SONET-SDH

Fabio Neri e Marco Mellia
Gruppo Reti – Dipartimento di Elettronica
e-mail: nome.cognome@polito.it
http://www.tlc-networks.polito.it/

fabio.neri@polito.it - tel 011 564 4076
marco.mellia@polito.it - tel 011 564 4173

SONET/SDH

Today telephone network is largely based on the evolution of the first digital infrastructure, based on a TDM system, with strict synchronization requirements, or PDH – Plesiochronous Digital Hierarchy:

- SONET – Synchronous Optical NETwork (optical signal, based rate of 51.84Mbit/s)
- SDH – Synchronous Digital Hierarchy (European standard equivalent to SONET)
- STS – Synchronous Transport Signal (equivalent standard for electric signals)

Plesiochronous Digital Hierarchy

Plesiouchonous Digital Hierarchy (PDH) is the original standard for telephone network, now abandoned in favors of SONET/SDH

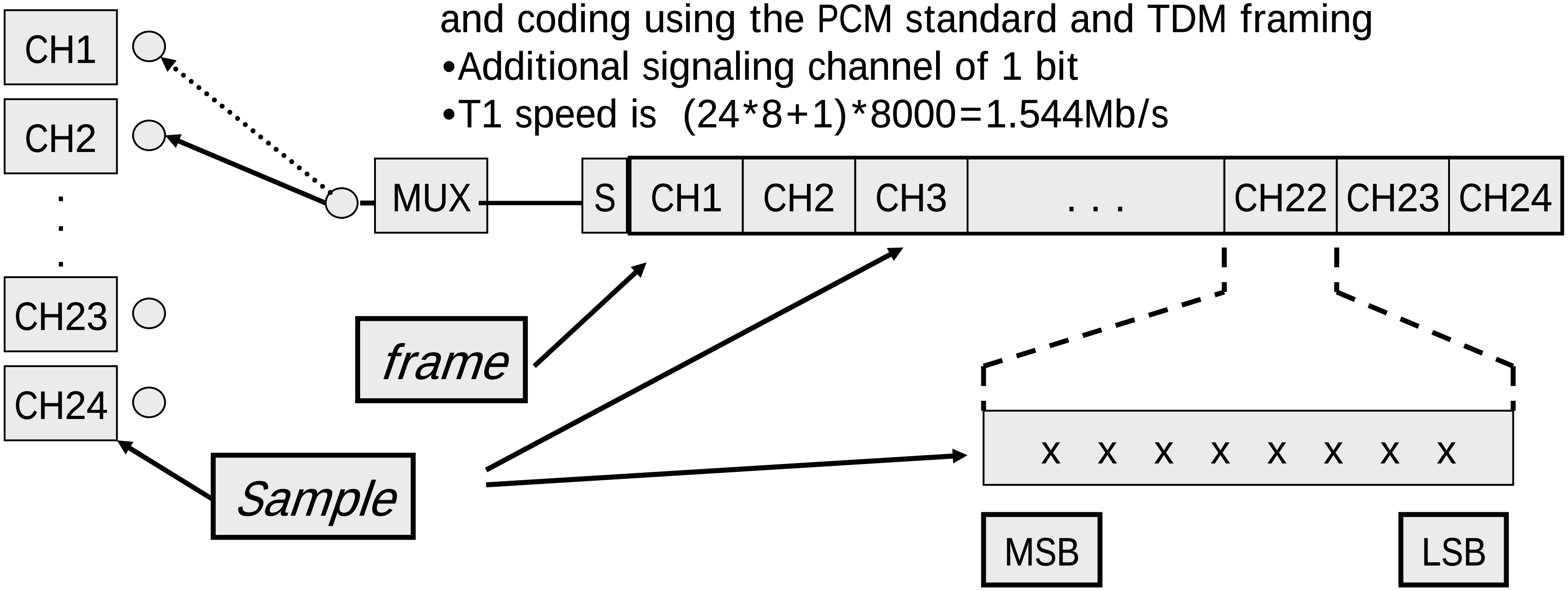
- Exploits Time Division Multiplexing
- Designed to support digital voice channels at 64kb/s
- No store and forward: imposes strict synchronization between TX and RX. A “plesio-synchronous” solution is adopted (almost synchronous)
- Different standard in US/EU/Japan
  - Make it difficult to connect different networks5

T-, E- Hierarchy

Level	US (T-)	Europe (E-)	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	8.488 Mb/s	6.312 Mb/s
3	44.736 Mb/s	34.368 Mb/s	32.064 Mb/s
4	274.176 Mb/s	139.264 Mb/s	97.928 Mb/s

T-1 carrier system: US standard

- 24- voice channels are the results of voice sampling, quantization and coding using the PCM standard and TDM framing
- Additional signaling channel of 1 bit
- T1 speed is (24*8+1)*8000=1.544Mb/s



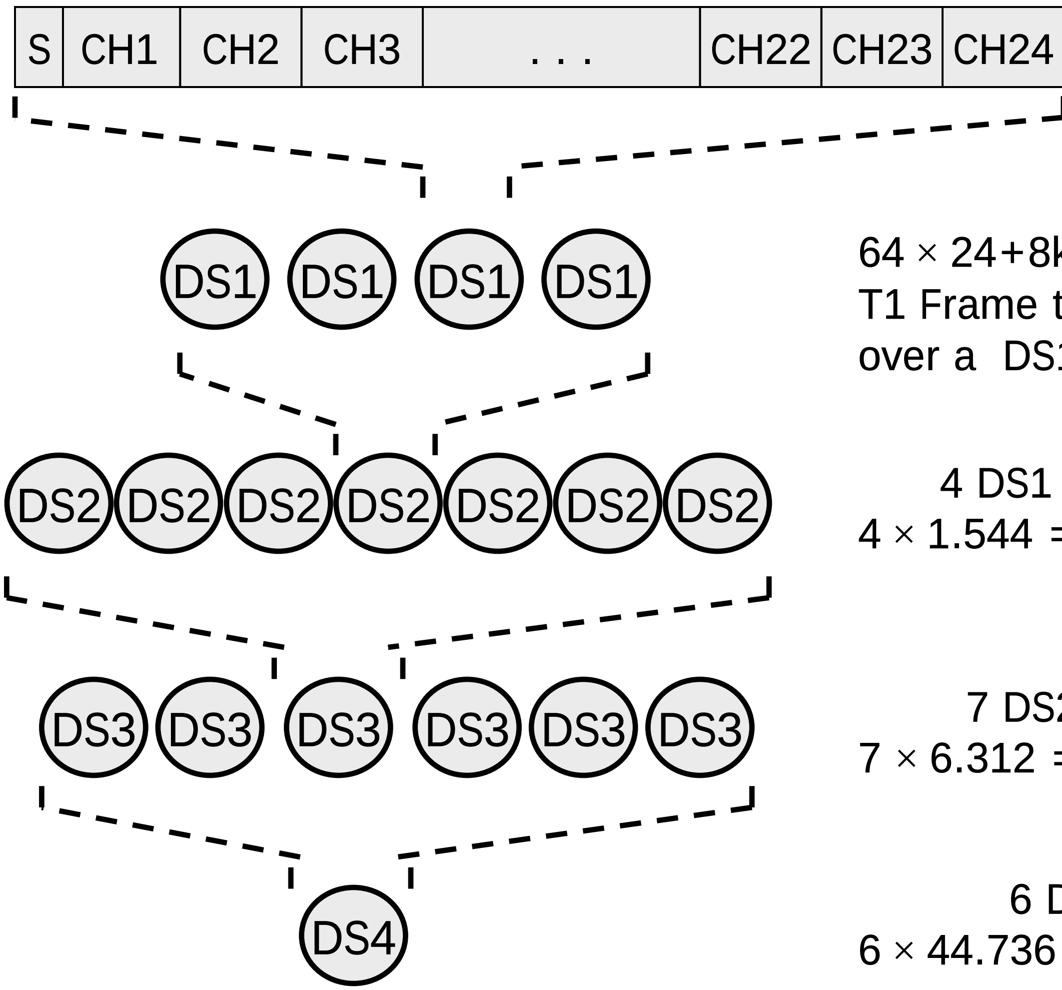
A sample every 125μsec

A frame every 125μsec

193 bits per frame

More frames can be multiplexed (TDM) on faster channels.

T- and DS- hierarchy



64 × 24+8k=1.544 Mb/s
T1 Frame transmitted over a DS1

4 DS1 = 1 DS2
4 × 1.544 = 6.312 Mb/s

7 DS2 = 1 DS3
7 × 6.312 = 44.736 Mb/s

6 DS3 = 1 DS4
6 × 44.736 = 274.176 Mb/s

It is difficult to have perfect synchronization between ALL nodes. “bit stuffing” to overcome this.

It is difficult to access a single channel in a high-speed stream: de-multiplexing of all tributaries must be performed

PDH

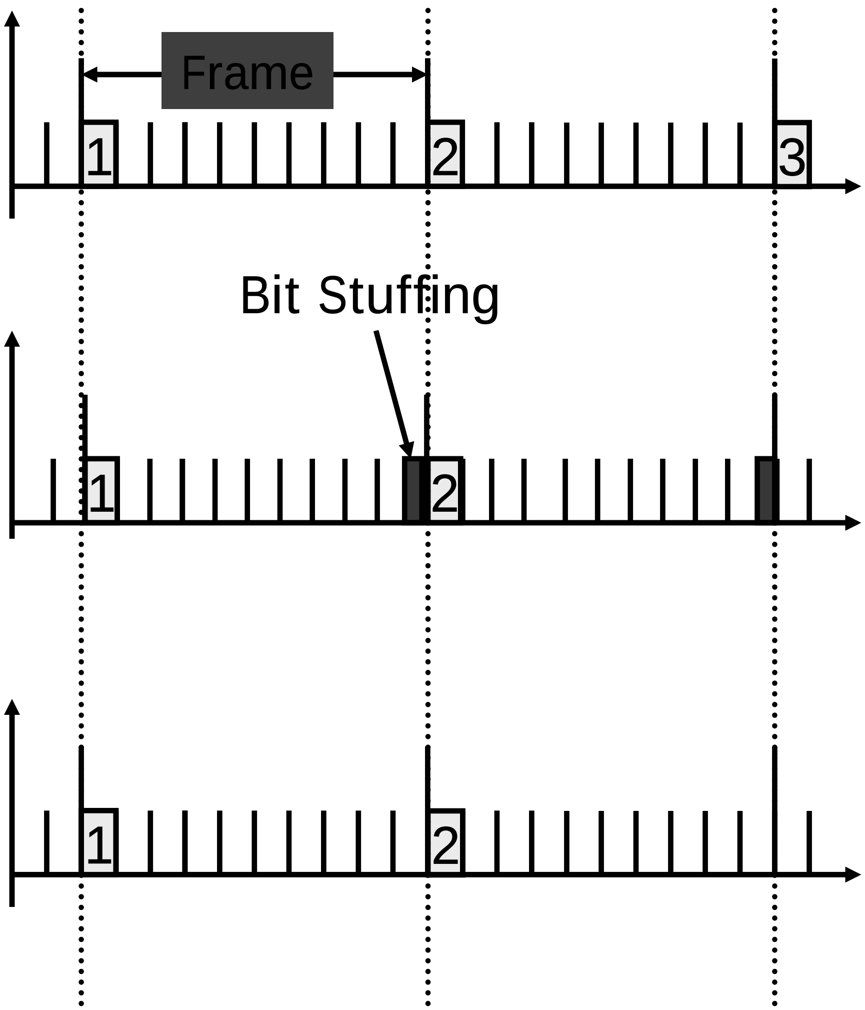
Digital transmission system (T-carrier, E-carrier) exploiting TDM to multiplex lower speed streams into higher speed channel

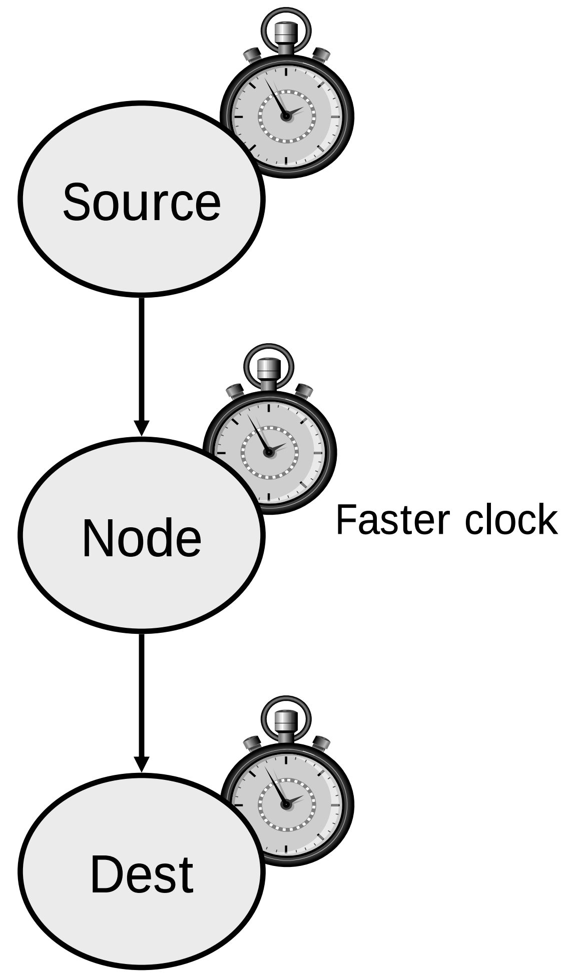
Every apparatus has its own clock. No network-wide synchronization is possible

Every clock is different, and therefore synchronization errors show up

Solution: insert (and remove) stuffing bits in the frame (but stuffing)

PDH - Sincronizzazione





PDH - Synchronization

- *Positive Stuffing*:
  - Data are written in a temporary buffer
  - Data are read from the buffer with a higher rate to transmit data to the (faster) transmission channel
  - Every time the buffer is going to be empty, stuffing bit is transmitted instead of real data
  - Stuffing MUST be signaled to the receiver, so that stuffing bits can be removed.
- A different frame is used at the data layer and at the transmission layer! This makes mux/demux operation much more complex.

PDH drawbacks

Lack of efficiency: it is hard to extract slower tributaries from the high speed aggregate

Lack of flexibility:

- No monitoring standard
- No management standard

Lack of “mid-fiber meet”

- No common physical standard – every manufacturer has its own (no NNI standard)

From PDH to SONET/SDH

SONET: Synchronous Optical Network: American standard

SDH: Synchronous Digital Hierarchy: EU and Japan standard

Standardization occurred in ’80

Telecom Providers drove the standardization process

- PDH system was not anymore scalable, and did not guarantee to support traffic growth
- Optical technologies were becoming commonly used, foreseeing bandwidth increase
- Interoperability among different providers were a nightmare.

What is SONET/SDH

Set of ITU-T recommendation (first from 1989):

- Define a structured multiplexing hierarchy
- Define management and protection mechanisms
- Define physical layer requirements (optical components)
- Define multiplexing of different sources and protocols over SONET/SDH

SONET/SDH Goals

Main goals of SONET/SDH:

- *Fault tolerance* of telecom providers requirement (99.999% - five nines - availability)
- *Interoperability* among different manufacturers
- *Flexibility* of upper layer formats to adapt to different source (not only voice)
- Complex *monitoring* capabilities of performance and of traffic (50 ms of recovery time)

SONET/SDH hierarchy

OC level	STS level	SDH level	Mbit /s
OC-1	STS-1		51.84
OC-3	STS-3	STM-1	155.52
OC-12	STS-12	STM-4	622.08
OC-24	STS-24	STM-8	1244.16
OC-48	STS-48	STM-16	2488.32
OC-192	STS-192	STM-64	9953.28
OC-768	STS-768	STM-256	39813.12
OC-3072	STS-3072	STM-1024	159252.48

SONET/SDH reference model

Path layer (close to OSI layer 3 - Network)

- Manages end-to-end connection
- Monitoring and management of user connection

Line Layer

- Multiplexing of several path-layer connection among nodes
- Protection and Fault Management

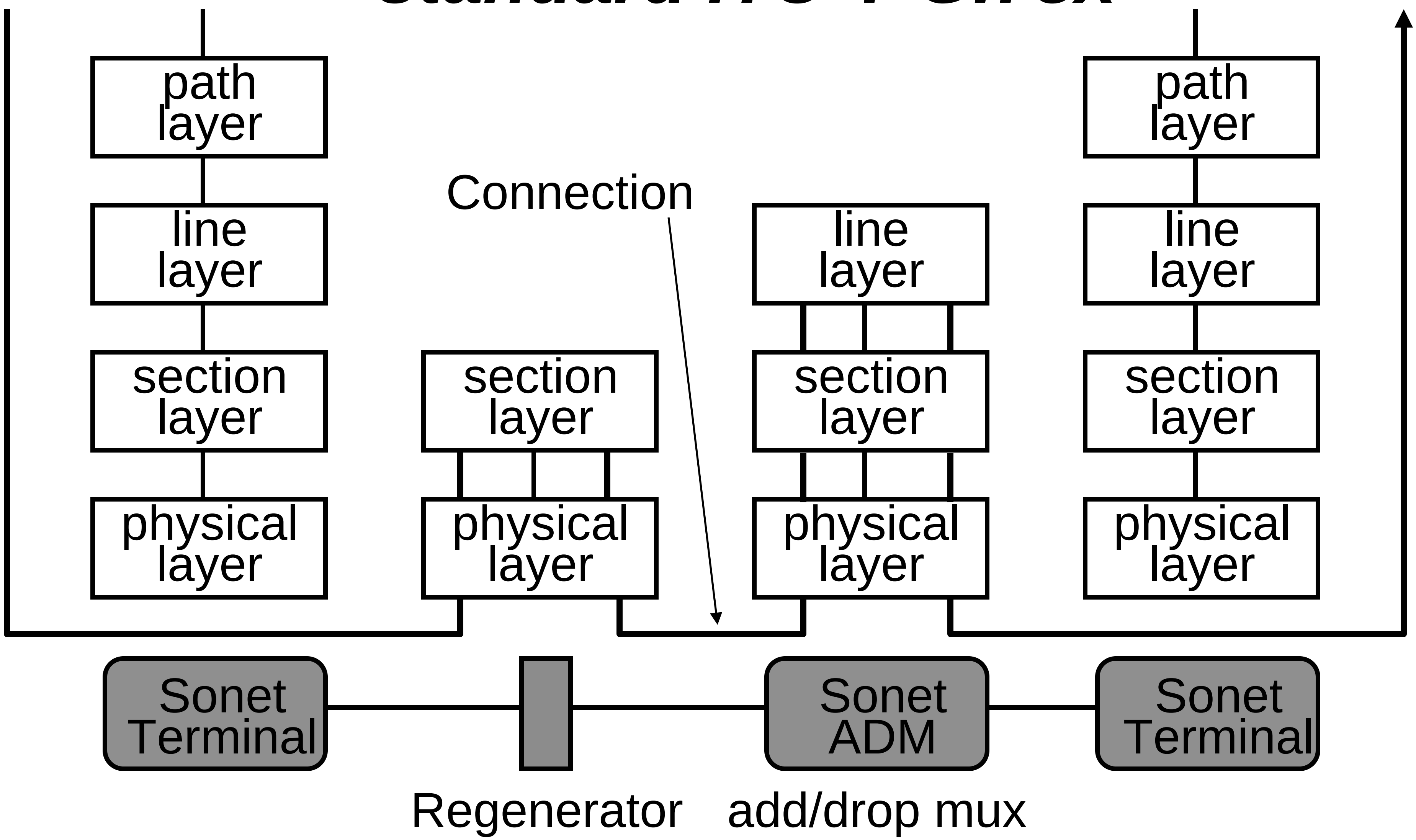
Section Layer

- Define regenerator functions
- SONET’s Line and Section layers are almost equivalent to 2 (Data Link) OSI layer

Photonic Layer (same as OSI layer 1)

- Defines all the transmission requirements of signals.

Layering in SONET/SDH standard ITU-T G.78x



SONET Physical Layer

SONET physical layer is strongly optically-centric

More important recommendations are:

- ITU-T G.957: Optical interfaces for equipments and systems relating to the synchronous digital hierarchy
  - Single span, single channel link without optical amplifiers
- ITU-T G.691: Optical interfaces for single-channel STM-64, STM-256 and other SDH systems with optical amplifiers
  - Single channel, single or multi span, optically amplified links at 622 Mbit/s, 2.5 Gbit/s, 10 Gbit/s
- ITU-T G.692: Optical interfaces for multichannel systems with optical amplifiers
  - Multi channel, single or multi span, optically amplified
  - Definition of the ITU frequency grid

Large variety of possibilities, from very short-haul interoffice links up to a ultra-long haul, WDM backbone links

- All physical parameter of all interfaces are defined

SONET Framing

SONET/SDH TX send a continuous, synchronous streams of bit a given rate

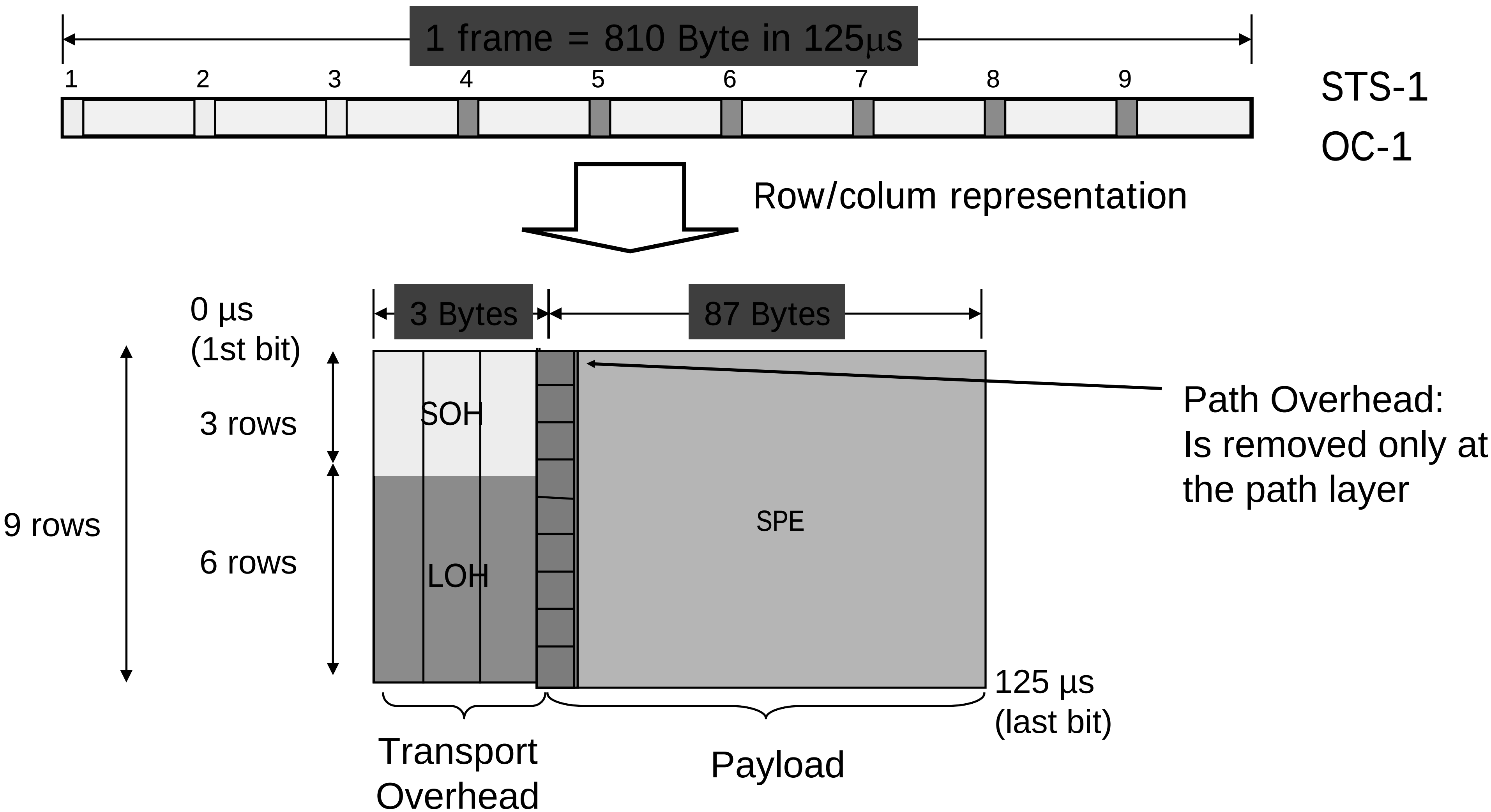
Multiplexing of different tributaries is performed by the means of TDM

Apparently complex, but the TDM scheme has been designed to simplify the VLSI implementation

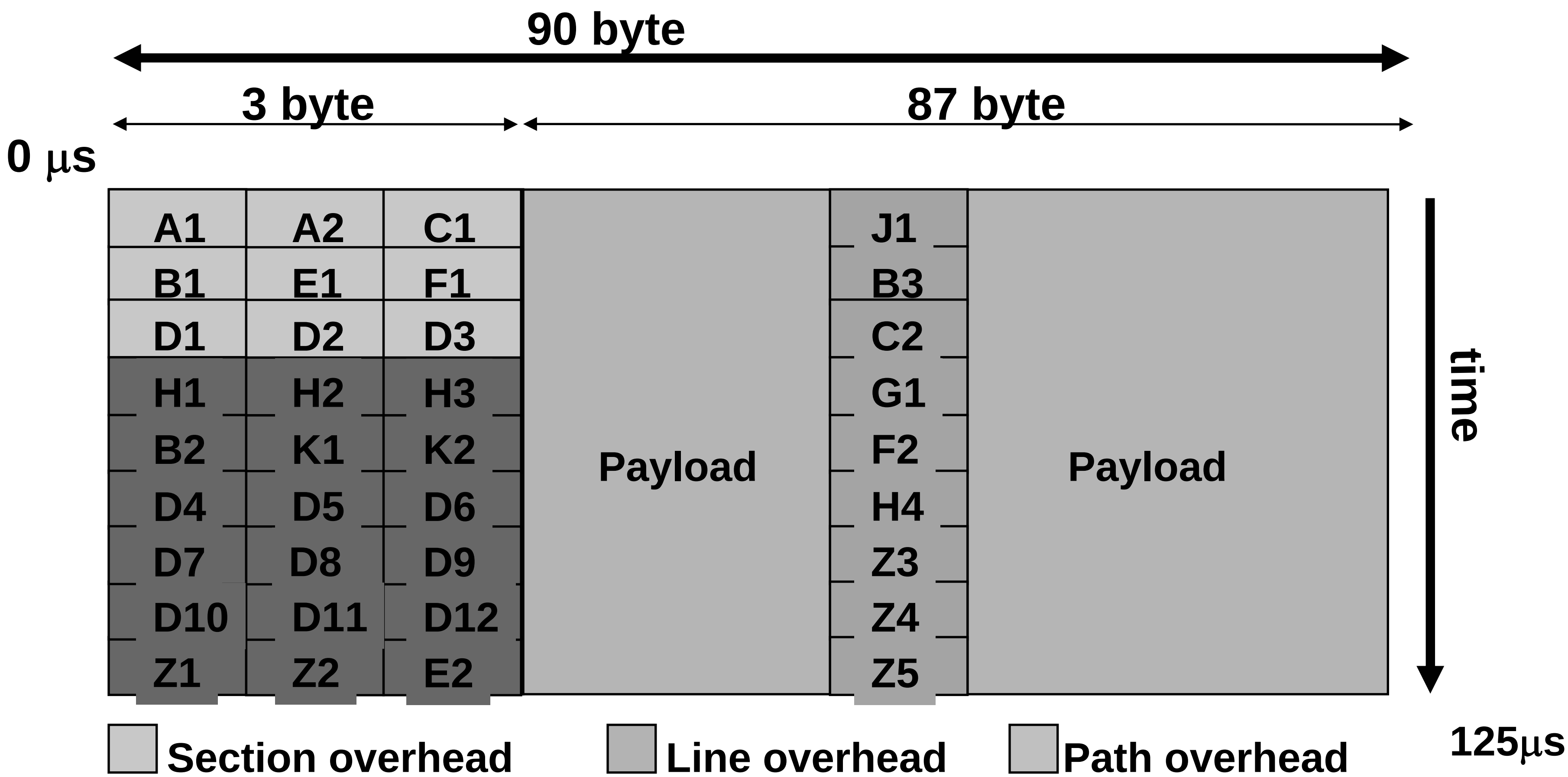
A SONET frame is a very organized stream of bits

- At a given multiplexing level, every tributary becomes a Synchronous Payload Envelope (SPE)
- Some bits, the Path Overhead, are added to the SPE, to implement monitoring, management, control functions
- SPE + Path Overhead are a PDU, called Virtual Tributary (VT)

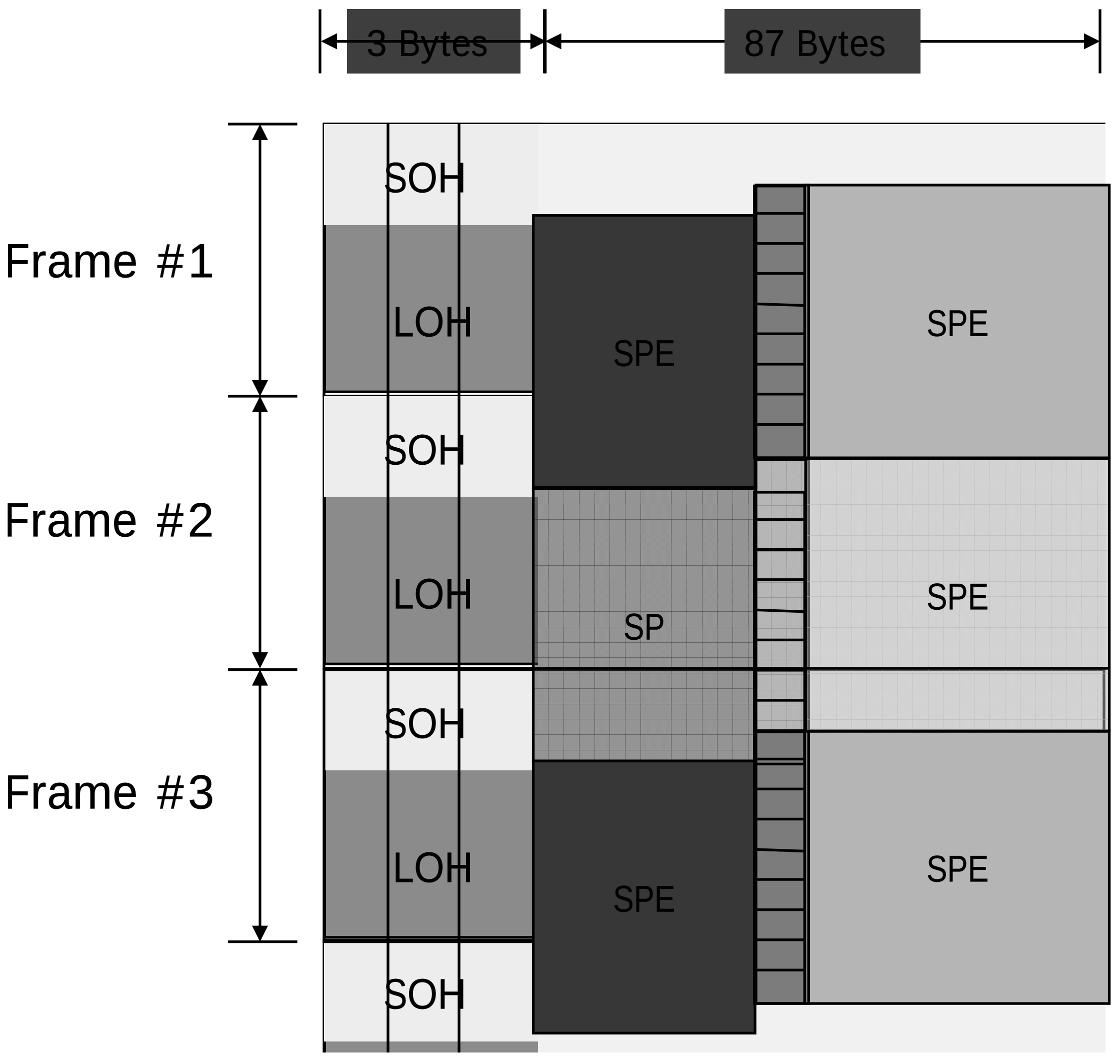
STS-1 framing



SONET: Framing STS-1



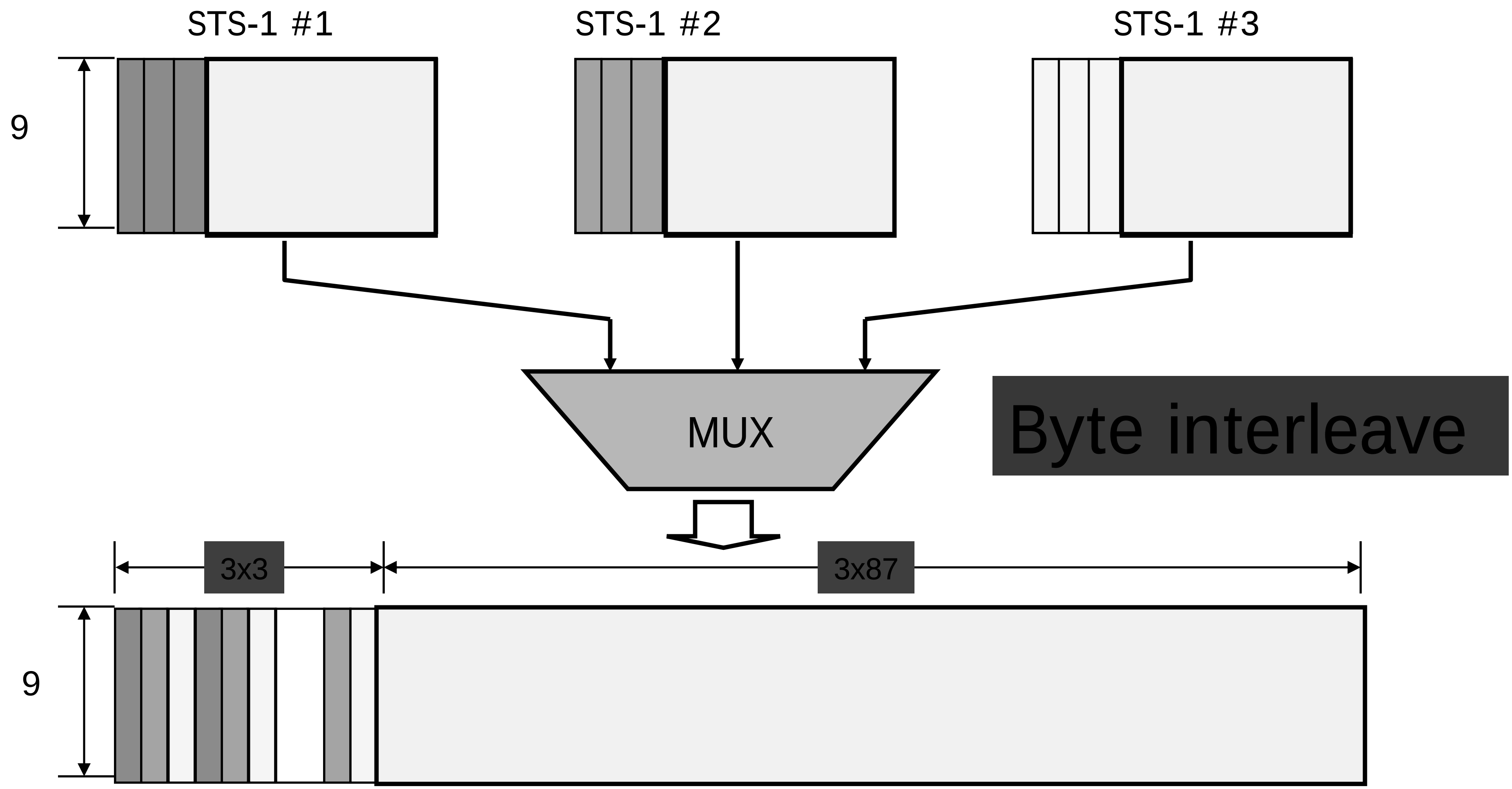
STS-1 frame



SPE of frame N can end in frame N+1

810 Bytes/frame
8 bit/sample
810 samples/frame
or
9x90 Bytes/frame
8000 frame/second
8 bit/Byte
or
51,840 Mb/s

Higher layer multiplexing

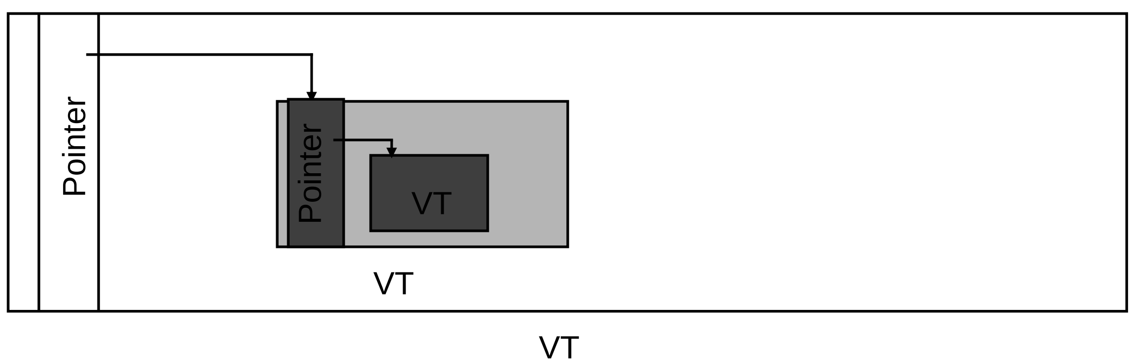


Virtual Tributary (VT)

VTs are identified by pointers along the frame. Pointers are stored in the line overhead

- A pointer states where a VT begins in the frame

A recursive approach is allowed: a VT may multiplex other smaller VTs

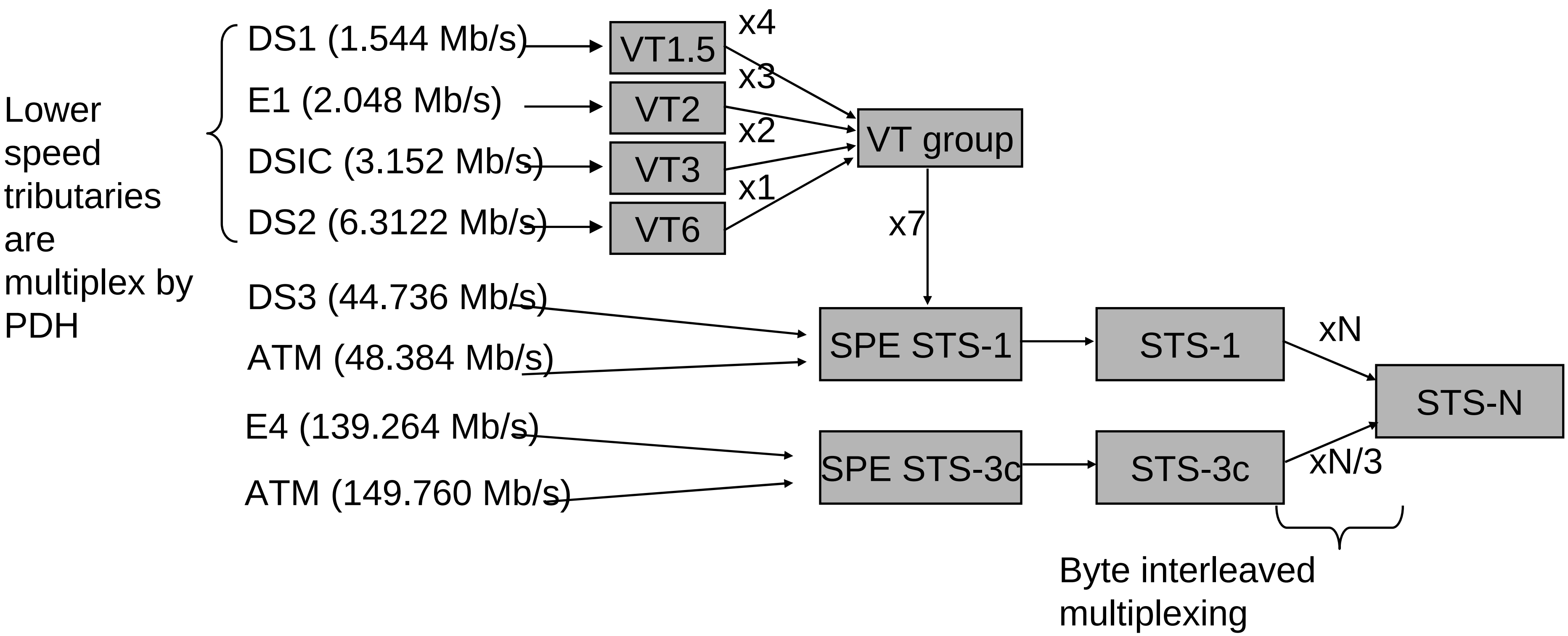


This allows to multiplex contributing tributaries running at very different speed in an efficient manner.

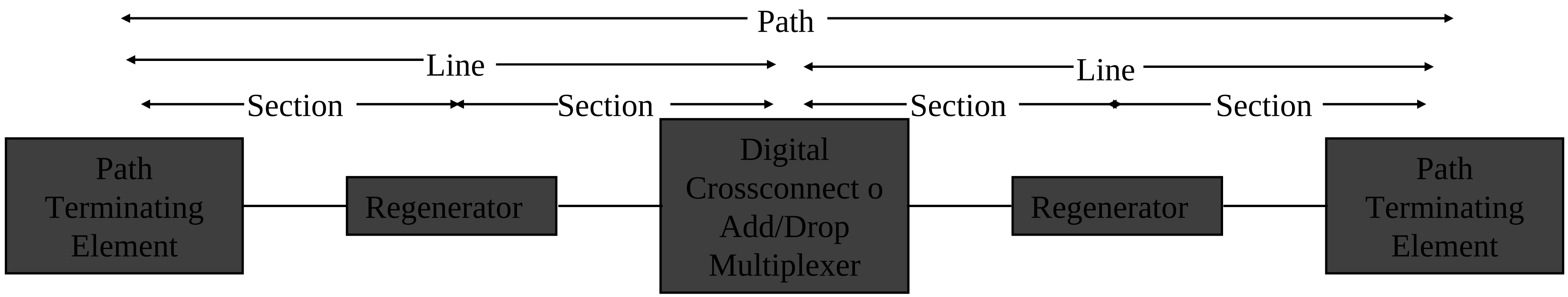
SONET hierarchy

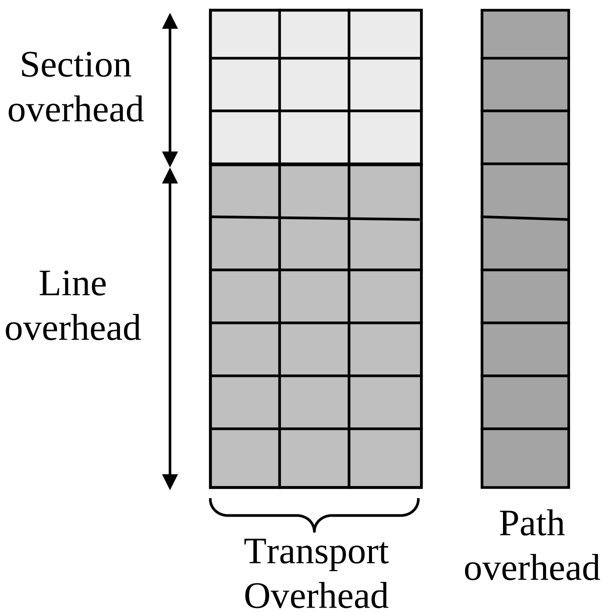
A sample of SONET hierarchy

- SONET has been designed to support a very large set of technologies: IP, ATM, PDH, …



SONET Overheads





Different overhead

- Section: used and managed by two section equipment
- Line: to allow signaling among STS multiplexers
- Path: end-to-end, added to the SPE to transform it in a VT

Each exploit a different function

- Multiplexing
- Management
- Allocation of resources

SONET overhead

Section Overhead:

- Generated and removed by Section Terminal Equipments (STE)
- Monitoring of the section performance
- Operation, administration and maintenance (OAM) voice channel
- Framing

SONET overhead - SOH

		1	2	3	Path Overhead
Section Overhead	1	A1	A2	J0/Z0	J1
	2	B1	E1	F1	B3
	3	D1	D2	D3	C2
Line Overhead	4	H1	H2	H3	H4
	5	B2	K1	K2	G1
	6	D4	D5	D6	F2
	7	D7	D8	D9	Z3
	8	D10	D11	D12	Z4
	9	S1/Z1	M0 or M1/Z2	E2	Z5

Transport Overhead (columns 1–3); Path Overhead

A1 A2	**framing bytes**— States the beginning of the STS-1 frame.
J0	**section trace (J0) / section growth (Z0)**— section trace byte or section growth byte

B1	**section bit-interleaved parity code (BIP–8) byte**— Parity code (even parity), used to detect transmission errors on this section. It is evaluated on the previous frame after the scrambling operation.
E1	**section orderwire byte**— 64Kbit/s digital channel to transport a voice signal between operators at the section endpoints
F1	**section user channel byte**— not defined
D1, D2, D3	**section data communications channel (DCC) bytes**— 192Kbit/s channel used for OAM&P.

SONET Overheads

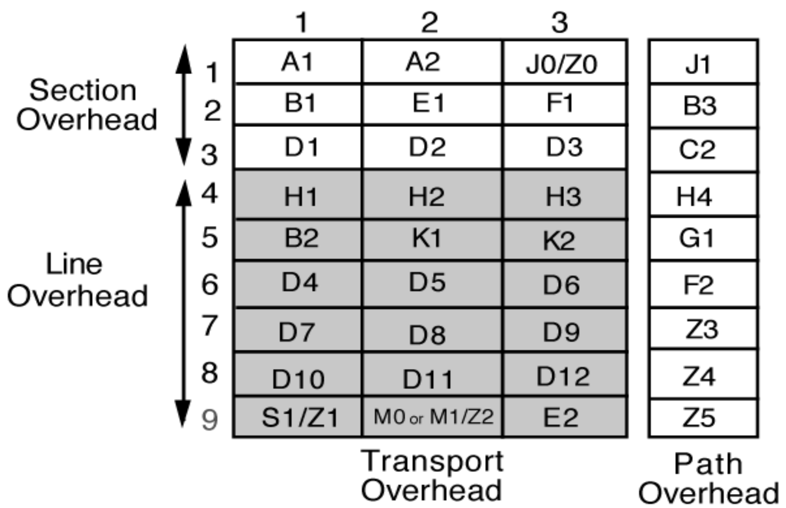
Line Overhead:

- Generated and removed by the line terminating equipment (LTE)
- VT identification in a frame
- Multiplexing/routing
- Performance monitoring
- Protection switching
- Line management

STS Path Overhead:

- Generated and removed by Path Terminal Equipment (PTE)
- end-to-end monitoring of VT/SPE
- Connection management

SONET overhead - LOH



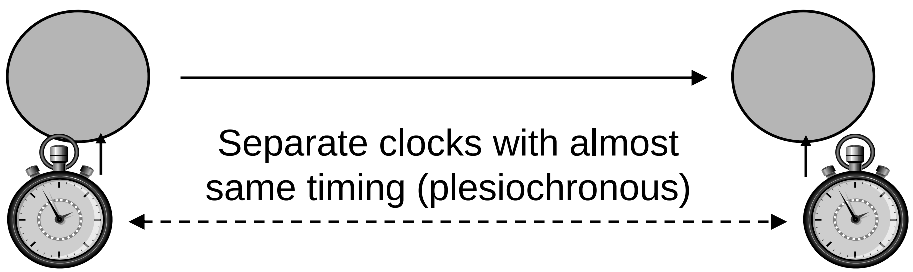
H1 **H2**	**STS payload pointer (H1 and H2)**— stores the pointer. It is the offset between the first payload byte and the actual VT first byte.
H3	**pointer action byte (H3)**— used when a negative stuffing is performed. It stores the additional byte of the last frame.
B2	**line bit-interleaved parity code (BIP–8) byte**— parity check code, used to detect errors at the line layer

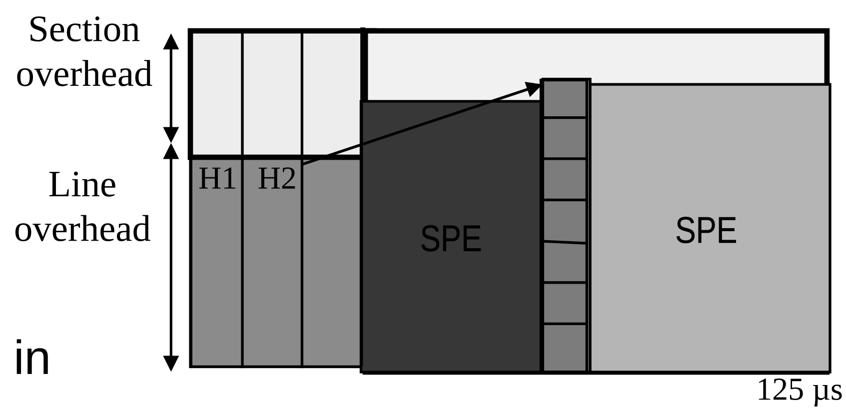
K1 **K2**	**automatic protection switching (APS channel) bytes**— signaling to face fault management
D4 **D12**	**line data communications channel (DCC) bytes**— 9 bytes for a 576Kbit/s management channel to carry over O&M operations
S1	**synchronization status (S1)**— Used to carry global network-wide synchronization.
Z1	**growth (Z1)**— not defined
M0	**STS–1 REI–L (M0)**— to carry signaling in case of remote error indication
M1	**STS–N REI–L (M1)**— to perform restoration operation
Z2	**growth (Z2)**— not used
E2	**orderwire byte**— 64Kbit/s digital channel to transport a voice signal between operators at the section endpoints

SONET pointers

How to manage de-synchronization among apparatus clocks?

- Use pointer to absorb frequency and phase shifting
- They allow to dynamically follow the phase shifting in a simple manner
- And avoid the need of buffering

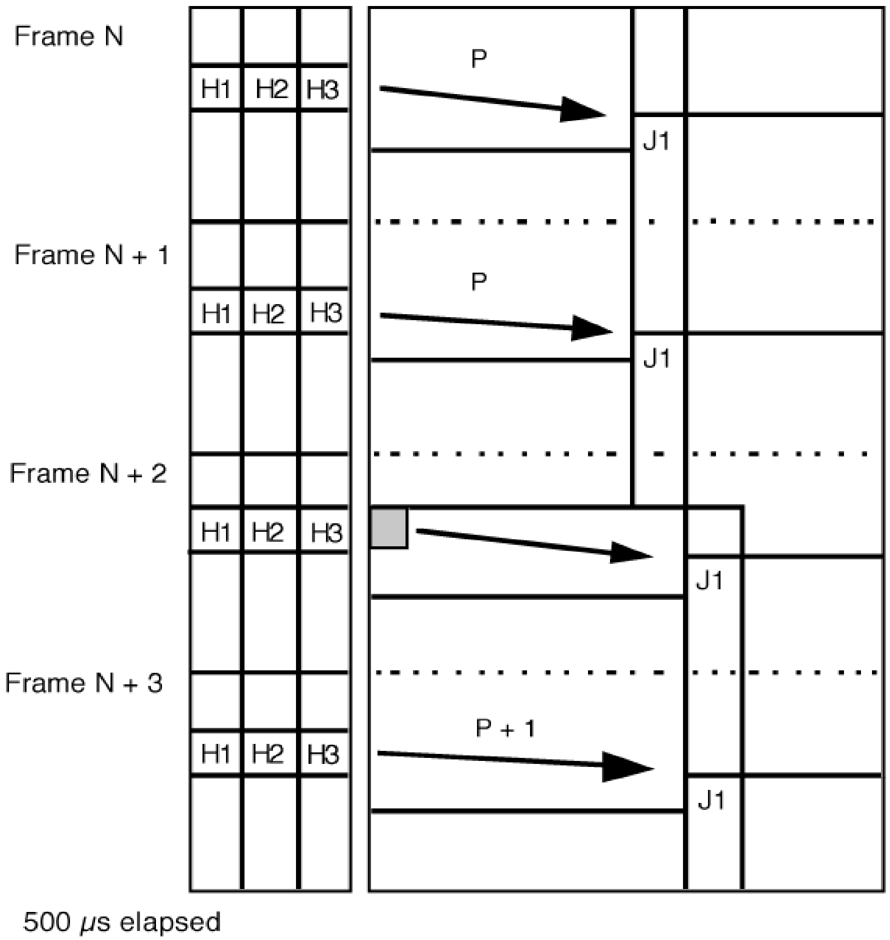




Bit Stuffing was used in PDH. Byte stuffing is used in SONET

- When the SPE speed is smaller than STS-1 speed, an extra byte is inserted
- When the SPE speed is larger than STS-1 speed, an extra byte is removed and transmitted in the overhead

Positive stuffing



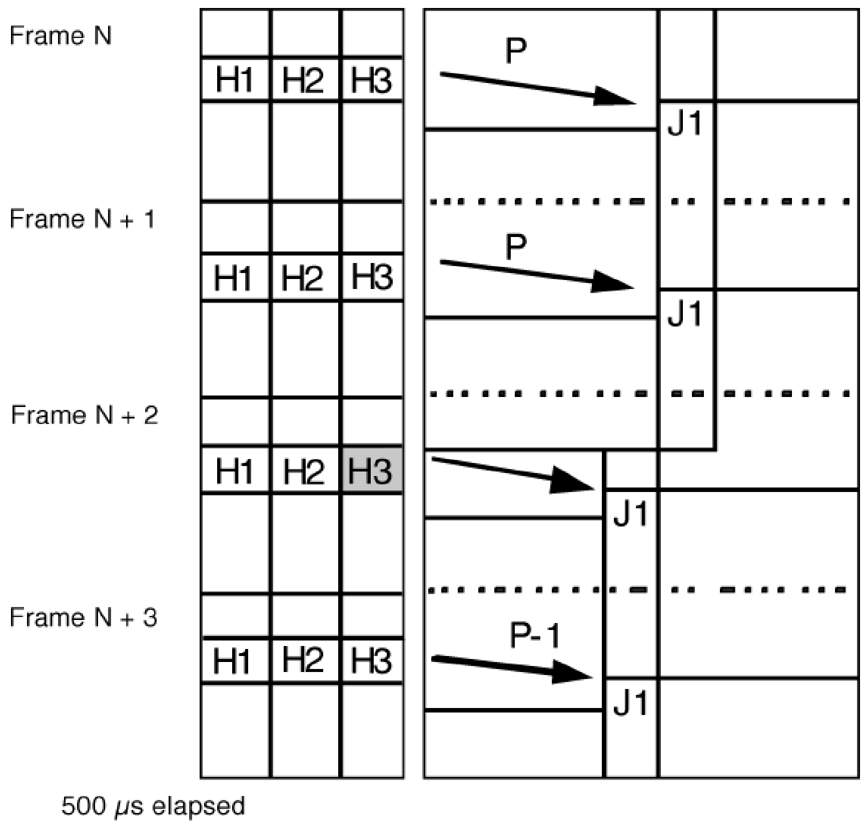
Extra bytes allow the SPE to slip back in time.

A positive stuff byte immediately follows the H3 byte.

SPE slower than STS-1

- Periodically, when the SPE has a delay of 1 byte, odd bits of pointers are negated, to signal a positive stuffing operation
- An additional byte is added in the VT, allowing it to be delayed by 1 byte
- The additional byte is always put close to the H3 header field
- The pointer is then incremented by 1 in the next frame, e following frames will hold the new value.

Negative stuffing



The SPE moves forward in time when a data byte has been stuffed into the H3 byte.

Actual payload data is written in the H3 bytes.

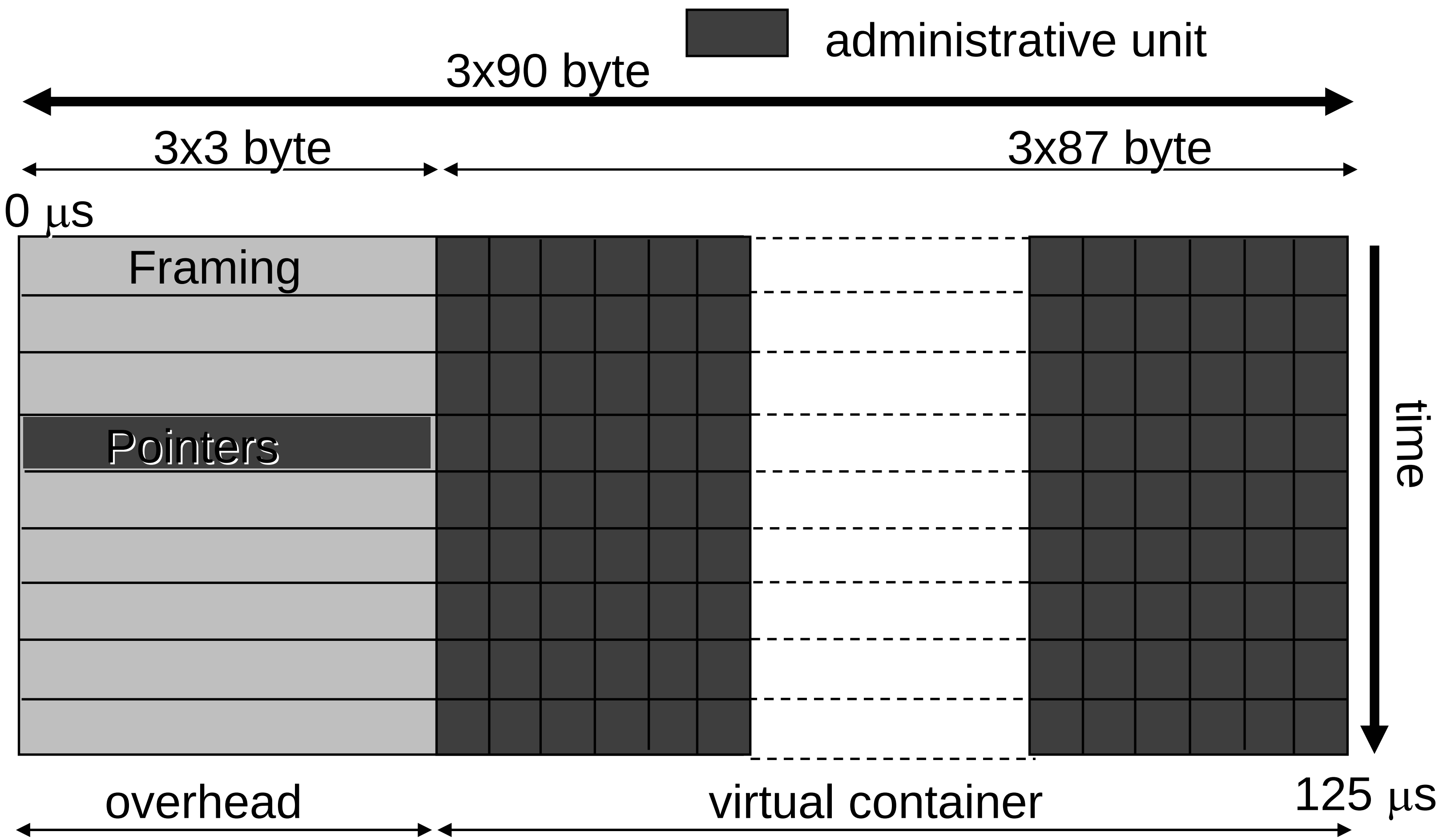
SPE faster then the STS-1

- Periodically, when the SPE has an additional byte, pointer even bits are negated, to signal a negative stuffing operation
- In next frame, the VT starts 1 byte earlier
- The additional byte of the previous VT is put into the H3 header field
- The pointer is then decremented by 1 in the next frame, e following frames will hold the new value.

SDH Framing

- In SDH a different naming scheme is used, but the design is similar to SONET's
- Base tributary is STM-1, with a period of 125 μs
- Frame has 19440 bits, giving a total speed of 155.520 Mbit/s
- Information is organized in bytes, using 9 rows of 270 bytes each
- Virtual container (VC) carried the payload (261 x 9 = 2349 bytes)
- Administrative unit (AU) is the VC plus headers (like the VT)

STM-1 frame in SDH



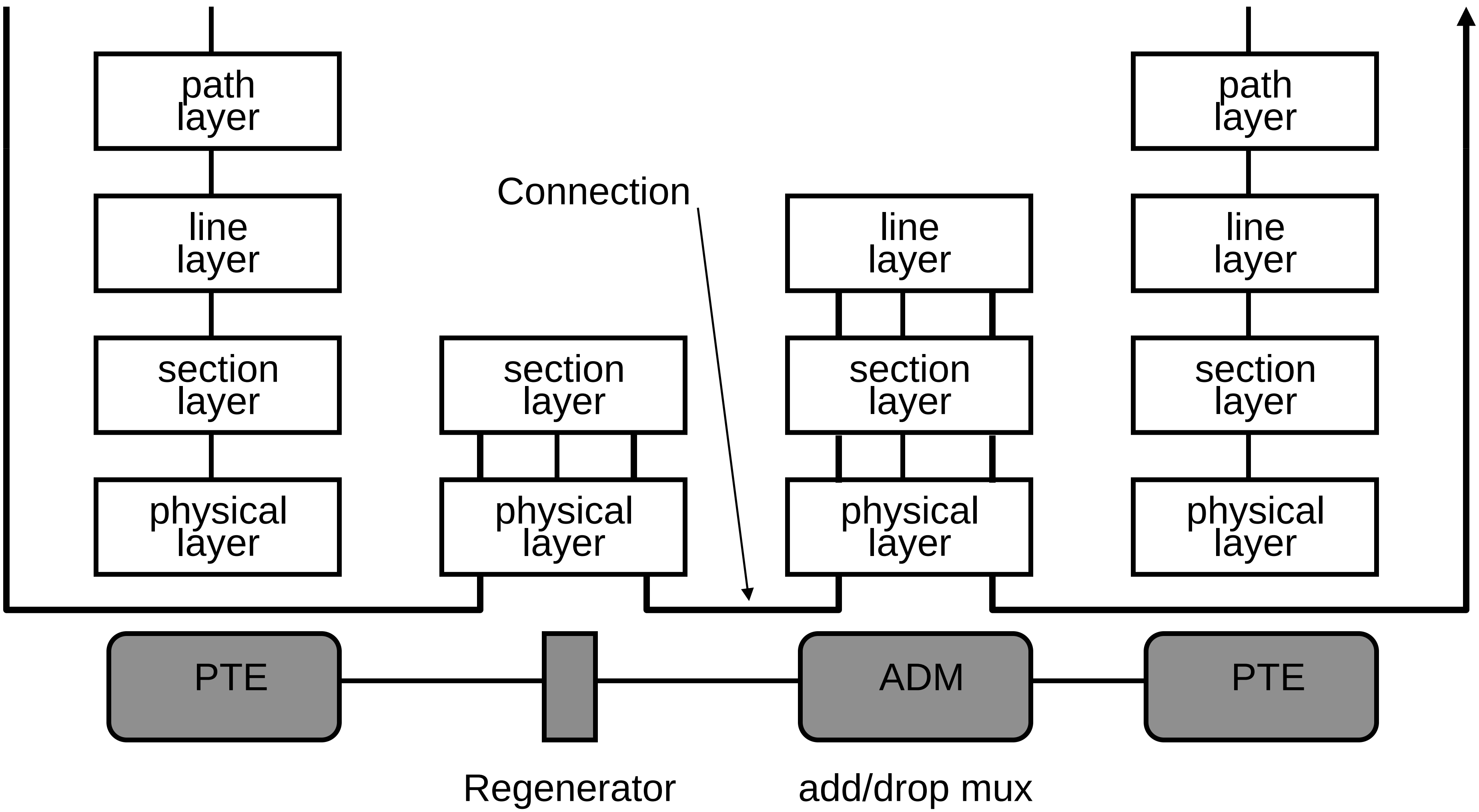
SONET Network Elements

SONET standard defines several apparatuses to fulfill different functionalities

- Multiplexer and de-multiplexer
- Regenerators
- Add-Drop multiplexers
- Digital cross-connects

All are “electronic” devices, with no elaboration done in the optical domain except transmission

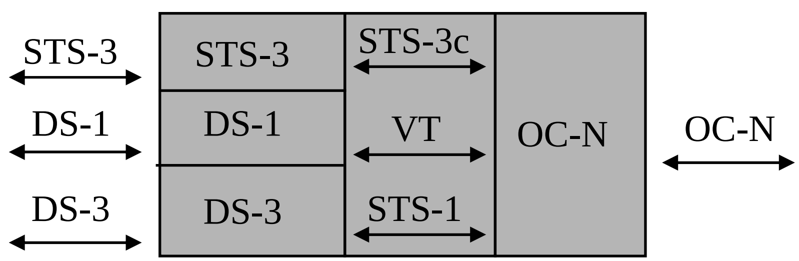
SONET/SDH layering



SONET Network Elements: PTE

Multiplexer and demultiplexer: The main function is mux and demux of tributaries

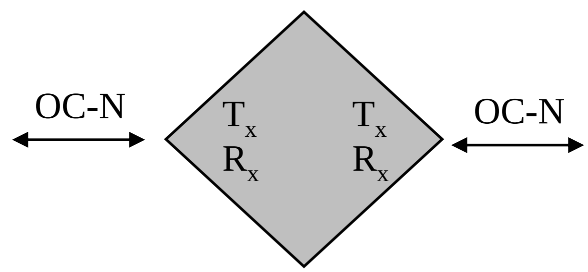
- II Path Terminating Element (PTE)
  - Simpler version of multiplexer path-terminating terminal
  - Multiplexes DS–1 channels, and generated the OC-N carrier
  - Two terminal multiplexers connected by a fiber are the simplest SONT topology (section, line, path on the same link)



SONET Network Elements: Regen

Regenerator

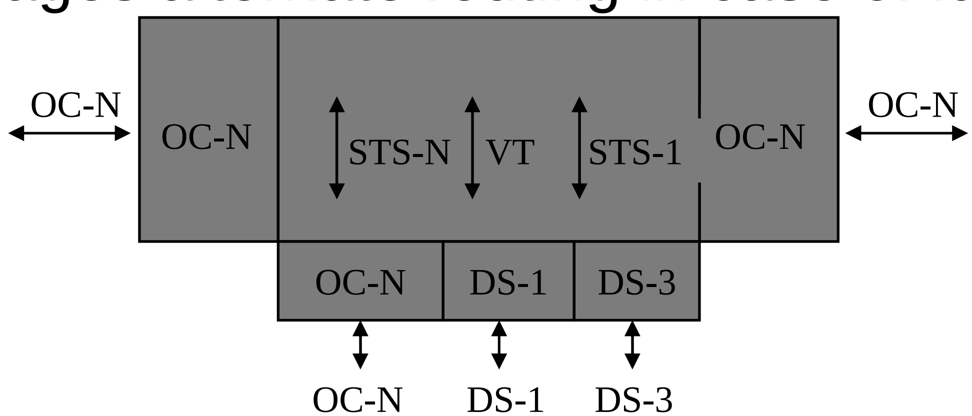
- Simplest SONET element. Perform 3R regeneration
- Allows to overcome distance limit at the physical layer
- Receives the input stream, and regenerates the section overhead before retransmitting the frame. Does not modify Line and Path overhead (behaves differently from an Ethernet repeater)



SONET Network Elements: ADM

Add-Drop multiplexer: multiplexing and routing over ring topologies

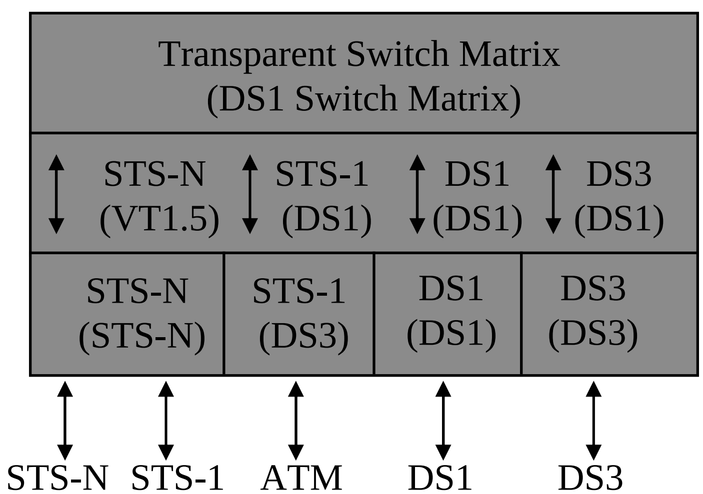
- Multiplexes different tributaries over a single OC–N
- The add/drop operation allows to elaborate, add/drop only signal that must be managed
- Transit traffic is forwarded without the need of particular operation.
- It manages alternate routing in case of fault



SONET Network Elements: DCS

Digital cross-connect: multiplexing in general meshed topology

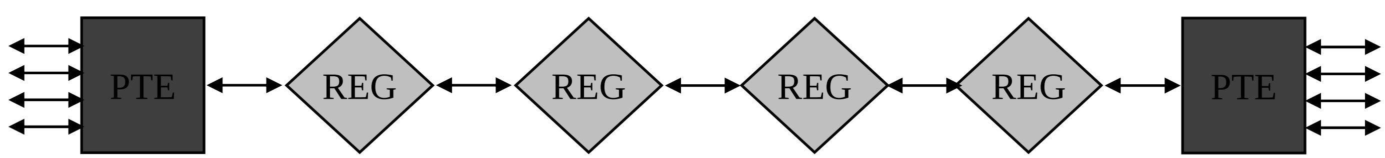
- Different line speed
- Works at the STS-1 granularity
- Used to interconnect several STS-1 inputs
- High-speed cross-connects are used to efficiently mux/demux several channels



SONET Network Configurations

Point-to-point topology

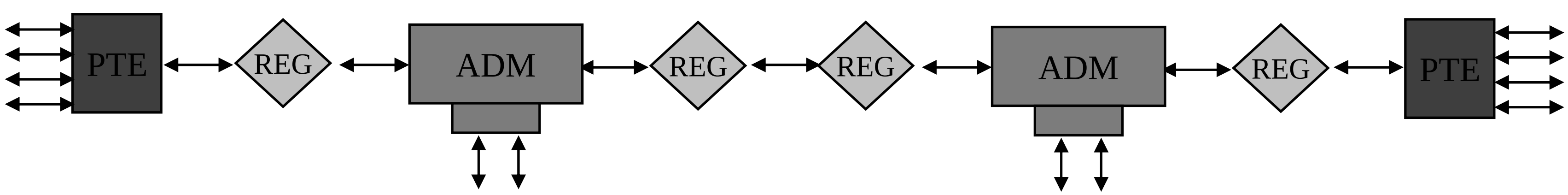
- Simplest topology
- The point-to-point start and end on a PTE, which manages the mux/demux of tributaries
- No routing, and no demux along the path
- Regenerators may be used to avoid transmission problems



SONET Network Configurations

Linear add-drop topology

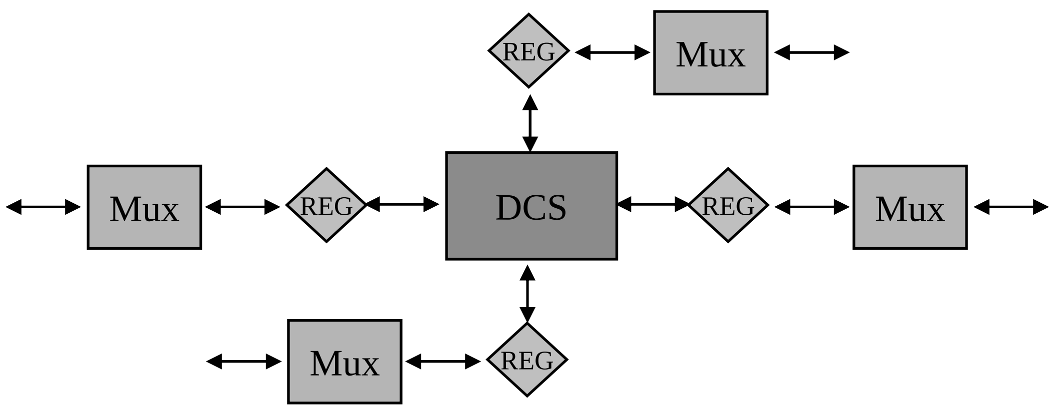
- Still al linear topology
- ADM (and regen) along the line
- ADM allow to add and drop tributaries along the path
- ADM are designed to work in this kind of topologies, which allows a simpler structure than a general cross-connect (there is no need to mux and remux in transit tributaries)



SONET Network Configurations

Hub network setup

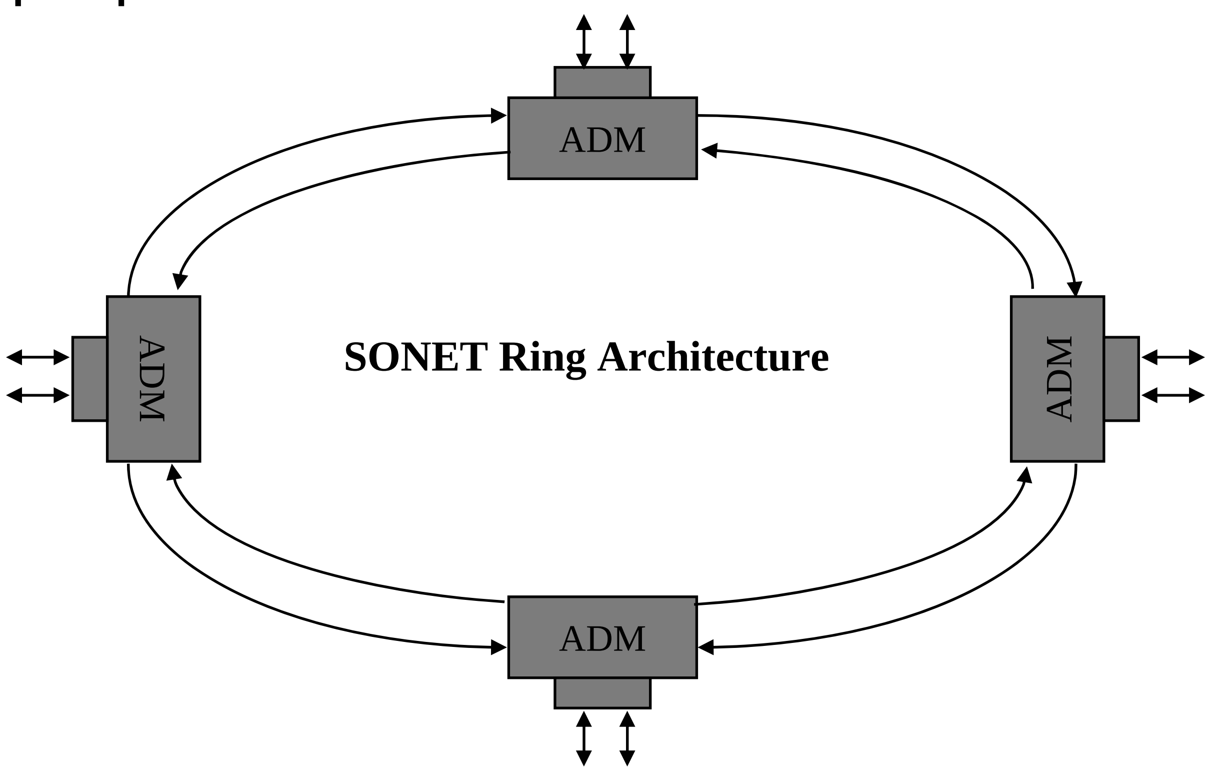
- Typically on big aggregation point
- Adopt Digital Cross connect (DCS) working at high rate
- DCSs are much more complex that ADMs: they have to manage both single tributary and SONET stream



SONET Network Configurations

SONET Rings

- The most used topology. Can use two or four fibers and an ADM at each node. Bidirectional topology
- Simple protection funcions



Survivability in SONET

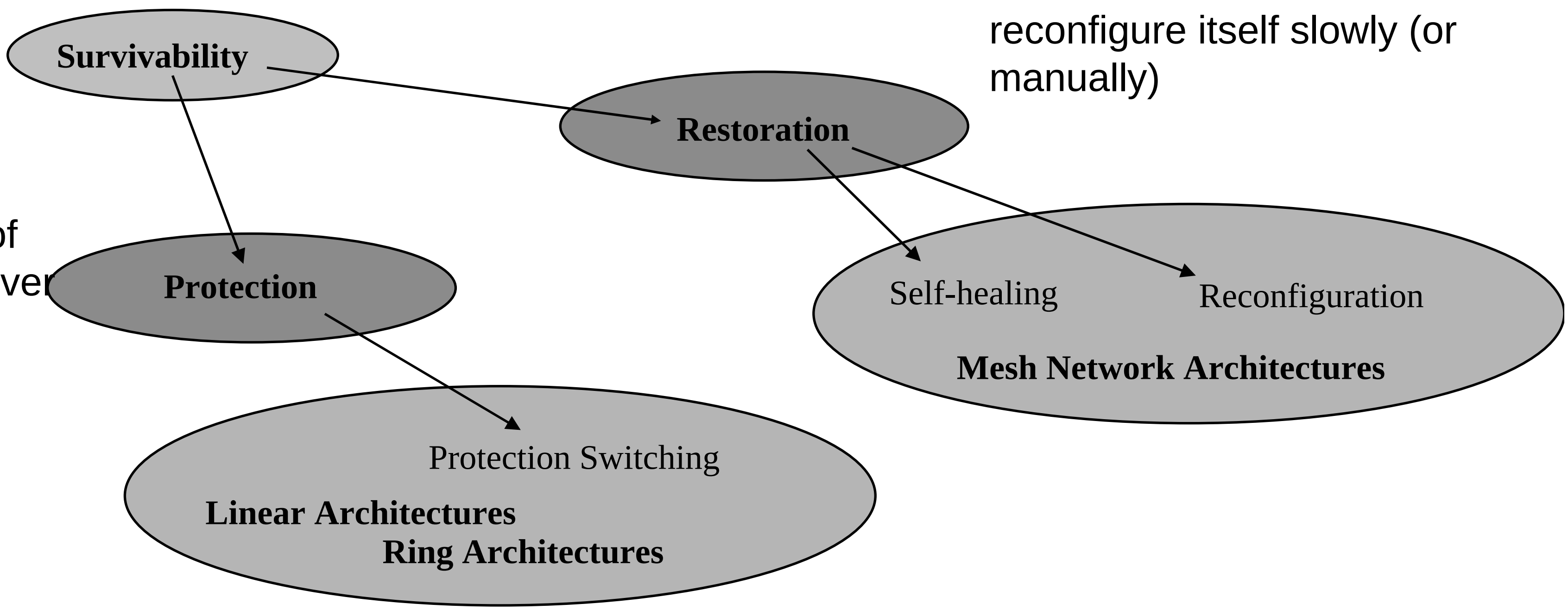
Network Survivability/Fault Management

Survivability: the network uses additional capacity to keep carrying all the traffic when a fault occurs

It’s a must on backbone networks

Restoration: typical of complex topologies in which find the network can reconfigure itself slowly (or manually)

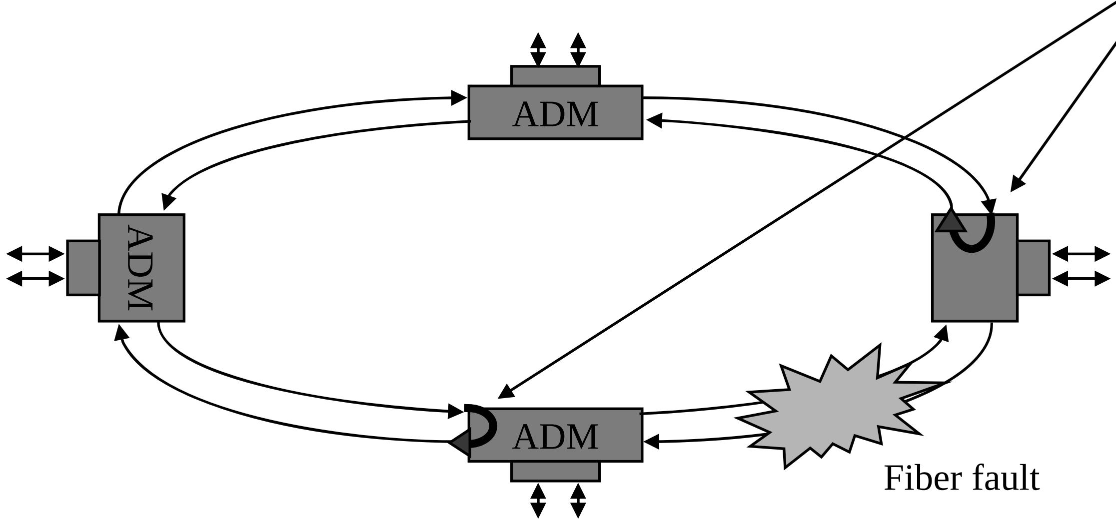
Protection: “Immediate” and automatic answer of the network to recover from fault



Survivability in SONET

SONET adopts several technique for Survivability, Protection and Restoration

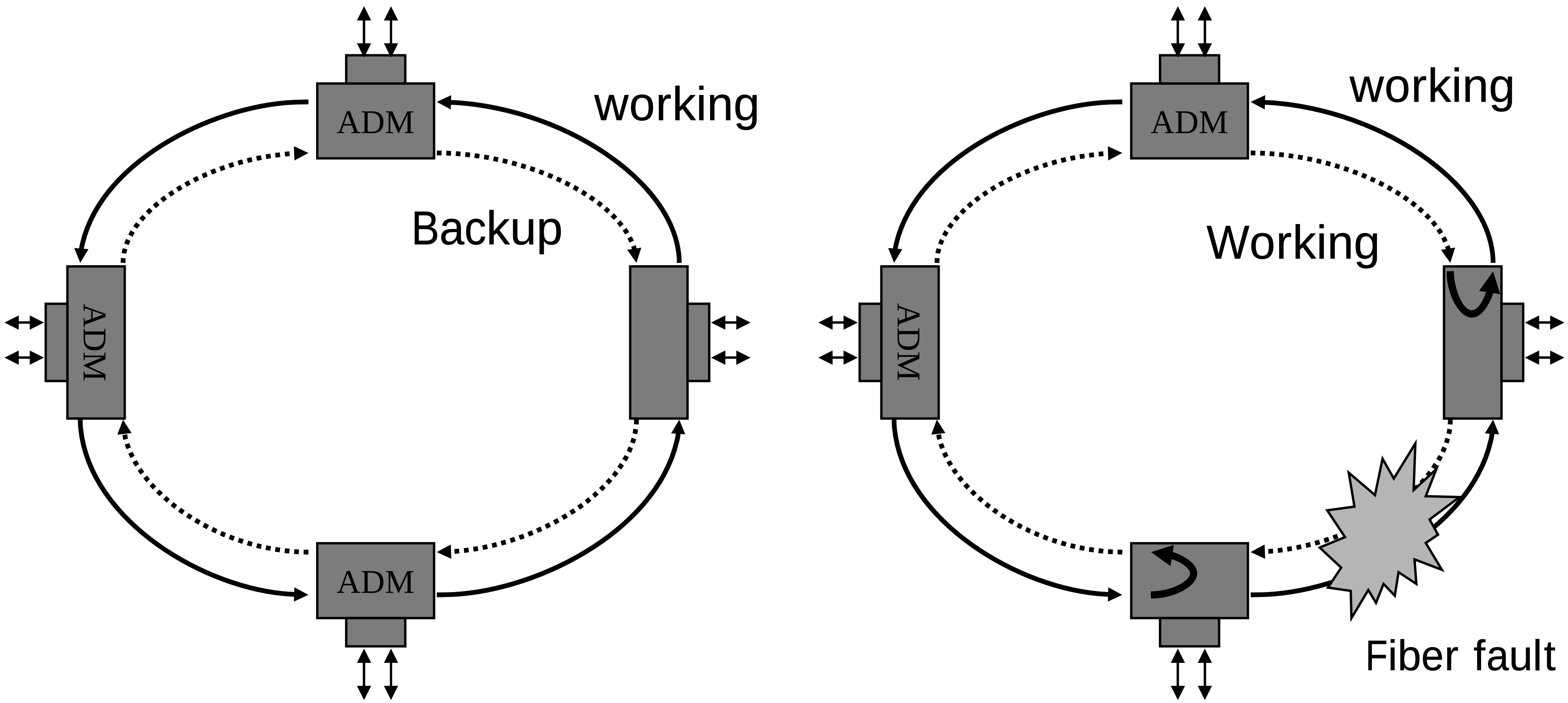
Typically, they are based on ring topologies that offer two alternating paths



Nodes close to the fiber fault create a loopback to reconfigure the ring

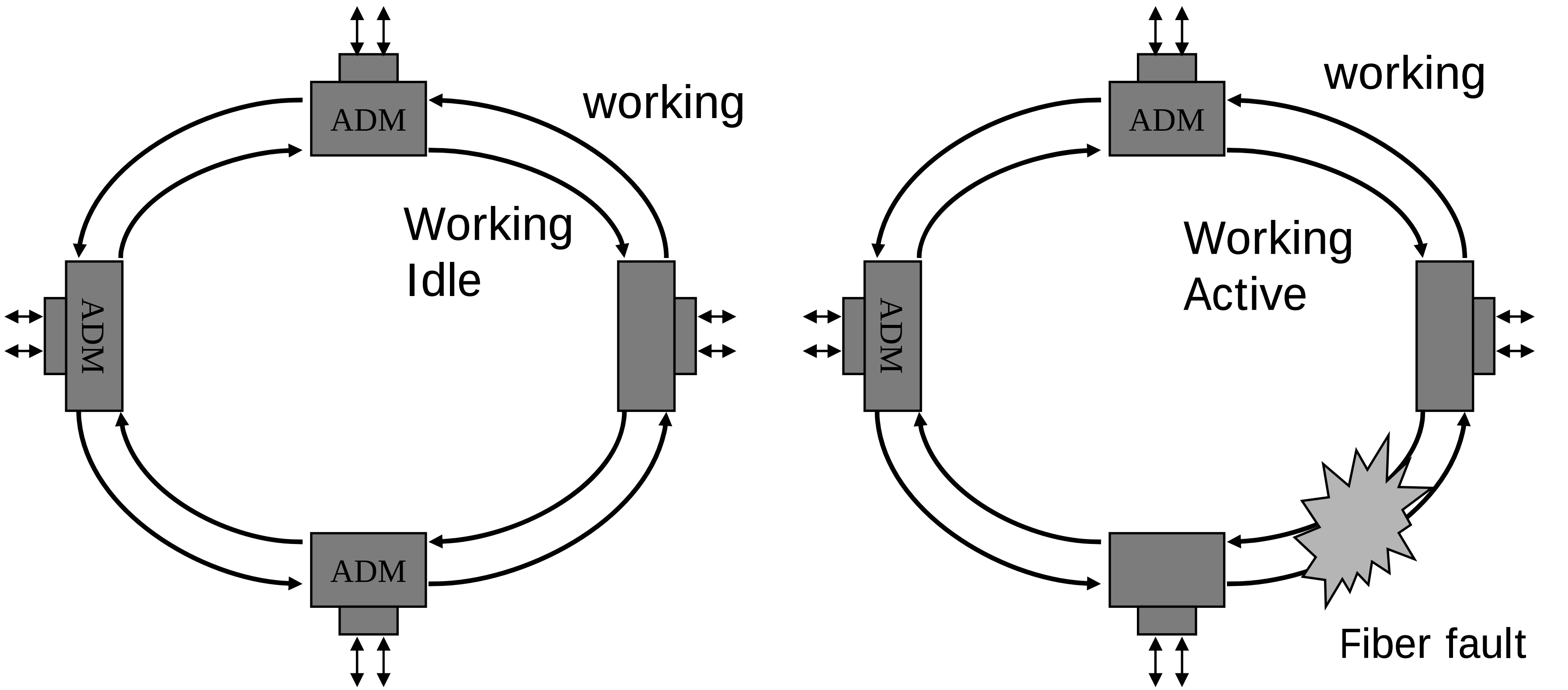
The topology after the reconfiguration is a monodirectional ring

1:1 protection

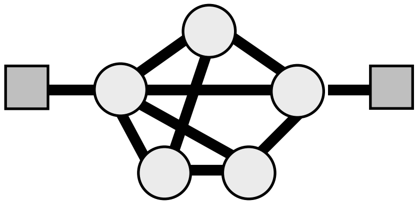


Only nodes close to the fault are involved in the protection

1+1 protection



Data is transmitted on both paths at the same time
Every ADM selects from which input to receive data



Protection and Restoration

Fault recovery is very quick:

- Less than 50ms

Restoration time

- In PDH was in the order of minutes
- In IP networks is takes several minutes
- In Ethernet LANs it takes tens of seconds (up to 60 seconds to reconfigure the spanning tree)