SONET : Synchronous Optical Network

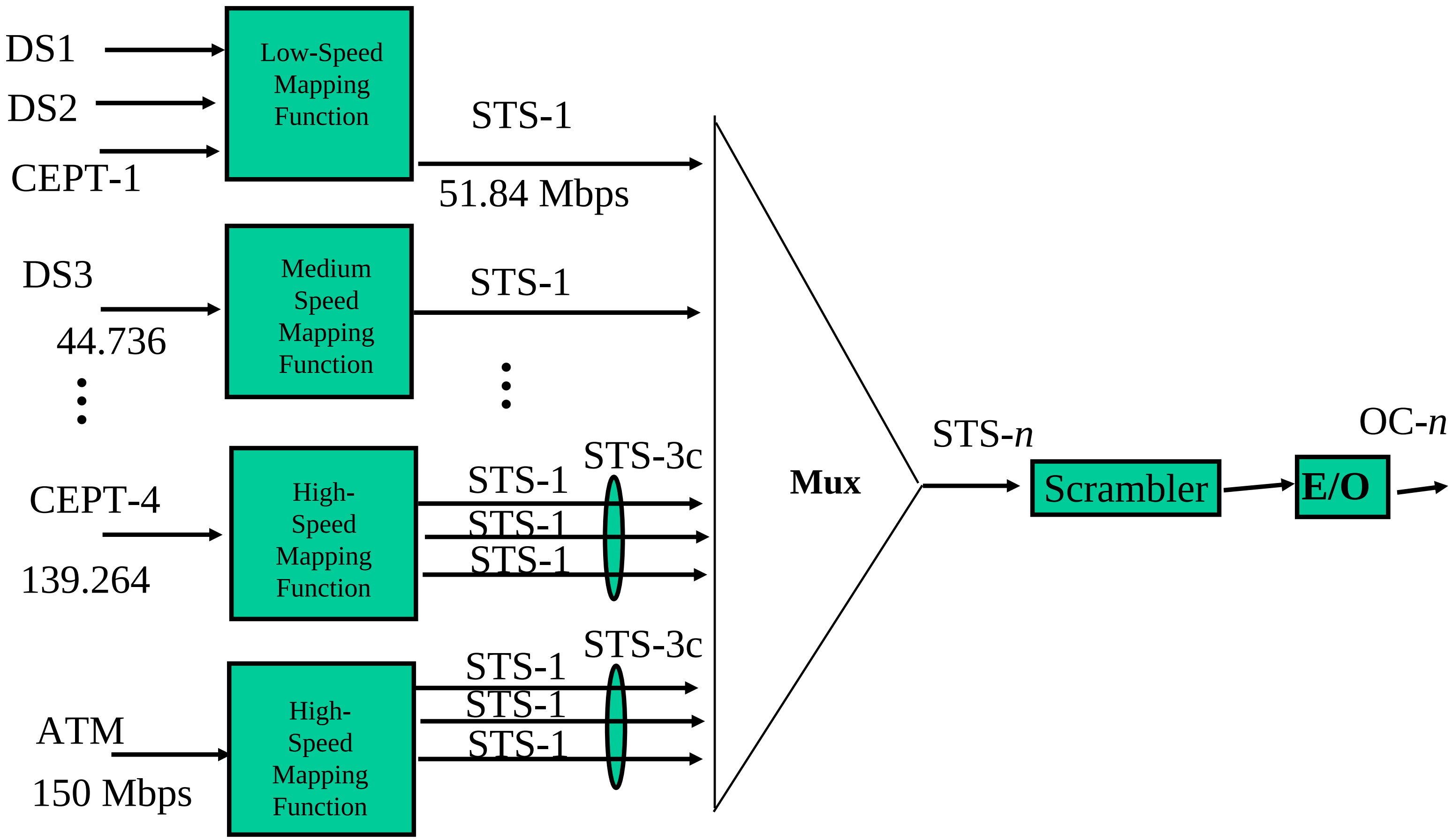
- US standard for optical telecomms transport
  - CCITT Synchronous Digital Hierarchy (SDH) the same standard worldwide
  - extensively used for long-distance backbones – 1000s of kilometres
  - replaced proprietary architectures, equipment, formats etc.
    - » telecomms carriers can mix and match equipment from different suppliers
  - overhead bytes as well as payload bytes to facilitate network management
    - » extensive capabilities for operations, administration and maintenance
    - » increased network reliability and the resilience of self-healing network topologies
  - interfaces for a variety of lower level signals e.g. DS-1 (≡T-1), ATM etc.
    - » provides considerable interconnect flexibility
  - a synchronous network
    - » all digital transitions throughout the network occur at exactly the same rate
    - » synchronised from a reference clock to better than 1 part in 10^{11}
    - » simplifies the interface to cross-connect switches and add-drop multiplexers

- Uses a 51.84 Mbps signal as its basic building block
  - – time-division multiplexes these basic signals into higher-speed signals
  - – STS-n : (Electrical) *Synchronous Transport Signal level n*
  - – OC-n : *Optical Channel level n*

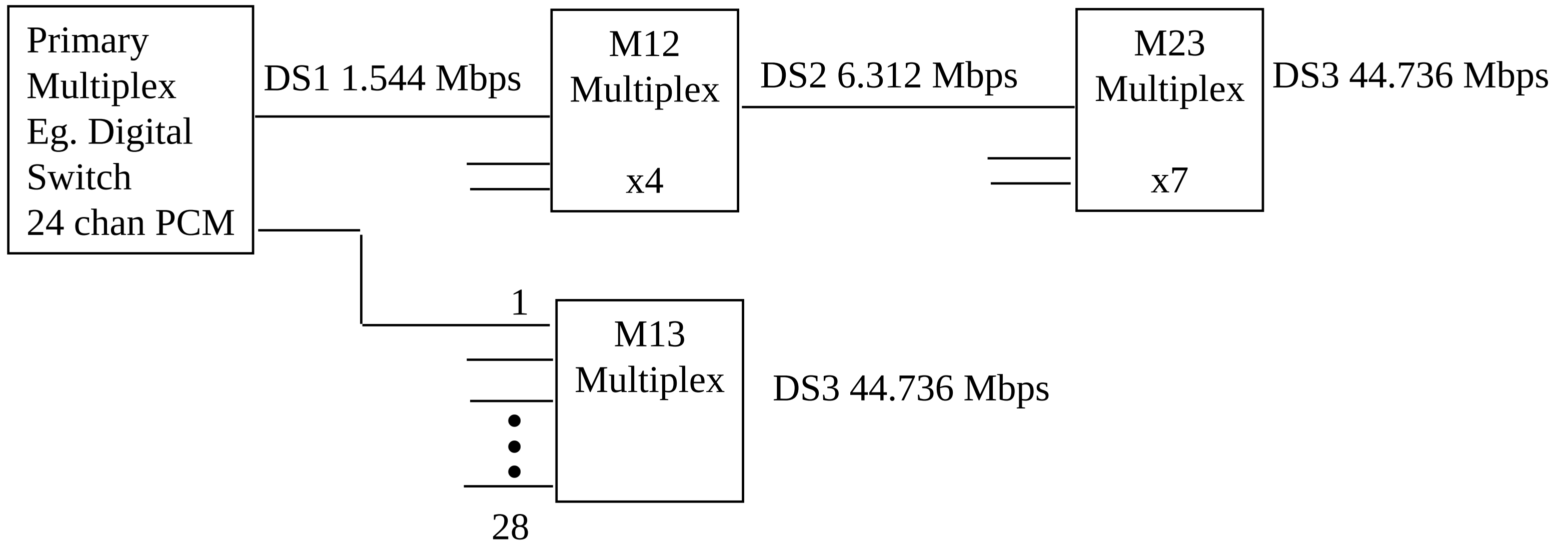
Electrical signal	Optical signal	Bit rate (Mbps)
STS-1	OC-1	51.84
STS-3	OC-3	155.52
STS-9	OC-9	466.56
STS-12	OC-12	622.08
STS-18	OC-18	933.12
STS-24	OC-24	1244.16
STS-36	OC-36	1866.24
STS-48	OC-48	2488.32
STS-192	OC-192	9953.28

  - – bit format of STS-n and OC-n is the same except for scrambling of the optical signal bits to aid timing recovery

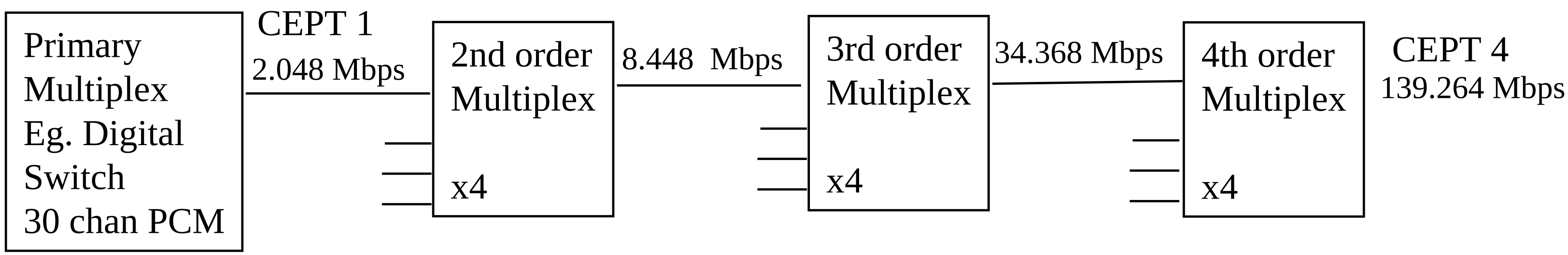
- SONET *tributaries* are the input streams multiplexed together



– the US hierarchy:

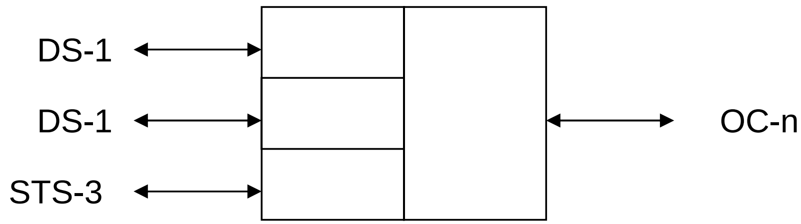


– the European hierarchy:

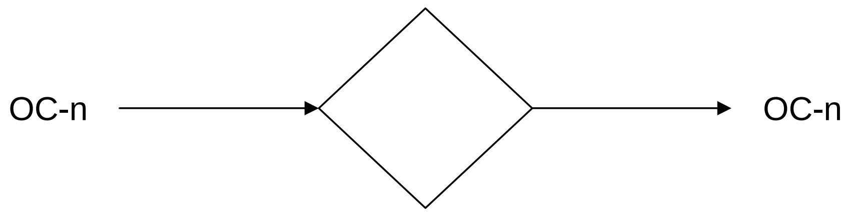


- tributaries such as DS-1 use free-running clocks
  - not synchronised with the higher-level network
  - accuracy specified as just 20 parts per million
  - *bit-stuffing* (adding extra bits) used to account for speed variations between streams when forming a DS-2 stream, and again to form a DS-3 stream etc.
- in SONET, average frequency of all clocks is either same or nearly the same
  - allows many synchronous STS-1 streams to be interleaved without stuffing
  - *pointers* accommodate minor differences in reference source frequencies
- network organised with a *master-slave* relationship
  - clocks of higher-level nodes feed timing signals to clocks of lower-level nodes
  - every clock can be traced back to a highly stable reference
    - a *Datum Inc. Stratum 1* caesium clock
  - less stable clocks adequate to support the lower nodes

- Network Elements:
  - – Path Terminating Element (PTE)
    - » a multiplexer concentrating DS-1 and other tributaries:



  - – Regenerator
    - » needed when signal level in the fibre becomes too low on long distance lines
    - » clocks itself off the received signal
    - » replaces section overhead bytes (*see later*) but leaves line and payload overhead bytes intact



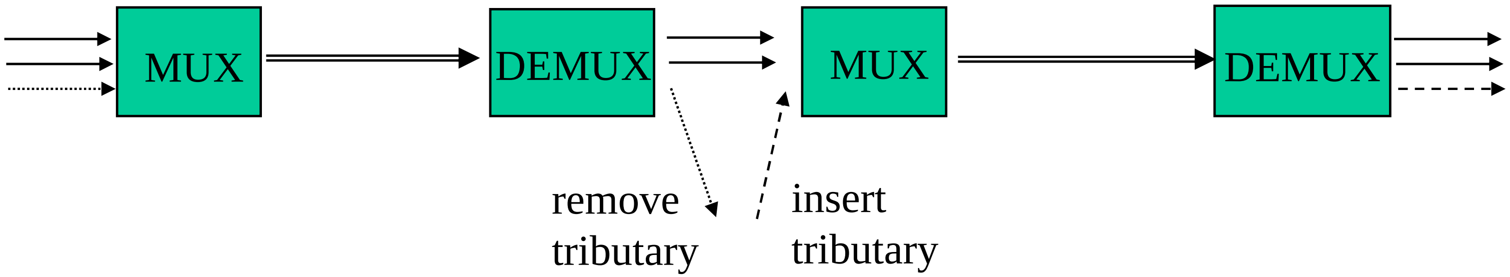
– Add-Drop Multiplexer (ADM)

» individual tributaries in the multiplexed stream can be dropped and added independently of other tributaries

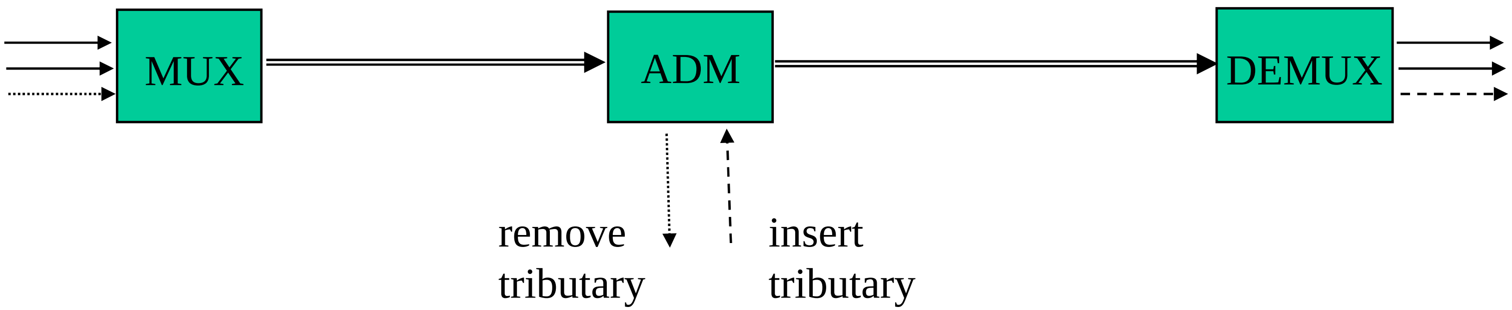
- different types provided by different manufacturers
- e.g. only add/drop DS-1 streams; add/drop both DS-1 and DS-3 streams etc.

» under *software* control

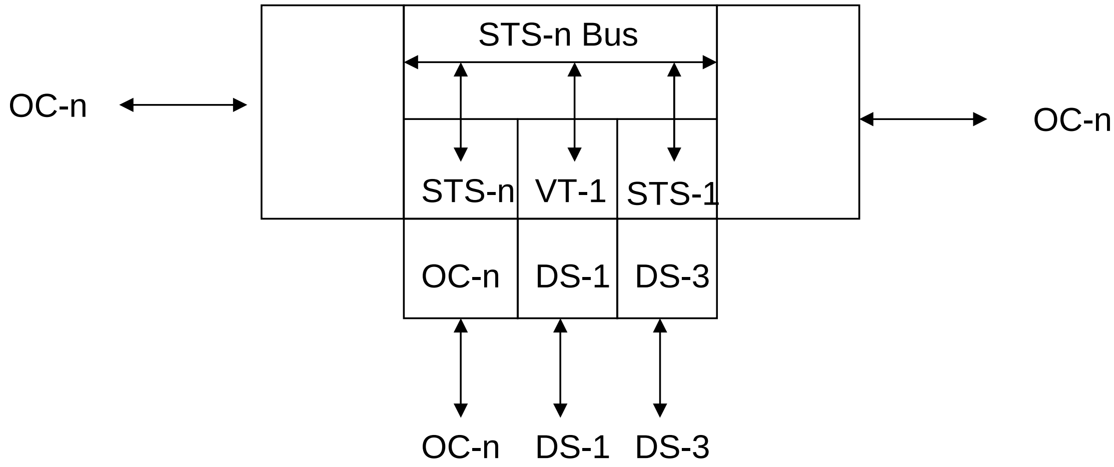
» earlier systems required multiplexed streams to be demultiplexed before a tributary could be removed or added:



» SONET ADMs allow this without demultiplexing and remultiplexing:



– both optical and electrical tributaries can be added and dropped:



– *drop and continue* also possible

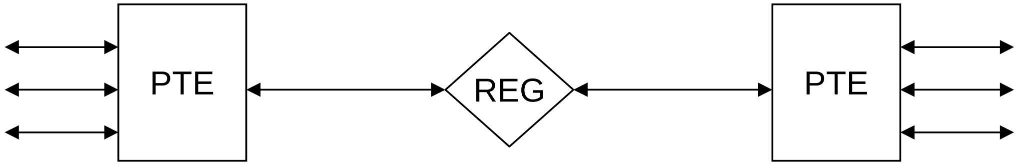
» signal terminates at one node, is duplicated and then also sent on to subsequent nodes

» a key capability in telephony and cable TV applications

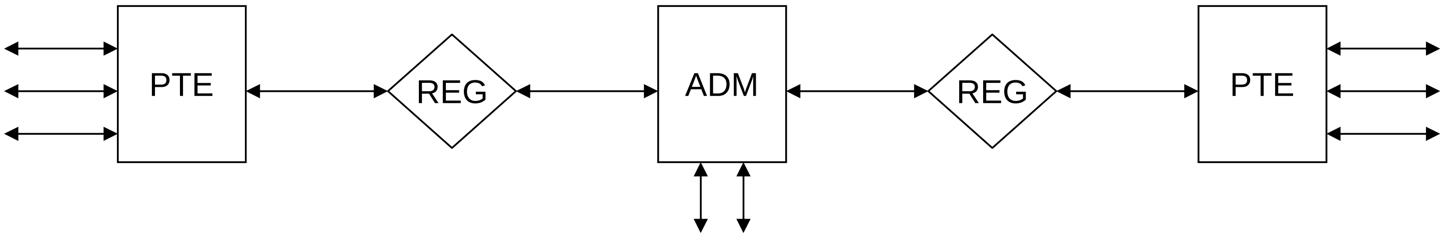
- Digital Cross-connect Switches (DCS)

– accepts various optical carrier rates, accesses the STS-1 signals and switches them between paths

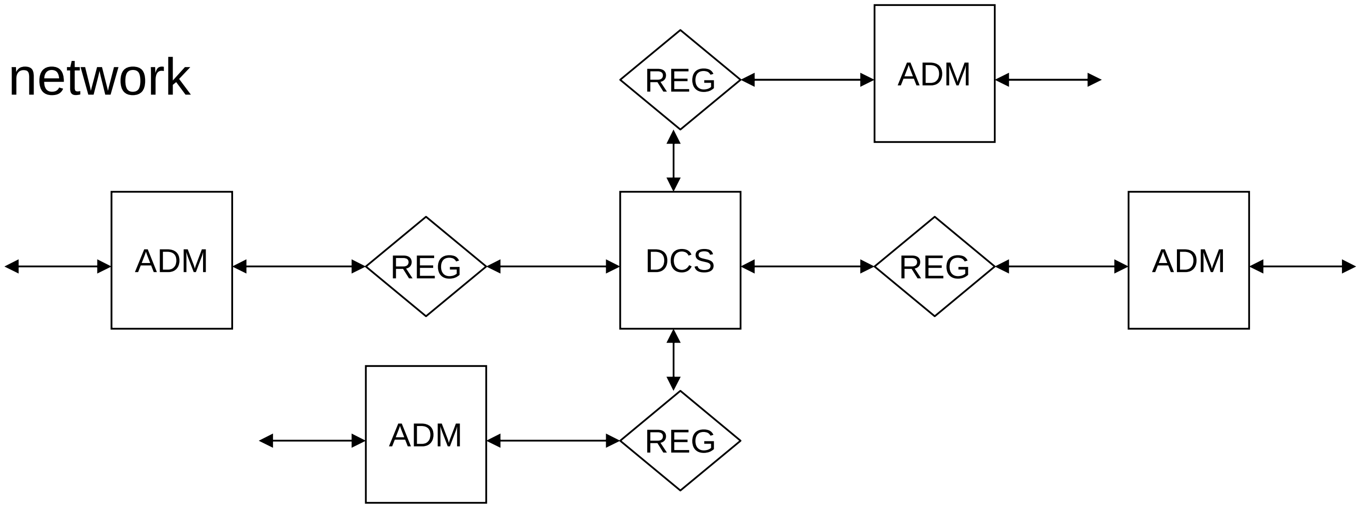
- Network Configurations:
  - Point-to-Point



  - Point-to-Multipoint

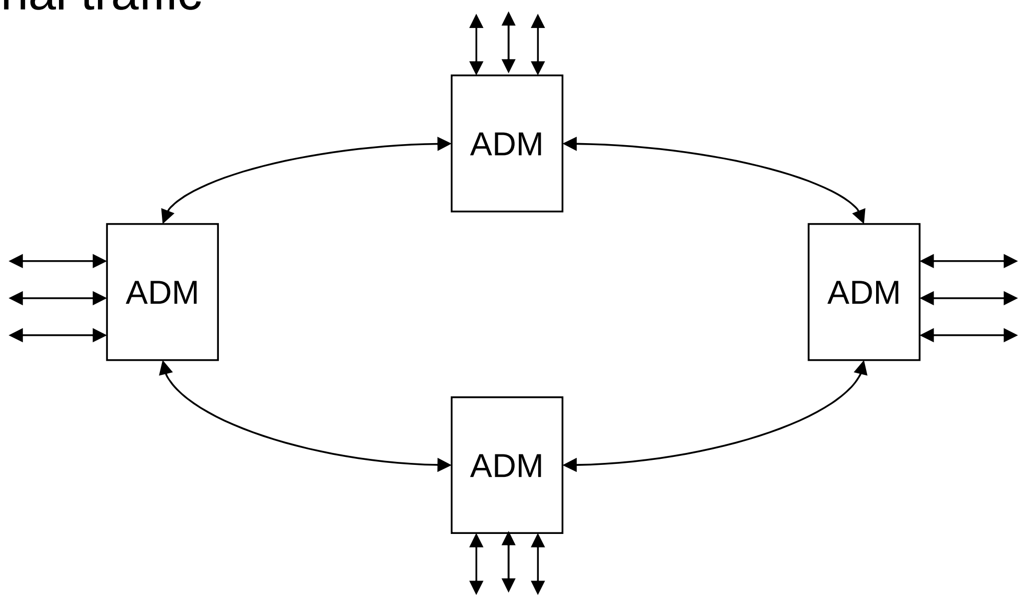


– Hub network



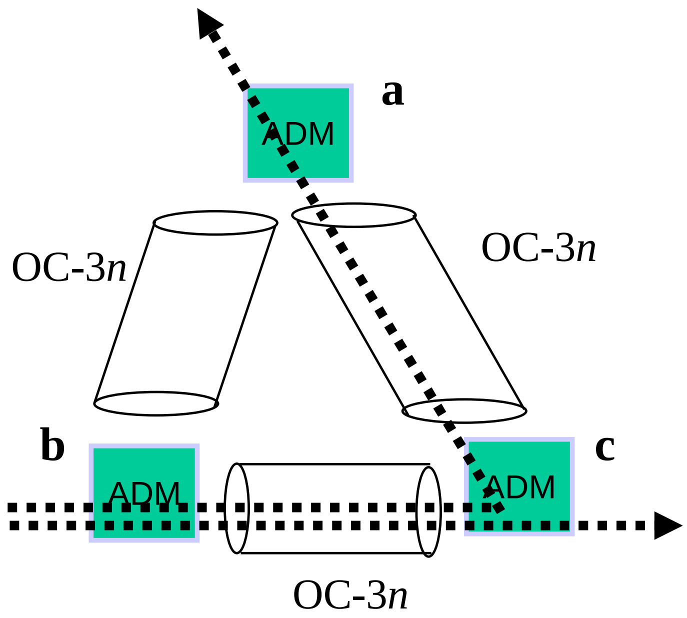
– Ring architecture

» multiple ADMs can be put into a ring configuration for either bidirectional or unidirectional traffic



– a ring of three unidirectional OC-3n ADMs

» carries three STS-n signals

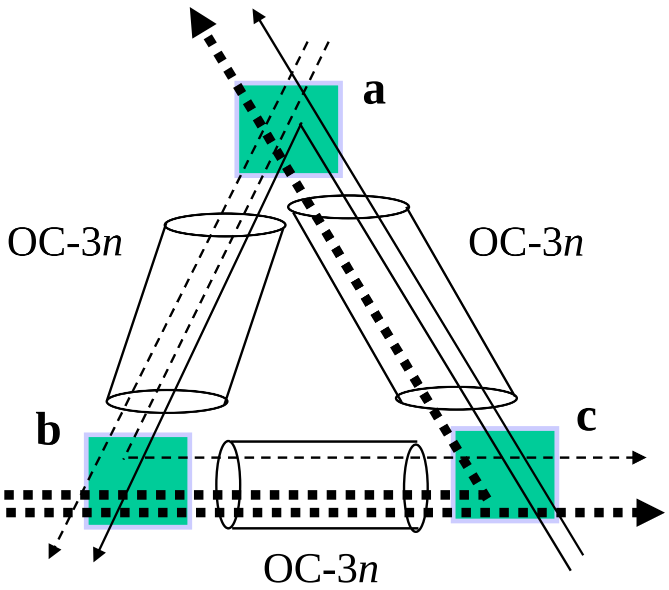


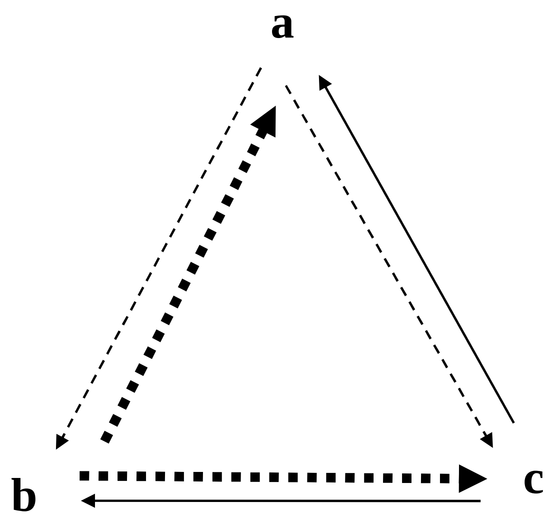
» at node b, two STS-n tributaries are inserted

- destined one for node c and one for node a

» first tributary terminates and emerges at node c

» second tributary flows across node c and terminates at node a





– all the nodes here drop two tributaries, add two tributaries and pass one through

» effectively a *fully-connected* topology

» since each pair directly connected by a tributary

» even though not physically connected

– this ability allows arbitrary *logical* connections through the use of tributaries added at source nodes and dropped at destination nodes

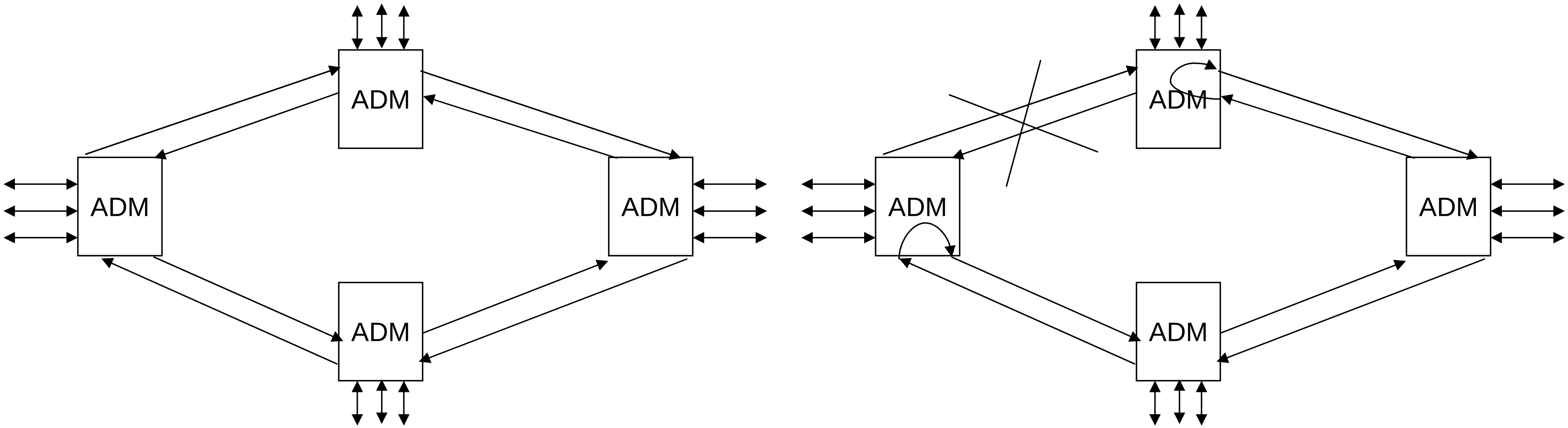
» dynamically controlled by software

– provides enormous flexibility in managing resources to meet user requirements

– main advantage of rings is *survivability*

» if a fibre is cut, ADMs have sufficient intelligence automatically to send services via an alternate path through the ring without interruption

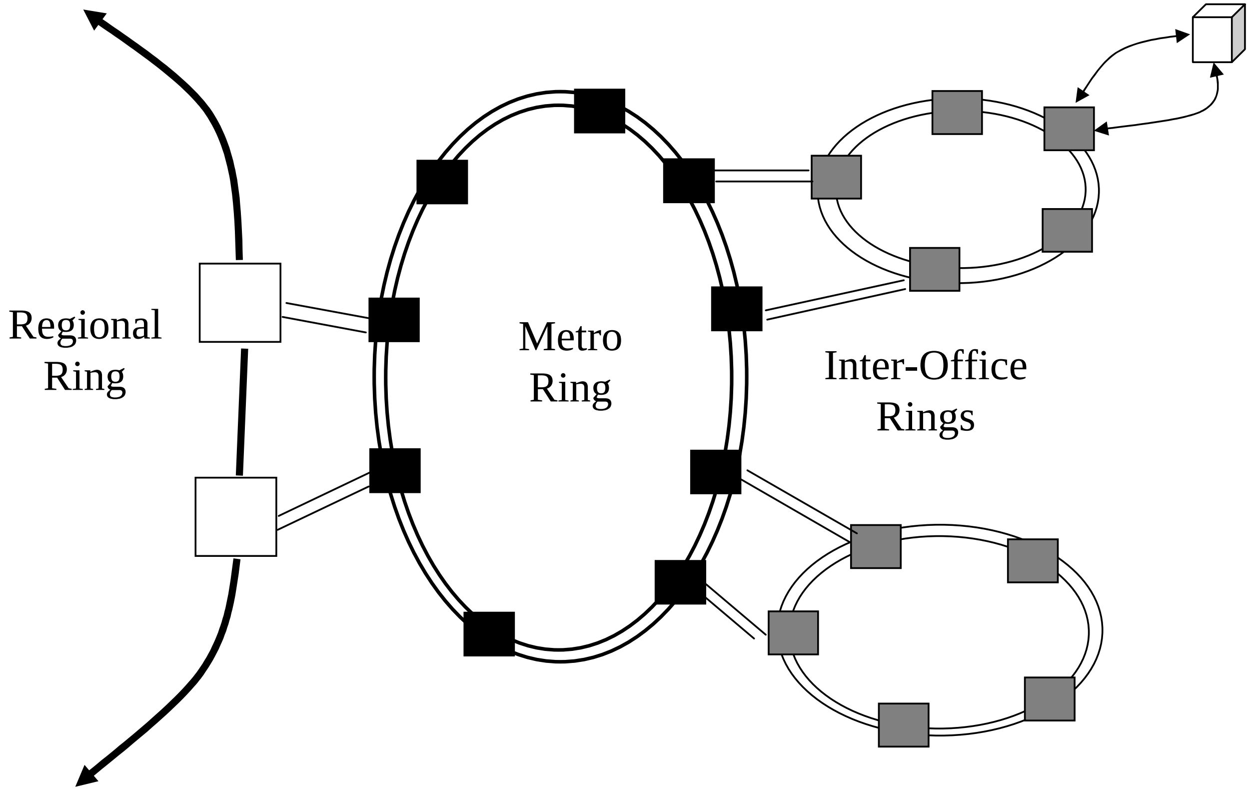
» typically within 50ms



» similarly if an ADM fails, traffic is redirected by the two adjacent nodes

- only traffic to the faulty node is discontinued

– the SONET architecture has largely changed the topology of long-distance and metropolitan point-to-point links to ring networks:

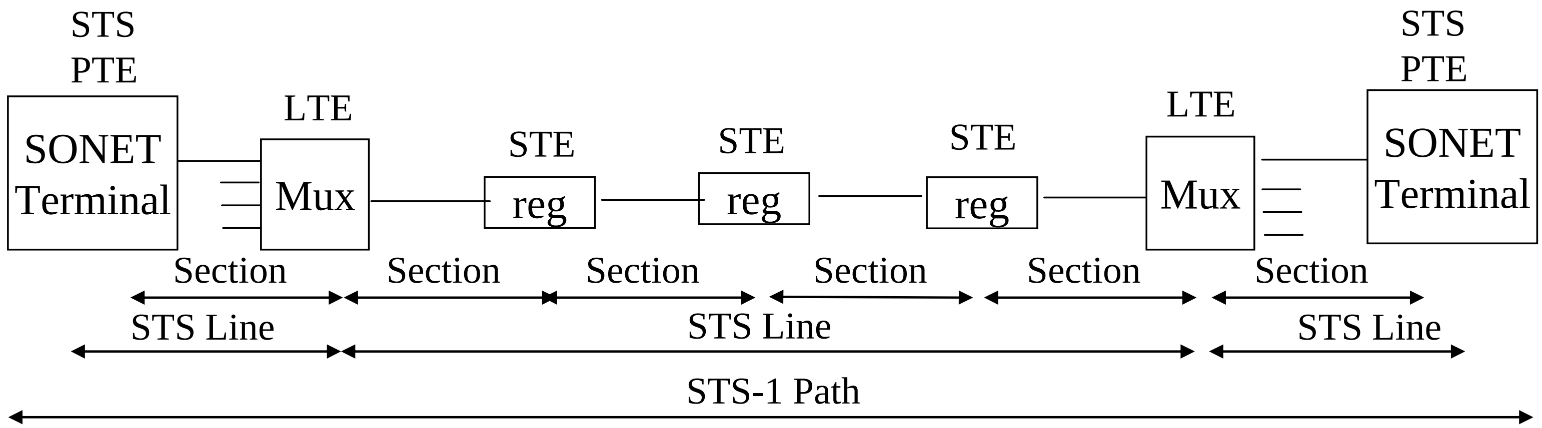


– a hierarchy of rings

  » dual ring interconnections for redundancy

    - traffic flows simultaneously in both links but only one flow used until failure

- The SONET network structure



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

– a *section* deals with transmission of STS-n signals across the physical medium
   » muxes and terminals incorporate Section Termination capability
– a line refers to the span between two adjacent multiplexers (ADMs or DCSs)
   » terminal equipment also terminates lines
– a path is the span between two terminals, encompassing one or more lines

– multiplexers associated with the path level work at a lower level of the STS-n hierarchy than the multiplexers at the line level

» a typical information flow along a path starts at the edge of the network at a flow rate e.g. STS-1

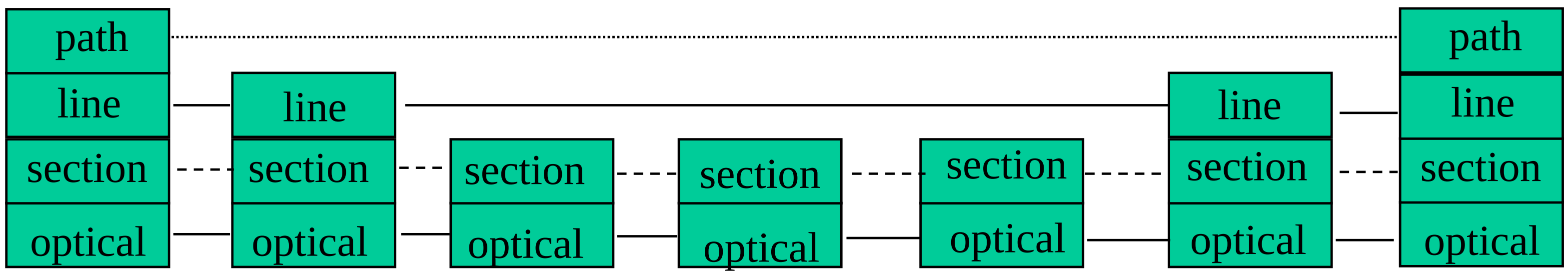
» this is then aggregated into higher flow rates within the network

» and is delivered at the end-point back at the lower flow rate

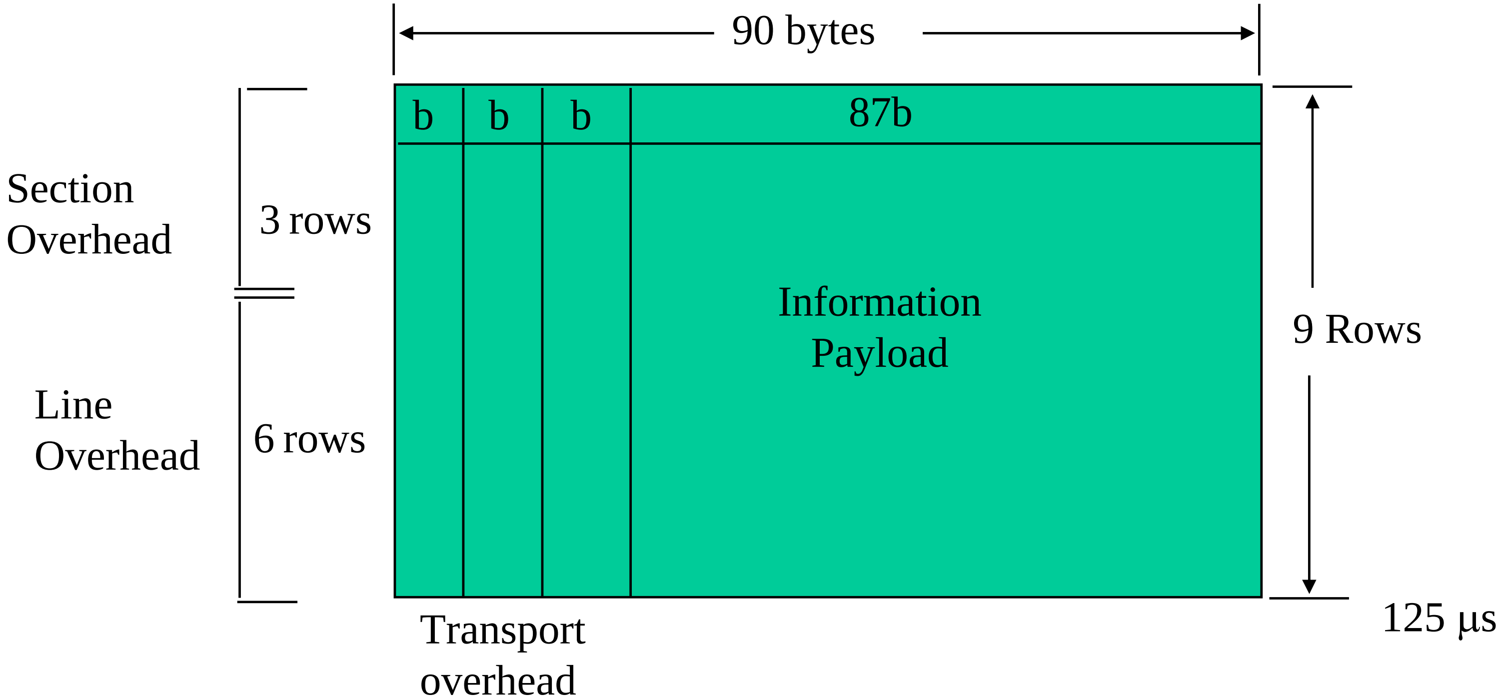
– each type of equipment works in both the electrical and optical domains

» converts from optical to electrical on reception

» converts from electrical to optical for onward transmission:



- the SONET STS-1 frame structure:
  - defined at the *line* level



  - a frame transmitted every 125µs i.e. 8000 times per sec
    - » 8000 x 90 x 9 x 8 = 51.84 Mbps
  - physically transmitted row by row, left to right
  - also a *Path Overhead* column in the information payload area

– section overhead (9 bytes):

» interpreted and modified at every section termination

» supports performance monitoring, framing, administration etc.

		1	2	3	
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			Path Overhead

» A1, A2 : framing bytes indicating beginning of an STS-1 frame

» B1 : parity byte over previous frame

» D1, D2, D3 : 3 bytes of a 192-kbps message channel between pieces of section-terminating equipment, used for administration & maintenance

» E1 : 1st byte of a voice channel for maintenance personnel (*orderwire* channel)

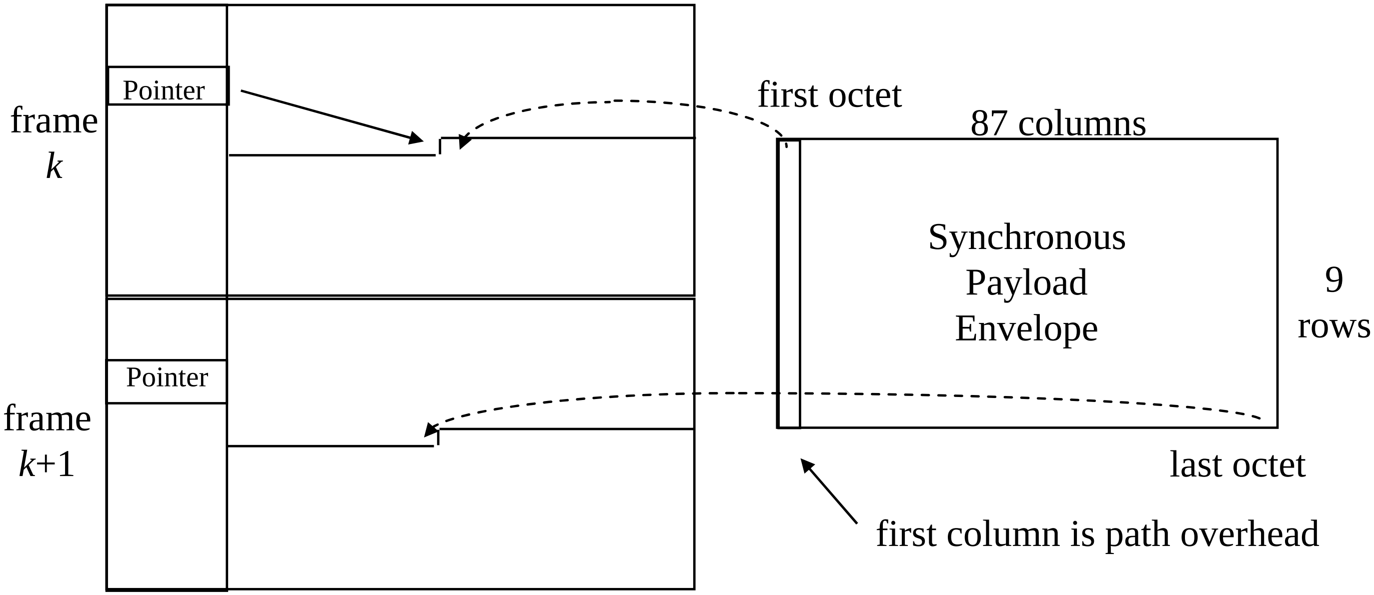
- line overhead bytes (18 bytes):
  - interpreted and modified at every line termination
  - provides status and performance monitoring
  - H1, H2 : payload pointer : locates payload within the frame
  - H3 : extra byte for frequency justification
  - B2 : parity byte for line overhead bytes of previous frame
  - K1, K2 : alarm indication and remote defect monitoring signals
  - E2 : 2^{nd} byte of orderwire channel
  - etc.
- path overhead bytes (9 bytes)
  - monitoring of payload envelope
  - J1 : path trace byte to verify continued connection to intended terminal
  - B3 : parity byte
  - G1 : path status byte conveys status info back from destination terminal
  - etc.
- IEC tutorial at : http://www.iec.org/online/tutorials/sonet/topic01.html

– the user data and path overhead are contained in the *synchronous payload envelope* (SPE)

– the SPE is *not* aligned with the STS-1 frame

» H1 & H2 bytes point to first byte of the SPE

» SPE overlaps two successive STS-1 frames in general



– pointer structure maintains synchronisation of frames and SPEs where their clock frequencies differ slightly

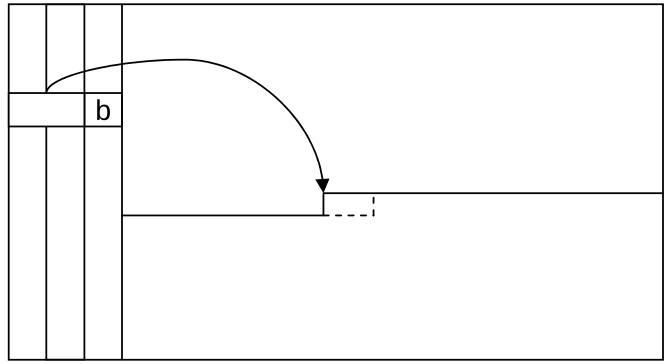
– when the payload stream is *faster* than the frame rate

» a buffer is required to hold payload bits as the frame falls behind

» the frame can catch up by transmitting an extra SPE byte in a frame every so often

- the extra byte is put in H3 of the line overhead area
- the pointer in H1 & H2 is moved up by one

» *negative stuffing*

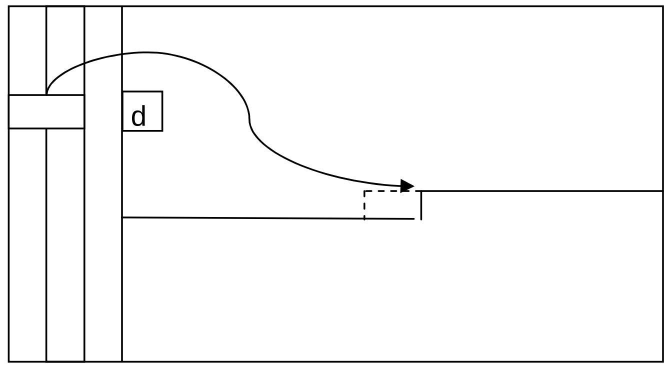


» when payload stream is slower than frame rate

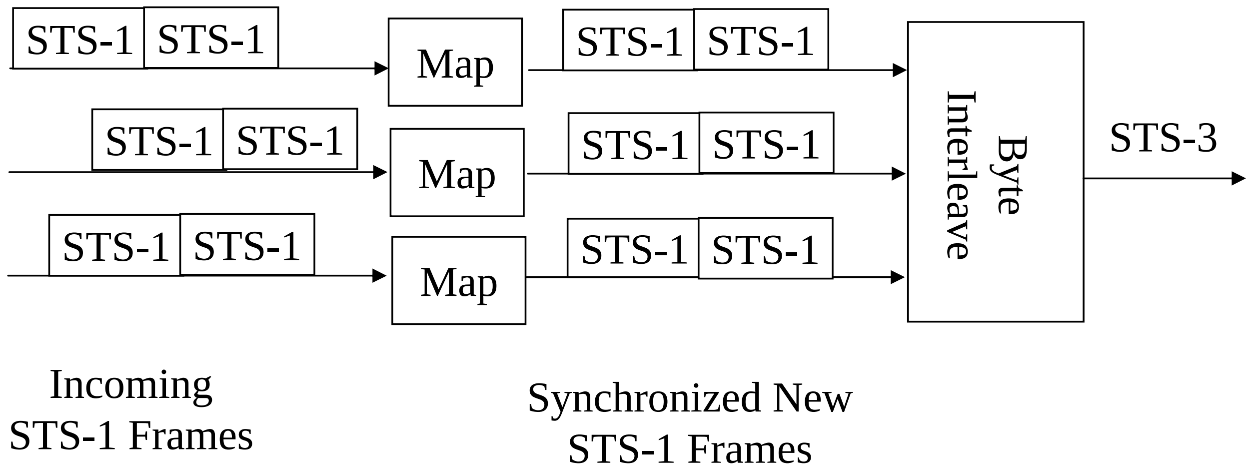
» a dummy byte inserted every so often

- pointer moved down by one

» *positive stuffing*



- Multiplexing STS-1 signals into an STS-n signal:
  - – byte-interleaved time-division multiplexing
  - – each STS-1 signal has to be synchronised to the local clock of the multiplexer
    - » section and line overhead of incoming STS-1 signal are terminated
    - » SPE payload remapped into a new STS-1 frame synchronised with local clock:
      - pointer in new STS-1 frame adjusted as necessary
      - the mapping done on the fly



  - – for n incoming STS-1 frames, interleaved one byte from each to produce an STS-n signal
  - – to multiplex k STS-n signals into an STS-kn signal, STS-n signal first de-interleaved into STS-1 signals and then re-interleaved

- Virtual tributaries
  - synchronous formats also defined at sub-STS-1 level
  - STS01 payload can be subdivided into *virtual* tributaries (VTs)
  - various rates are defined:

VT type	Bit rate (Mbps)	Size of VT
VT1.5	1.728	9 rows, 3 cols
VT2	2.304	9 rows, 4 cols
VT3	3.456	9 rows, 6 cols
VT6	6.912	9 rows, 12 cols

  - VT1.5 corresponds to the DS-1 rate, etc.
  - VTs are still visible at higher rates
    - » an individual VT containing a DS-1 can be extracted without demultiplexing the entire STS-1 frame
    - » improves switching and *grooming* performance (consolidating or segregating traffic for efficiency)

– an STS-1 SPE that is carrying VTs is divided into seven VT groups

» each group uses 12 columns of the SPE

- number of columns in each type are all factors of 12
- with two spare columns (*fixed stuff*)

» columns for each VT group are interleaved

» each VT group can contain several VTs but only of one VT type

- four VT1.5s, three VT2s, two VT3s, one VT6
- e.g. a VT group at the VT1.5 rate can carry four DS-1 signals

» columns for each VT sub-group are also further interleaved

- Frame *Concatenation*

– several STS-1 frames can be concatenated to accommodate signals with bit-rates faster than can be handled by a single STS-1

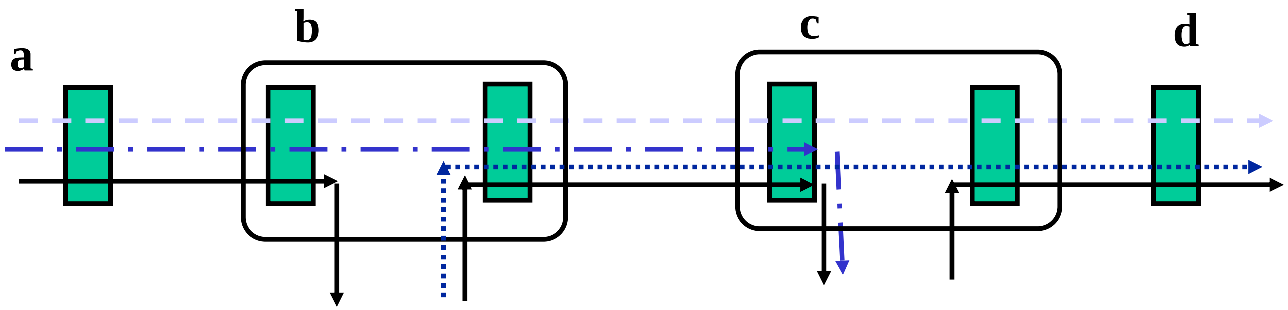
» e.g. a 139.264 Mbps CEPT-1 signal

» uses three STS-1 frames, designated STS-3c

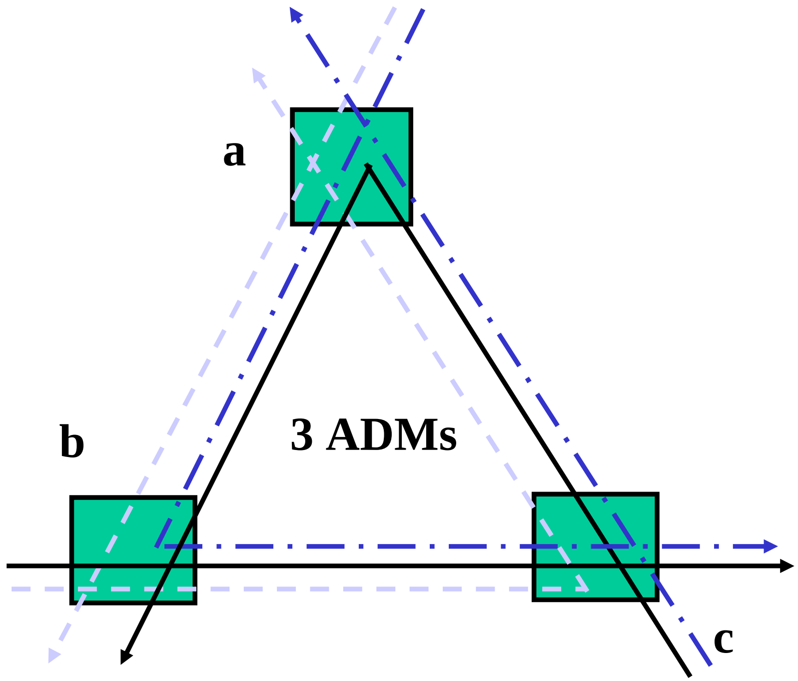
- concatenated frames only carry *one* path overhead column in total

– a mapping is defined for an STS-3c frame to carry a stream of ATM cells

- Optical Add-Drop multiplexers
  - multiple SONET or other optical streams can be multiplexed using DWDM



  - topologies similar to SONET can then be constructed:



- Optical Switches
  - arrays of micromirrors