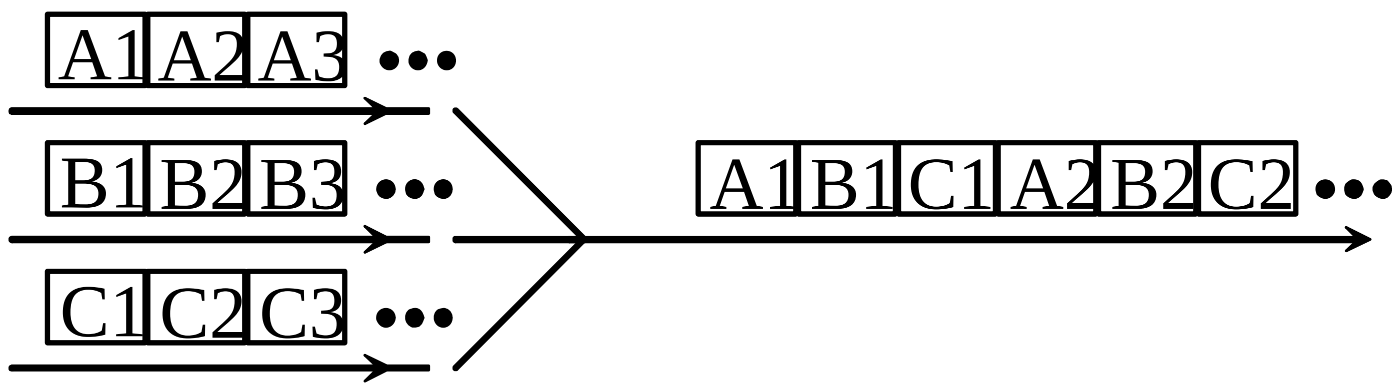
Signal Hierarchy

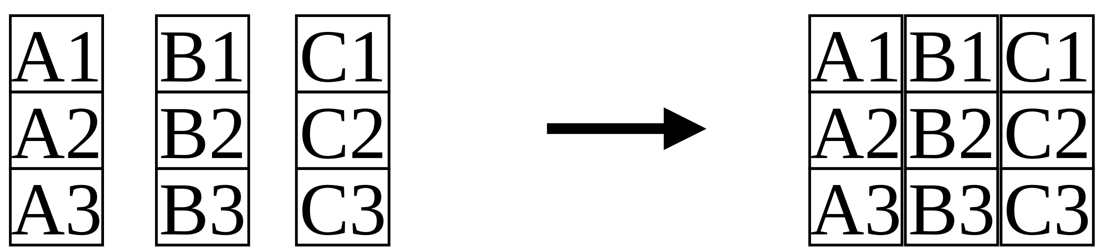
Synchronous Transport Signal Level n = STS-n = $n \times 51.84$ Mbps
STM=Synchronous Transport Module, OC=Optical Carrier level

ANSI Designation	Optical Signal	CCITT Designation	Data Rate (Mbps)	Payload Rate (Mbps)
STS-1	OC-1		51.84	50.112
STS-3	OC-3	STM-1	155.52	150.336
STS-9	OC-9	STM-3	466.56	451.008
STS-12	OC-12	STM-4	622.08	601.344
STS-18	OC-18	STM-6	933.12	902.016
STS-24	OC-24	STM-8	1244.16	1202.688
STS-36	OC-36	STM-12	1866.24	1804.032
STS-48	OC-48	STM-16	2488.32	2405.376
STS-96	OC-96	STM-32	4976.64	4810.176
STS-192	OC-192	STM-64	9953.28	9620.928

Byte Multiplexing

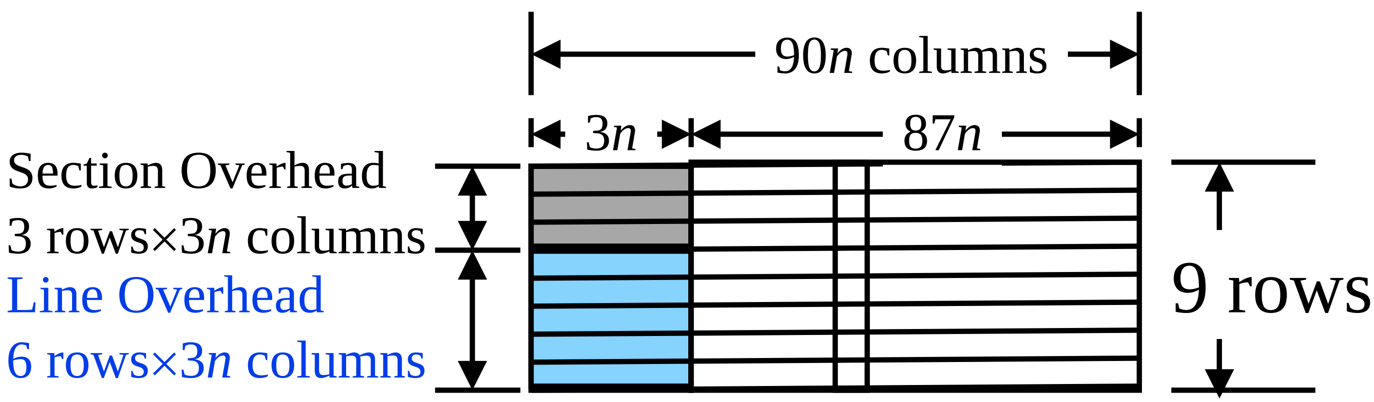
- Also known as byte interleaving
- Easier to view in two dimension. Transmitted row first.





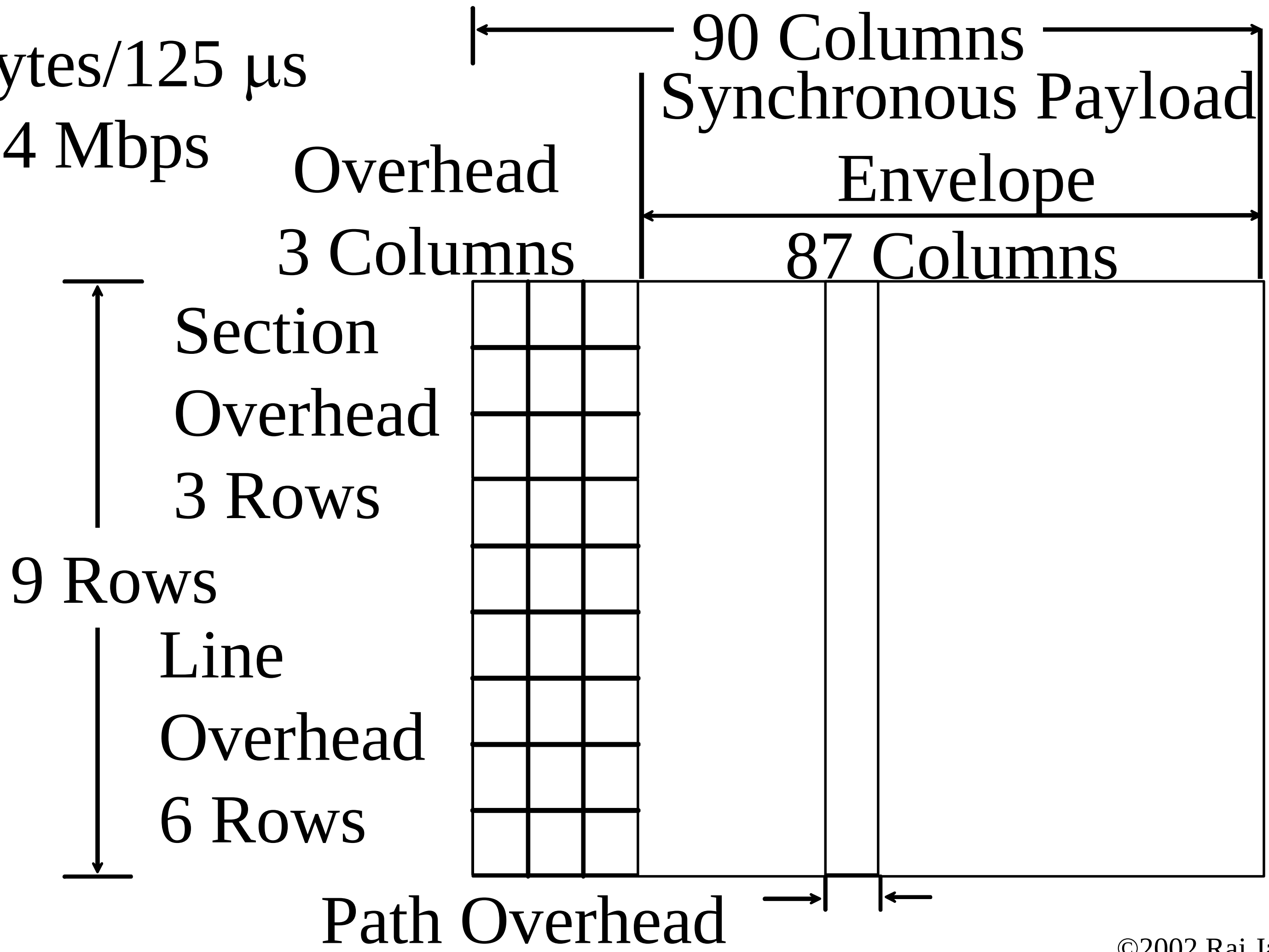
SONET Frame Format

- OC-1 = 51.84 Mbps (payload and overhead)
- OC-n = $n \times 51.84$ Mbps
  e.g., OC-3 = $3 \times 51.84 = 155.54$ Mbps
- All SONET frames are 125 μs long.
  E.g., OC-3 frames are 2430 (125×155.54) bytes
- Represented as 2D arrays of bytes.
  9 rows × 90n columns. Transmitted row-wise



STS-1 Frame Format

- Overhead = Header.
- 810 Bytes/125 μs = 51.84 Mbps



STS-1 Overhead Bytes

Section Overhead	Framing A1	Framing A2	STS-1 ID C1
	BIP-8 B1	Order wire E1	User F1
	Data Com D1	Data Com D2	Data Com D3
Line Overhead	Pointer H1	Pointer H2	Pointer Action H3
	BIP-8 B2	APS K1	APS K2
	Data Com D4	Data Com D5	Data Com D6
	Data Com D7	Data Com D8	Data Com D9
	Data Com D10	Data Com D11	Data Com D12
	Growth Z1	Growth Z2	Order wire E2

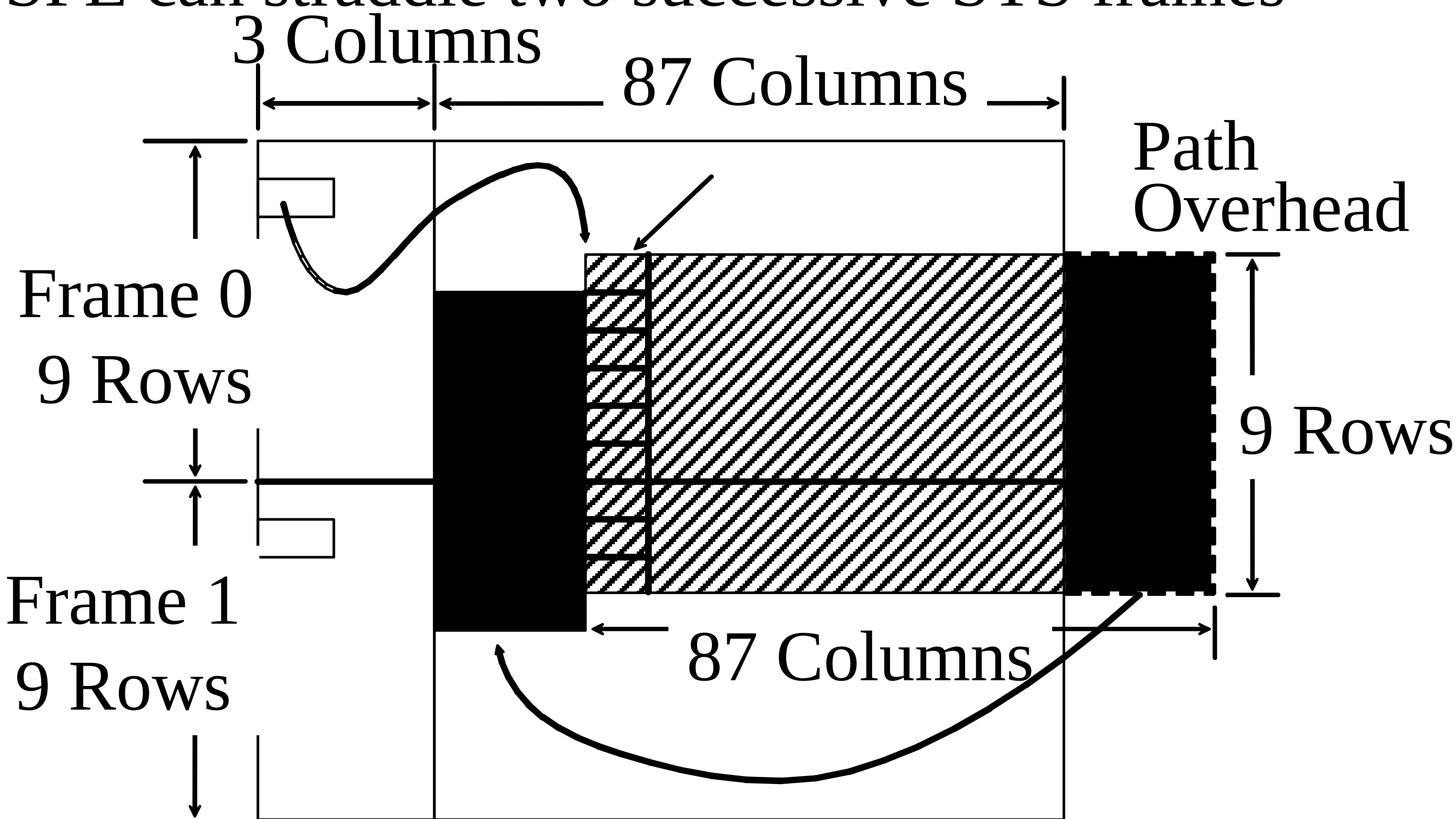
Path Layer Overhead
Trace J1
BIP-8 B3
Signal Label C2
Path Status G1
User Channel F2
Multi-frame H4
Growth Z3
Growth Z4
Growth Z5

SONET Overhead Bytes

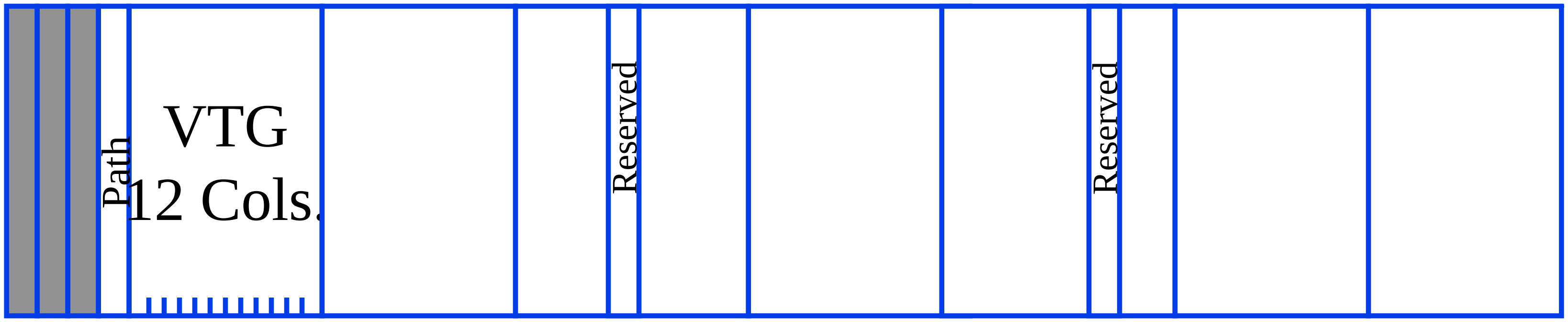
Section Overhead:	
A1, A2:	Framing bytes = F6-28$_{16}$ (11110110-00101000$_2$)
C1:	STS-1 ID identifies the STS-1 number (1 to N) for each STS-1 within an STS-N multiplex
B1:	Bit-interleaved parity byte 8 (BIP81) providing even parity over previous STS-N frame after scrambling
E1:	Section-level 64-kbps PCM voice channel for section maintenance
F1:	64-kbps channel set aside for user purposes
D1-D3:	192-kbps data communications channel for alarms, maintenance, control, and administration between sections
Line Overhead:	
H1-H3:	Pointer bytes used in frame alignment and frequency adjustment of payload data
B2:	Bit-interleaved parity for line-level error monitoring
K1, K2:	Two bytes allocated for signaling between line-level automatic protection switching equipment
D4-D12:	576-kbps data communications channel for alarms, maintenance, control, monitoring, and administration at the line level
Z1:	Reserved for future use
Z2:	Count of blocks received in error
E2:	64-kbps PCM voice channel for line maintenance
Path Overhead:	
J1:	64-kbps channel used to send a 64-byte fixed-length string repetitively so a receiving terminal can continuously verify the integrity of a path; the contents of the message are user-programmable
B3:	Bit-interleaved parity at the path level
C2:	STS path signal label to designate equipped versus unequipped STS signals and, for equipped signals, the specific STS payload mapping that might be needed in receiving terminals to interpret the payloads
G1:	Status byte sent from path-terminating equipment back to path-originating equipment to convey status of terminating equipment and path error performance
F2:	64-kbps channel for path user
H4:	Multiframe indicator for payloads needing frames that are longer than a single STS frame; multiframe indicators are used when packing lower rate channels into the SPE
Z3-Z5:	Reserved for future use

Floating Payload

- Synchronous Payload Envelope (SPE) from the user can arrive at any time
  $\Rightarrow$ SPE can straddle two successive STS frames



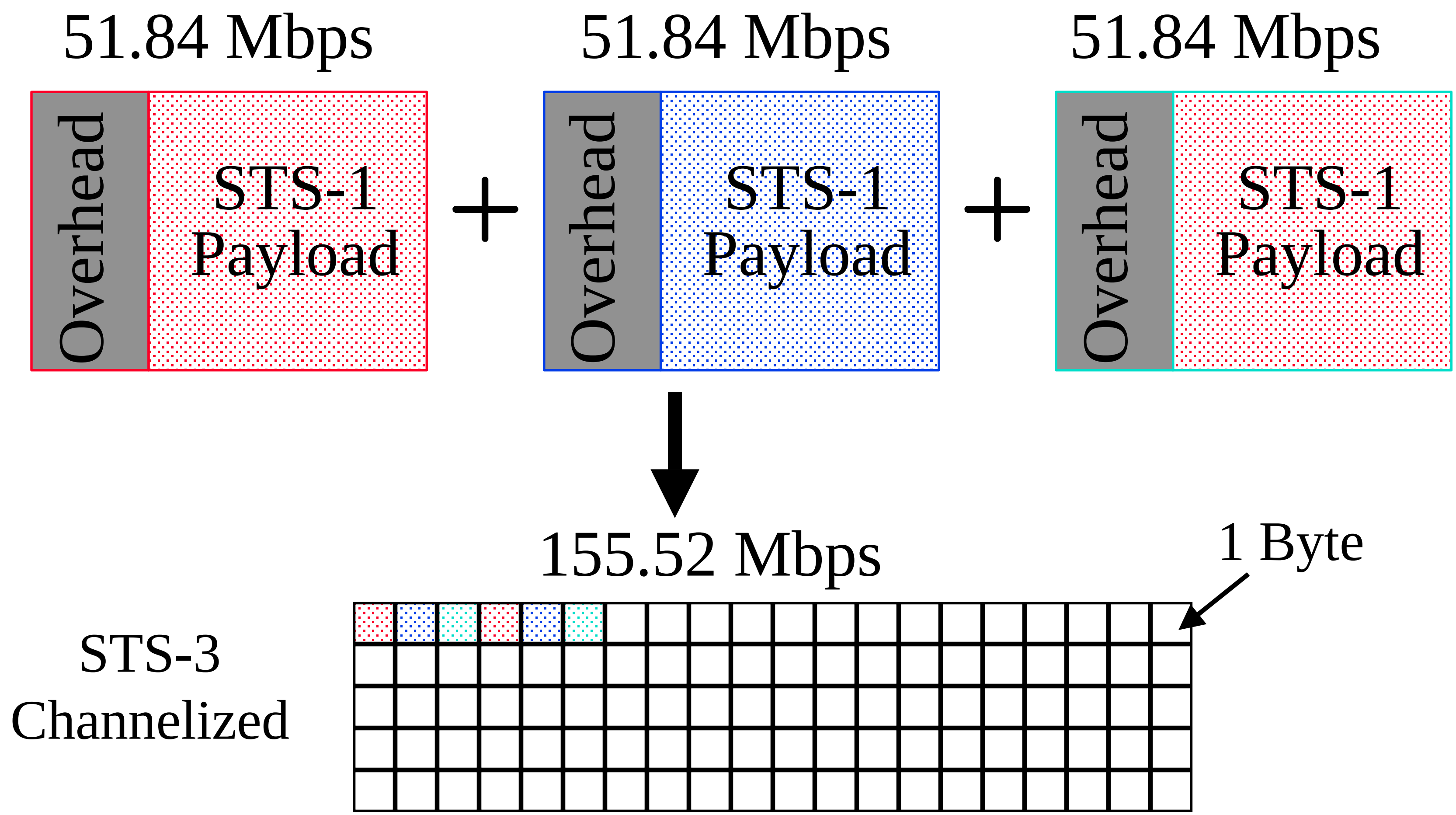
Virtual Tributaries



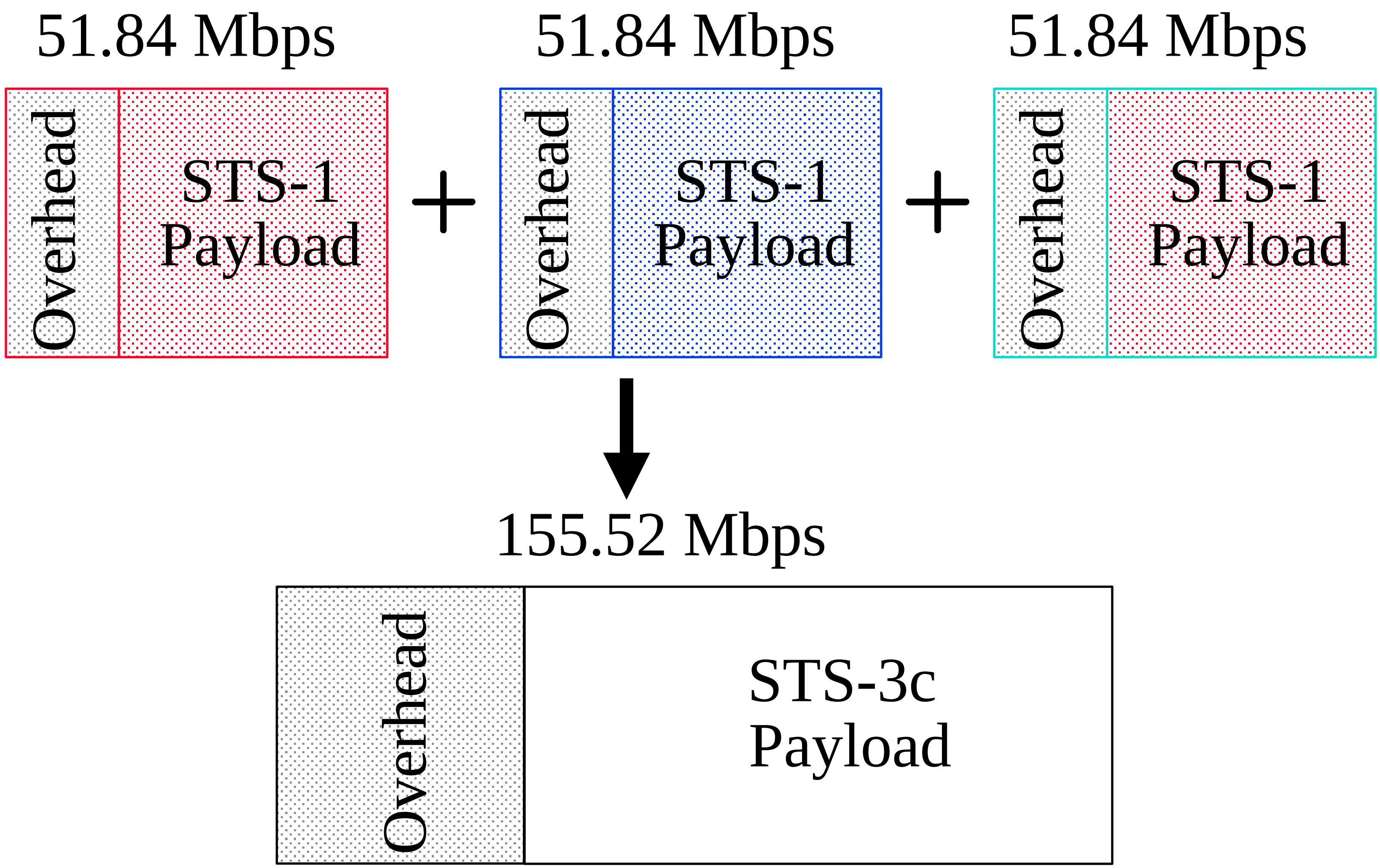
- STS-1 payload is 87 columns
  One column is used for path overhead
  Two columns (30th and 59th) are reserved for future
  84 columns = 7 VT groups of 12 columns each

VT Type	VT/Group	Payload	Mbps	Columns
VT1.5	4	T1	1.544	3
VT2	3	E1	2.048	4
VT3	2	DS-1c	3.152	6
VT6	1	DS-2	6.312	12

Multiplexing

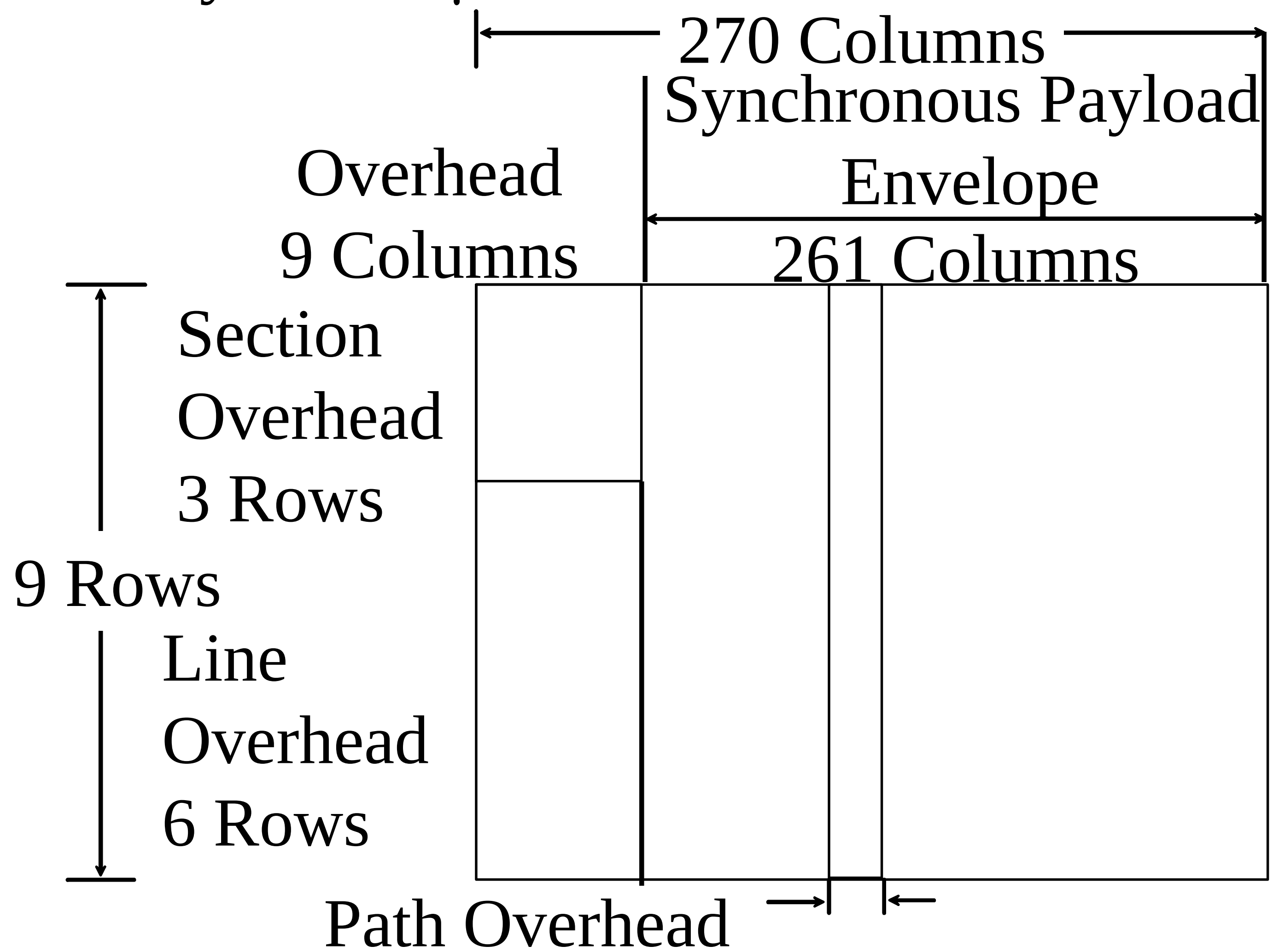


Concatenation



STS-3c Frame Format

- 2430 Bytes/125 μs = 155.54 Mbps



STS-3c Overhead bytes

- Only one of the 3 bytes in the overhead is used.

A1	A1	A1	A2	A2	A2	C1	C1	C1
B1			E1			F1		
D1			D2			D3		
H1	H1	H1	H2	H2	H2	H3	H3	H3
B2	B2	B2	K1			K2		
D4			D5			D6		
D7			D8			D9		
D10			D11			D12		
Z1	Z1	Z1	Z2	Z2	Z2	E2		

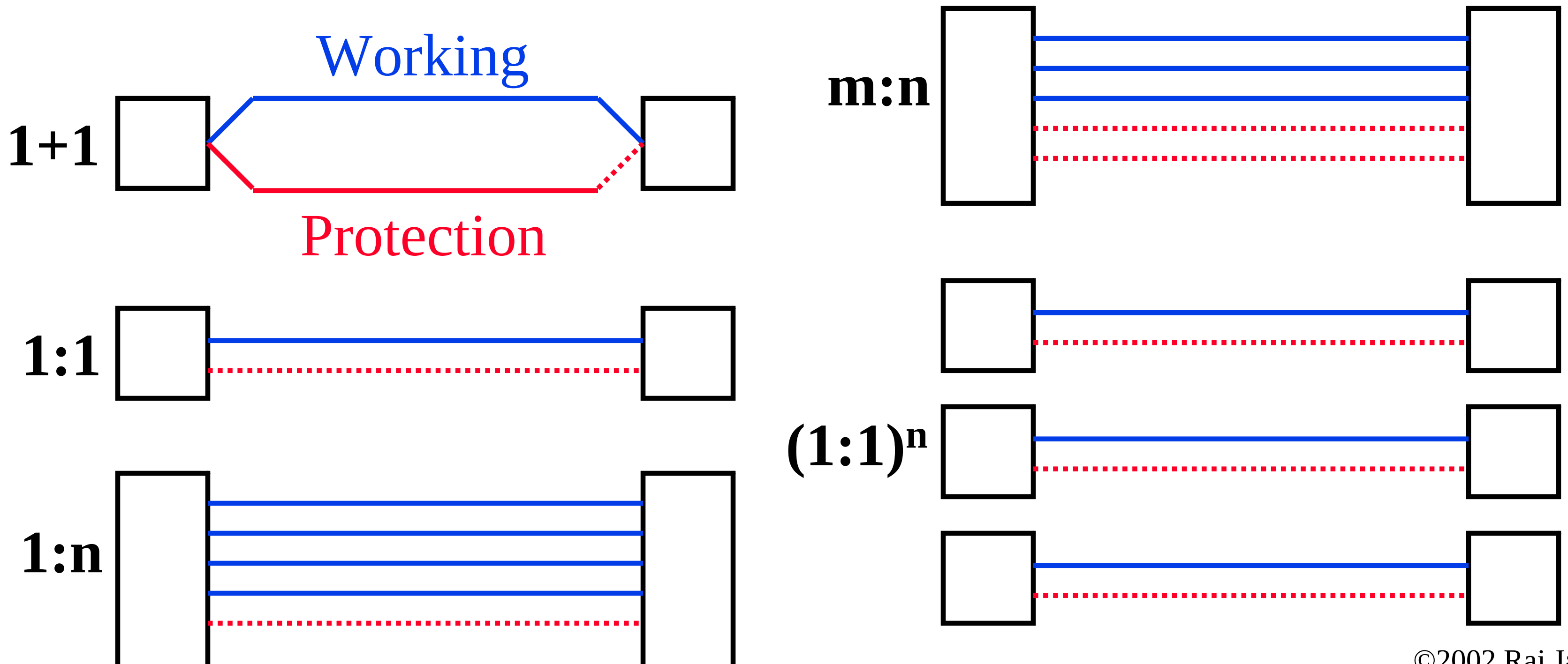
(a) Section and line overhead

J1
B3
C2
G1
F2
H4
Z3
Z4
Z5

(b) Path overhead

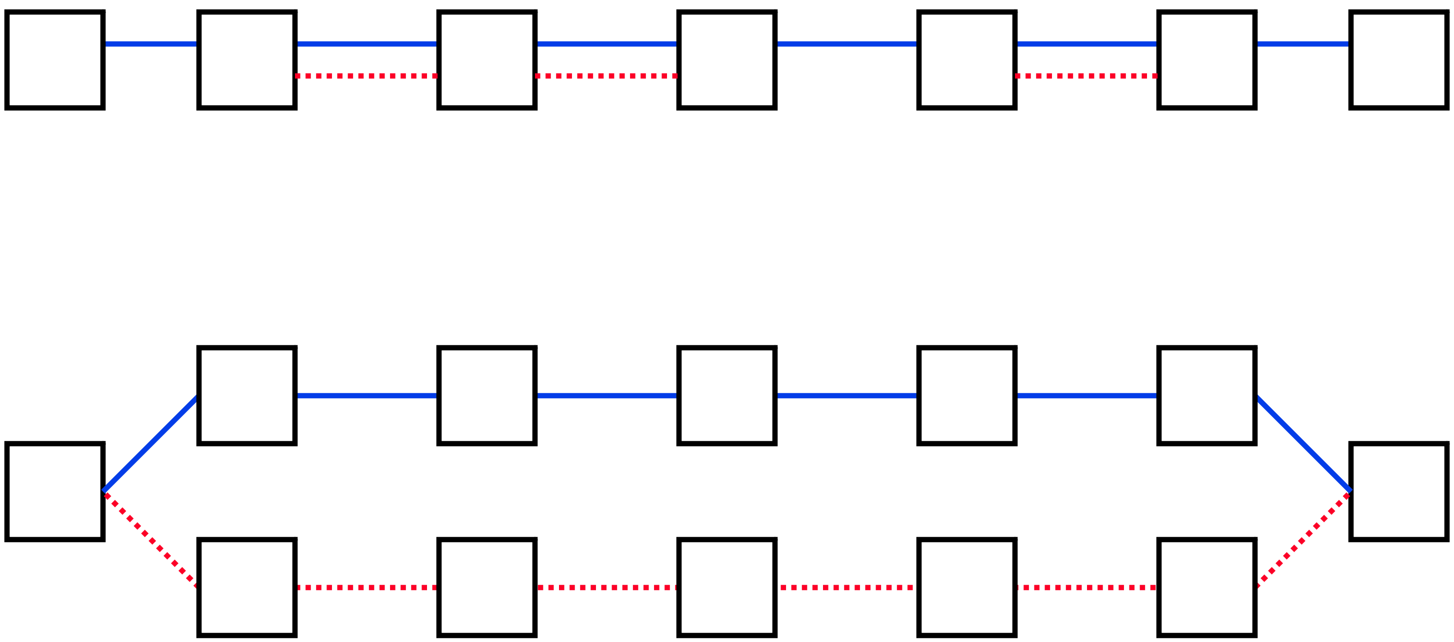
Protection

- Protection: Reserving resources for quick recovery from failures



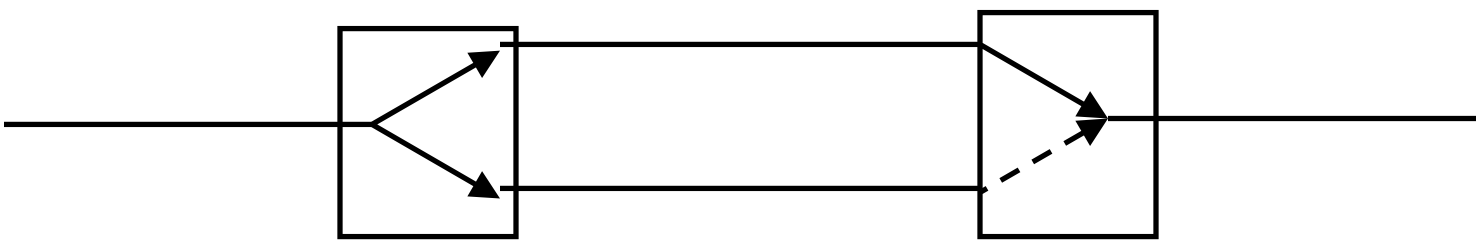
Line vs. Path

- Redundant links or paths



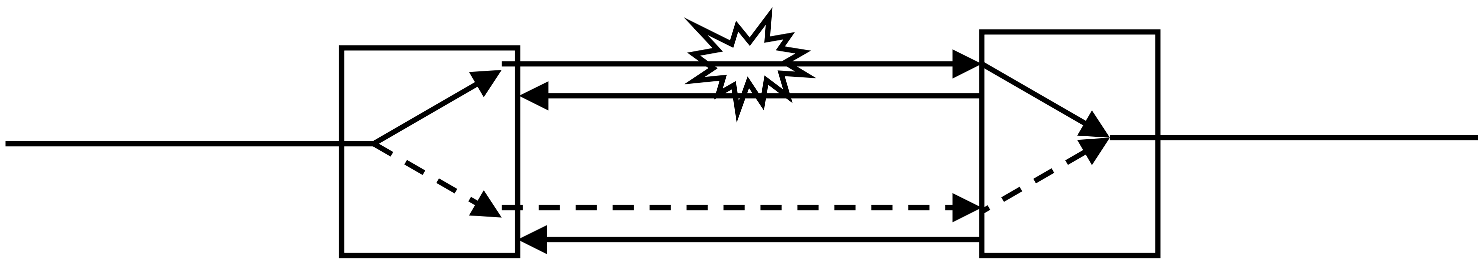
1+1 Protection

- Signal is sent on both routes
- Receiver chooses the stronger signal
- No need for signaling ⇒ Fast
- Can be revertive or non-revertive
  Revertive = Return to original path after repair



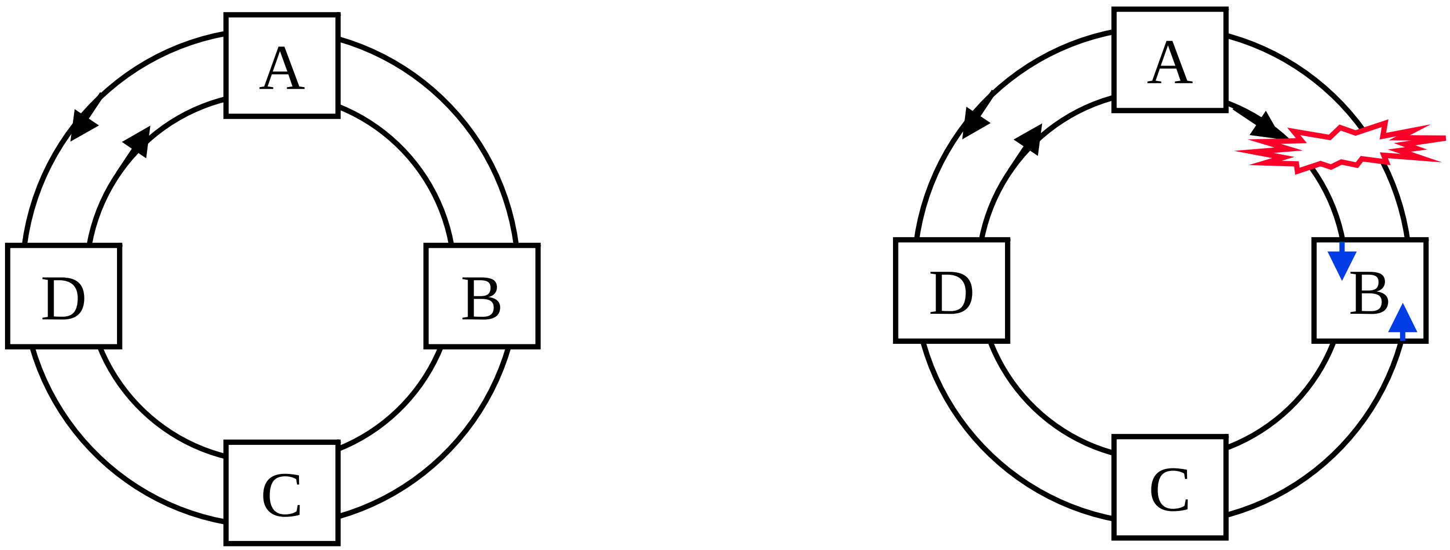
1:1 Protection

- Signal is sent ONLY on working route
- Receiver signals the failure to the transmitter to switch
- Need an signaling channel for Automatic Protection Switching (APS)
- Protection line is used for APS signaling
- All switching is revertive



APS Signaling

Unidirectional Path Switched Ring

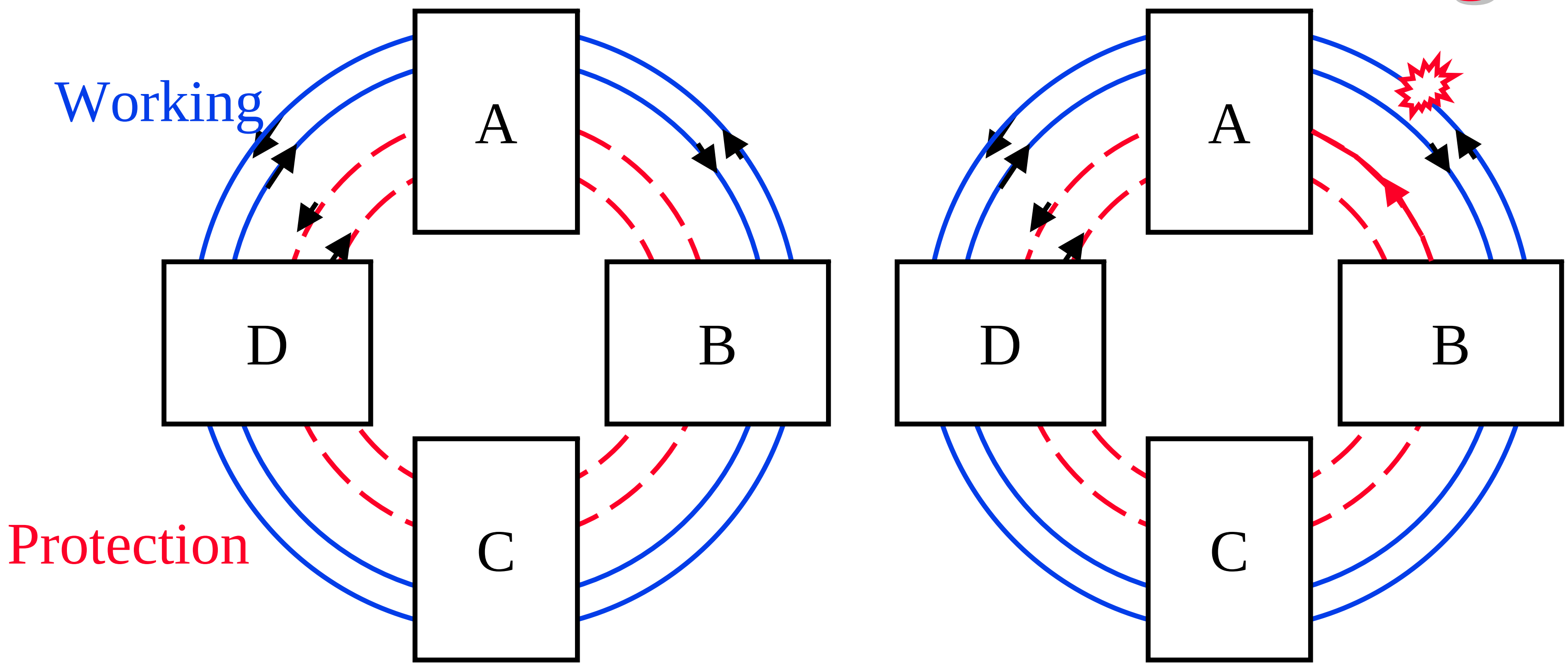


- Two counter rotating fibers: working+protection
- 1+1 $\Rightarrow$ Signal is sent on both fibers, receiver takes the stronger signal
- Unidirectional: Working ring is in one direction

UPSR (Cont)

- Path-Switched: the path changes on a link failure. SONET Path overhead is used.
- Receiver controls the switching. No transmitter involvement $\Rightarrow$ Fast
- No APS signaling channel required

Bi-directional Line-Switched Ring

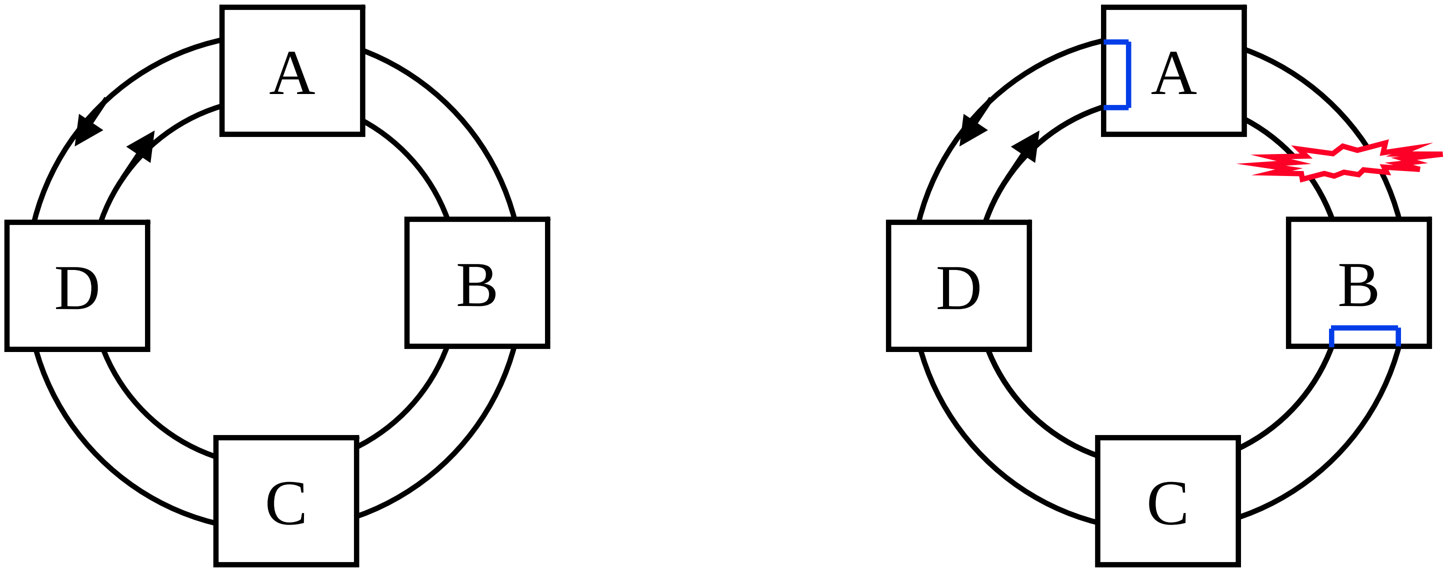


- Two working rings in counter-rotating directions
- Two protection rings in counter-rotating directions
- Bi-directional: Working signals between two nodes on shortest path in both directions

4-Fiber BLSR (Cont)

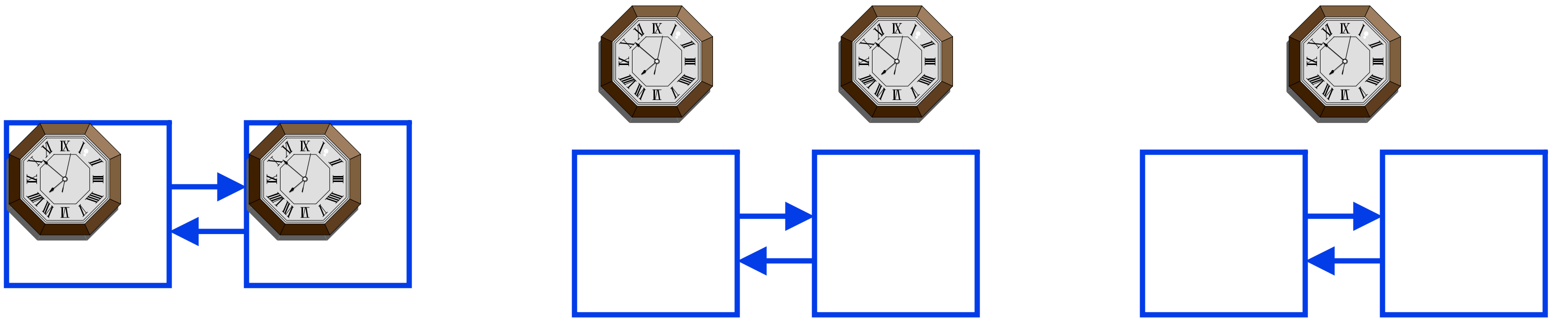
- Line Switched: If only one fiber is cut, traffic is switched from working to protection fiber in the same direction
- SONET line overhead is used for APS signaling
- Ring Switched: If both fibers are cut, traffic is switched to protection ring
- 1:1 Protection: APS signaling channel is required
- Signaling ⇒ Restoration time more than UPSR
- Preferred by long-haul carriers.

Bi-directional Line-Switched Ring (2-Fiber)



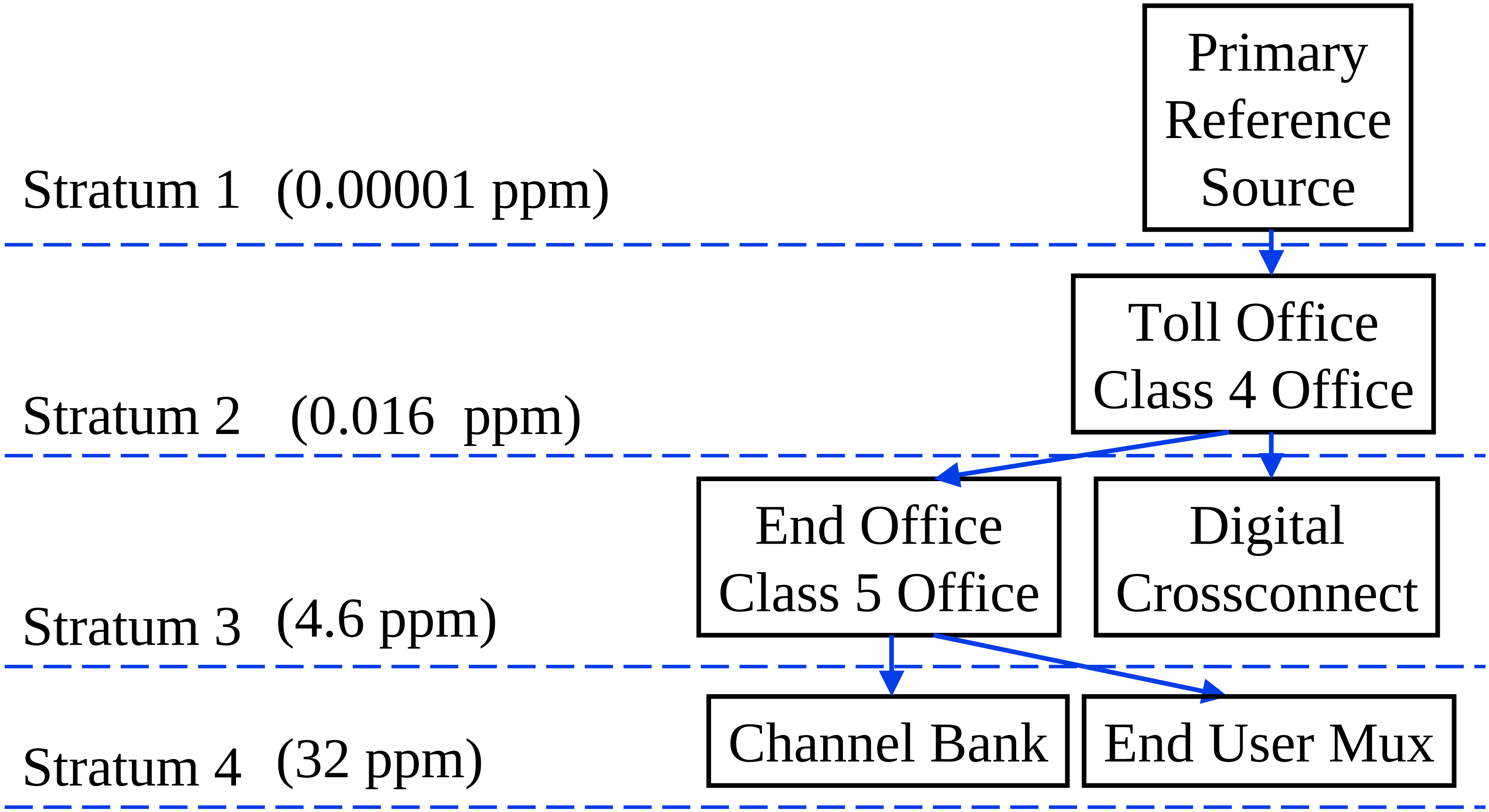
- Two counter rotating rings: both 1/2 working and 1/2 protection using TSI
- Allows only ring switching if one fiber is cut
- Ring wraps if both fibers are but

Timing in Networks



- Asynchronous: Each system has its own free running clock, e.g., data networks
- Plesiochronous: Each system derives its clock from its own primary reference source (PRS). Clocks are almost the same, e.g., T1 networks (nearly-synchronous)
- Isochronous: All systems derive their clock from one common primary reference source, e.g., SONET

Clock Distribution



Scrambling

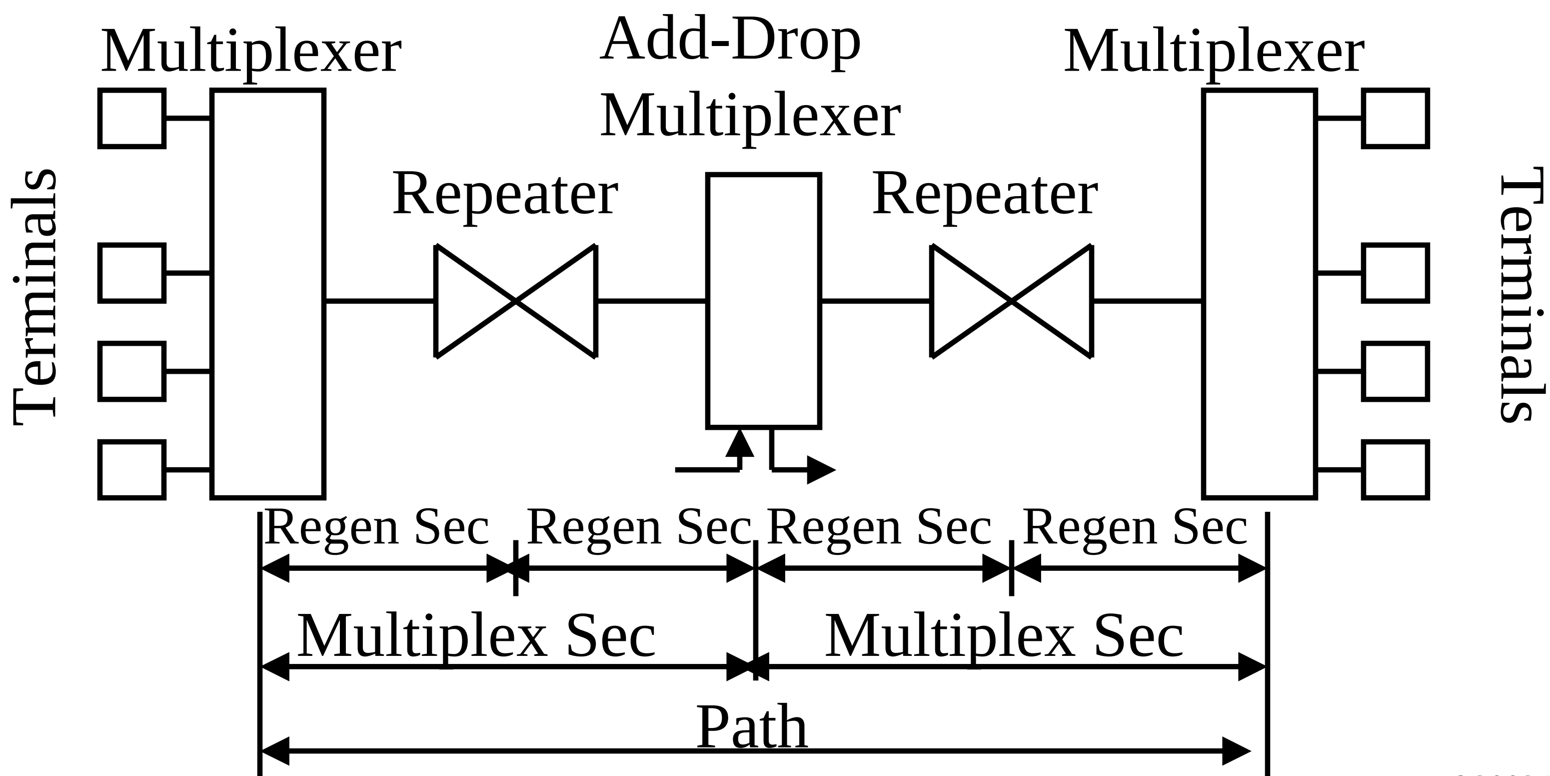
- SONET uses NRZ coding.
  1 = Light On, 0 = Light Off.
- Too many 1's or 0's ⇒ Loss of bit clocking information
- All bytes (except some overhead bytes) are scrambled
- Scrambling = Adding a number or dividing by a number
- Example:
  - Division by 7: To send 10,000,000 send 1,428,751
  - Add 142: Send 24,214,214
- Network devices use large binary numbers represented as polynomials, e.g., 10111 = x^4+x^2+x+1

SONET Scrambling

- SONET uses an additive scrambler:
  XOR the following 127 bits to incoming bits
  1111 1110-0000 0100-0001 … 010
- Generated by polynomial $1 + x^6 + x^7$ with a seed of 1111111
- Implemented easily in hardware with binary shift registers

Synchronous Digital Hierarchy

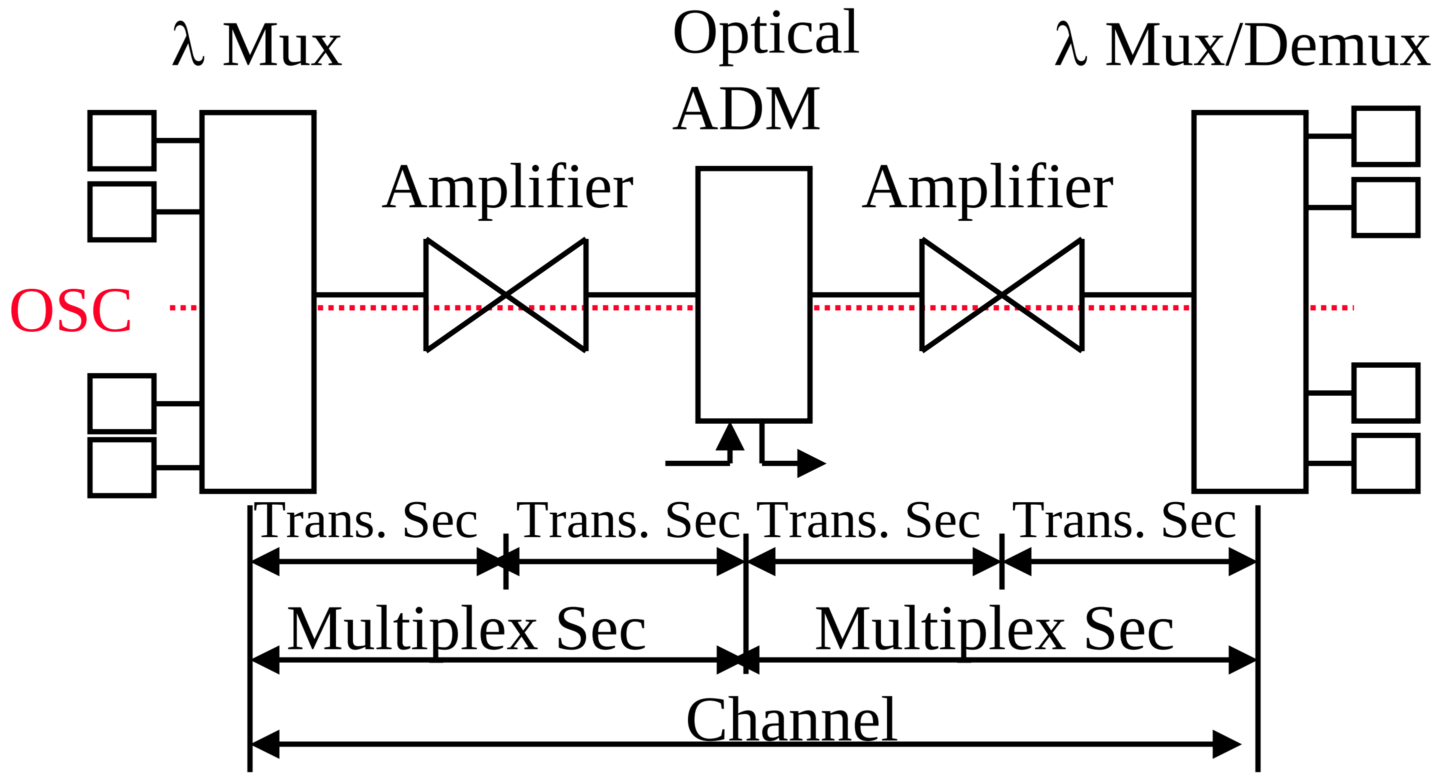
- Regenerator Section = Single run of fiber
- Multiplex Section = Between multiplexers
- Path = End-to-end



SONET vs SDH

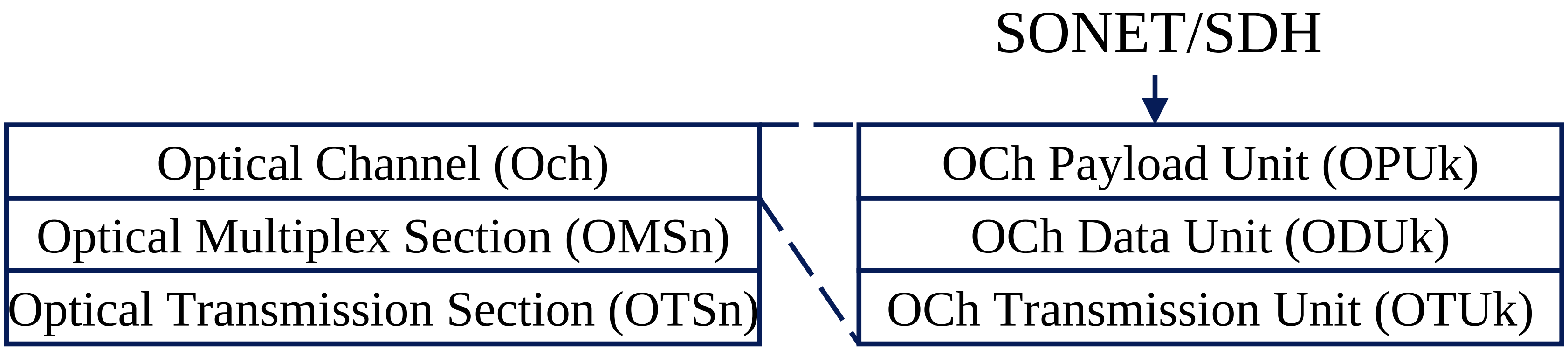
SONET	SDH
Section	Regeneration Section
Line	Multiplex Section
Path	Path
Byte	Octet
Tributary	Container
	Virtual Container
Virtual Tributary	Tributary Unit
Virtual Tributary Group	Tributary Unit Group
	Administrative Unit
UPSR	SNCP
BLSR	MS-SPRing

Optical Transport Network (OTN)



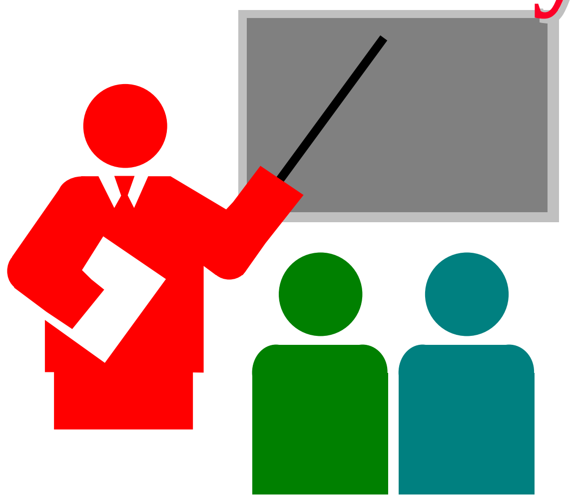
- G.709 Digital Wrapper designed for WDM networks
- OTN*n*.*k* = *n* wavelengths at *k*th rate, 2.5, 10, 40 Gbps plus one Optical Supervisory Channel (OSC)
- OTNnr.k = Reduced OTNn.k ⇒ Without OSC

OTN Layers and Frame Format



- **OTU1 Frame Format:** 4×4080 Octets/125 ms Forward Error Correction (FEC) increases distance by 2x to 4x. Frame Alignment (FA).

Summary



- All telephone systems use a 125μs cycle
- T1/T3 are electrical transports used in access networks
- STS-n = OC-n = n X 51. Mbps line rate
  STM-n = STS-3n is used in Europe
- SONET/SDH have ring based protection
- OTN uses FEC digital wrapper and allows WDM

Homework 4

True or False?

T F

- ❑ ❑ Telephone networks are designed to carry voice signal of 8 kHz
- ❑ ❑ A T1 frame consists of 193 bits per 125 μs
- ❑ ❑ A single run of fiber between two amplifiers constitutes a SONET section.
- ❑ ❑ OC-768 is approximately 40 Gbps.
- ❑ ❑ A STS-1 frame consists of 9 rows and 90 columns
- ❑ ❑ T1's are sent through SONET network as VT1.5
- ❑ ❑ STS-3c indicates channelized STS-3
- ❑ ❑ 1:1 protection requires APS signaling
- ❑ ❑ UPSR provides 1:1 protection
- ❑ ❑ SONET is isochronous
- ❑ ❑ A single run of fiber between two repeaters constitutes a SDH multiplex section.
- ❑ ❑ OTNnr.k allows n wavelengths of rate r

Marks = Correct Answers _____ - Incorrect Answers_____ = ______