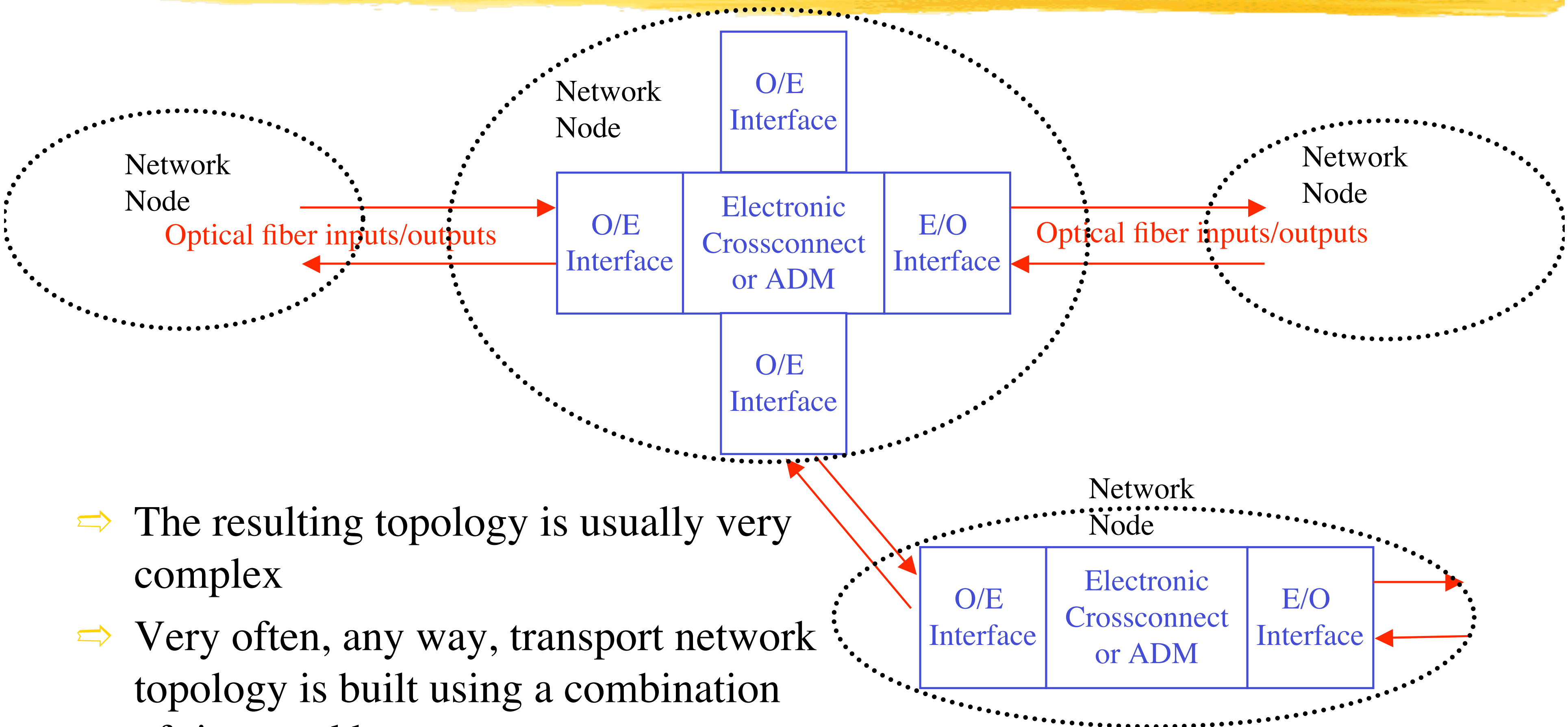
Lecture 2: First Generation Optic Networks

First Generation Optical Networks

- Fiber as transmission medium
  - The term "optical" refers to point-to-point transmission
- Switching and routing handled electronically
- Examples:
  - SONET/SDH
  - FDDI
  - Fiber Channel
  - ESCON, HIPPI
  - Gigabit Ethernet
  - Hybrid solution: coexistence on the same architecture of
    - Fiber and coaxial
    - Digital and analog formats

First Generation Optical Networks



- The resulting topology is usually very complex
- Very often, any way, transport network topology is built using a combination of rings and buses

SONET/SDH

- SONET: Synchronous Optical Network
  - Current transmission and multiplexing standard for North American carrier infrastructure.
- SDH: Synchronous Digital Hierarchy
  - Current transmission and multiplexing standard for Europe and Japan
- SONET and SDH first standardization dates back to the late 80s
- At that time, network carrier operators recognized that:
  - The previous PDH (Plesiocronous Digital Hierarchy) was not scalable enough for the expected traffic growth
  - Optical fiber transmission was getting a good level of reliability, and at that time started to show its huge potential
  - The available optical transmission systems were being developed in a totally proprietary manner, so that optical systems from different vendors could not interoperate
- Due to its pervasive use in transport networks, we will analyze SONET/SDH in detail

What is SONET/SDH

- It is a set of ITU-T Recommendations (first editions date back to 1989) that cover:
  - The definition of a very structured multiplexing hierarchy
  - The definition of network management and protection techniques
  - The definition of interfaces to the physical medium (fiber and optical components) to be used for transmission
  - The definition of interfaces with other protocols that can work over SONET/SDH
- Some of the most important targets of the standard are:
  - Network Reliability, compatible with national and international carrier requirements (99.999% availability)
  - Interoperability between different vendors
  - Format to accommodate different network architectures and upgrades
  - Extensive monitoring of performance and traffic

SONET/SDH

- The multiplexing hierarchy is the only fundamental difference between SONET and SDH
- SDH first level (STM-1) is 155 Mbit/s, while SONET first level (OC-1) is 51.8 Mbit/s

SONET	SDH	Optical Carrier	Line Rate (Mbps)	Capacity in DS1s
STS-1		OC-1	51.840	28
STS-3	STM-1	OC-3	155.520	84
STS-12	STM-4	OC-12	622.080	336
STS-48	STM-16	OC-48	2488.320	1344
STS-192	STM-64	OC-192	9953.280	5376
STS-768	STM-256	OC-768	39813.120	21504

Legacy Non-Synchronous Hierarchy definitions:

DSO = 64 kb/s (phone call)
DS1 = 1.544 Mb/s = 24 DS0s

SONET OC-*n* is thus a transmission at a bit rate equal to *n* times 51.84 Mbit/s

U.S. Long Haul SONET Deployment

Service Provider	1998 Deployment	March/99 Channels Lit	1999 Deployment	Transport Strategy
GTE	16 x OC192 Nortel		32 x OC192 Nortel	4F BLSR Rings
Qwest	16 x OC192 Nortel		32 x OC192 Nortel	4F BLSR Rings
IXC	16 x OC192 Nortel		32 x OC192 Nortel OC48/192 Transponder ALA/Ciena	4F BLSR Rings Linear Express Routes
Williams	16 x OC192 Nortel		32 x OC192 Nortel OC48 Sycamore SONET Switch	Linear Spurs Mesh Core
MCI	8 x OC192 Nortel		16 x OC192 Nortel	BLSR Rings
Worldcom	16 x OC192 Nortel		32 x OC192 Nortel 40 x OC48 Ciena	BLSR Rings
Frontier	16 x OC48 NEC	10/16	16 x OC48 NEC 32 x OC48/192 Pirelli OC192 SONET Hitachi	4F BLSR Rings
Sprint	16 x OC48 Ciena OC48 BLSR NEC	10/16 20/40	40 x OC48 Ciena	2F/4F BLSR Rings
AT&T	8 x OC48 Lucent		40 x OC48 Lucent OC192 NEC	4F BLSR Rings
Level 3	Lease OC12 fromFrontier			
Enron	Ciena 4000	2/96	Ciena 4000	Linear

Source: BancBoston Robertson Stephens www page

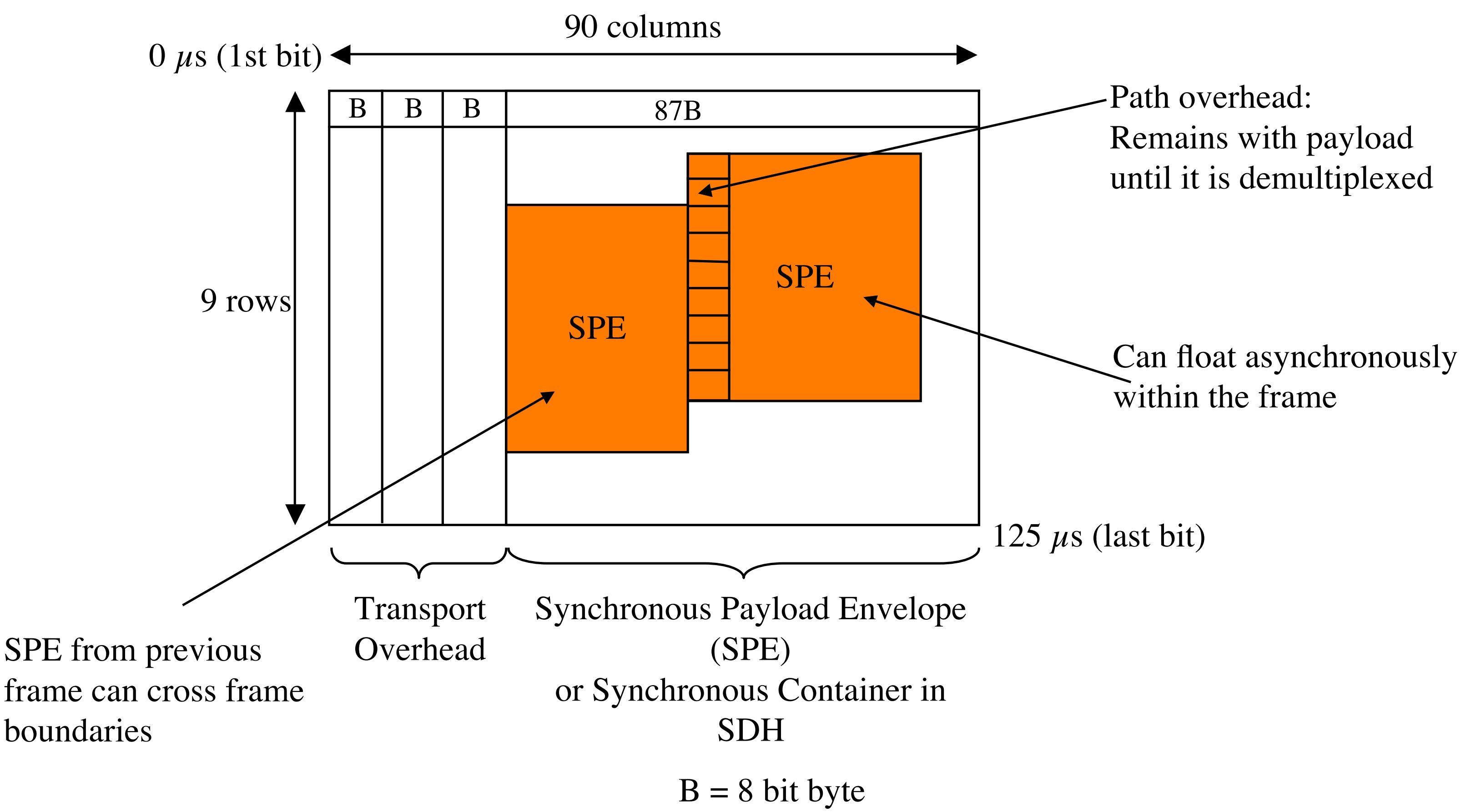
SONET/SDH Framing

- SONET/SDH transmits continuous streams of bit, at a given bit rate
- Multiplexing is obtained by a complex time division multiplexing (TDM) scheme
  - Though complex, the multiplexing architecture was developed having in mind a potentially efficient implementation in VLSI electronic circuits
- A frame is an organized sequence of bits
  - For a given multiplexing layer, each input tributary stream of bits is mapped into a Synchronous Payload Envelope (SPE)
  - A set of bits, called Path Overhead is added to the SPE, for control, monitor, etc.
  - SPE+its Path Overhead form a Virtual Tributary (VT)
- SDH uses a different terminology, but the principles are identical
  - We use in the following the SONET definitions

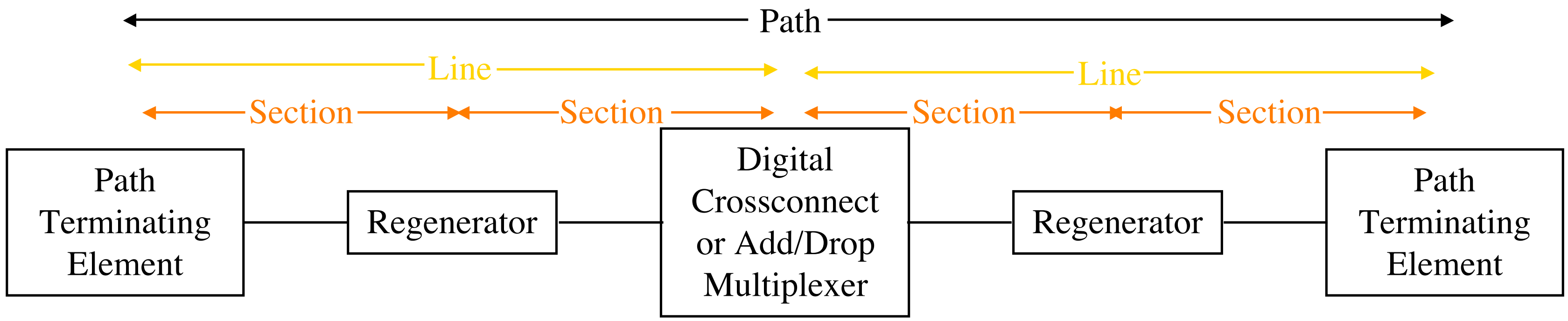
SONET/SDH layering

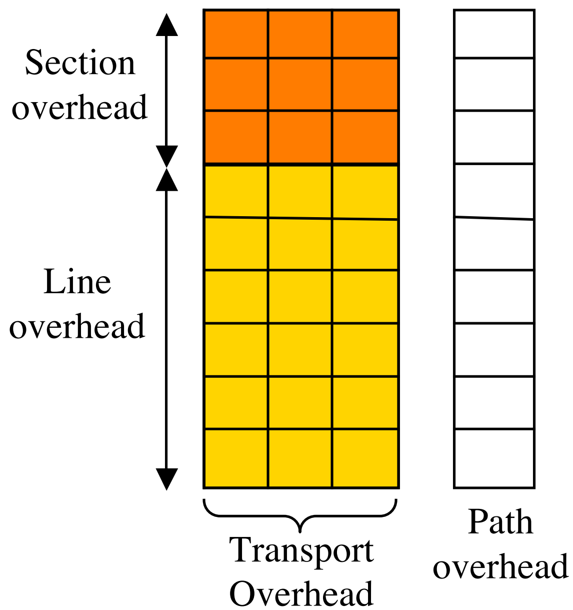
- Path layer (similar to OSI Layer 3 Network)
  - Responsible for End-to-end connections
  - Monitor and tracking the status of the connection
- Line Layer
  - Multiplexing of several path-layer connections between two nodes
  - Protection and restoration
- Section Layer
  - Defines the operation of regenerators, and between regenerators, along the link
  - Together, SONET Line and Section layers corresponds to OSI Layer 2 Data Link
- Physical layer (identical to OSI Layer 1)
  - Defines the actual transmission of bits across fibers

STS-1 Frame Format and Structure



SONET Overheads





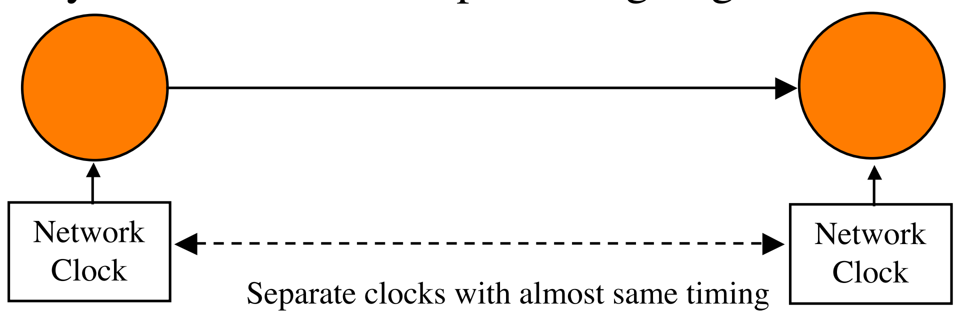
- Section Overhead: Accessed, processed and generated by STE
  - Performance monitoring (STS-N)
  - Data communications channel for OAM&P
  - Framing
- Line Overhead: Accessed, processed and generated by LTE
  - Locating SPE within a frame
  - Multiplexing
  - Performance monitoring
  - Protection switching
  - Line maintenance
- STS Path Overhead: Accessed, processed and generated by PTE
  - Performance monitoring of STS or VT SPEs
  - The content of the STS or VT SPEs
  - Path status and path trace

SONET Overheads

- Section Overhead:
  - Accessed, processed and generated by Section Terminal Equipments (STE)
  - Performance monitoring on the frame
  - Data communications channel for operation, administration and maintenance (OAM)
  - Framing
- Line Overhead:
  - Accessed, processed and generated by Line Terminal Equipment (LTE)
  - Locating VT within a frame
  - Multiplexing/routing
  - Performance monitoring
  - Protection switching
  - Line maintenance
- STS Path Overhead:
  - Accessed, processed and generated by Path terminal Equipment (PTE)
  - End-to-end performance monitoring of VT SPEs
  - Path status and path trace

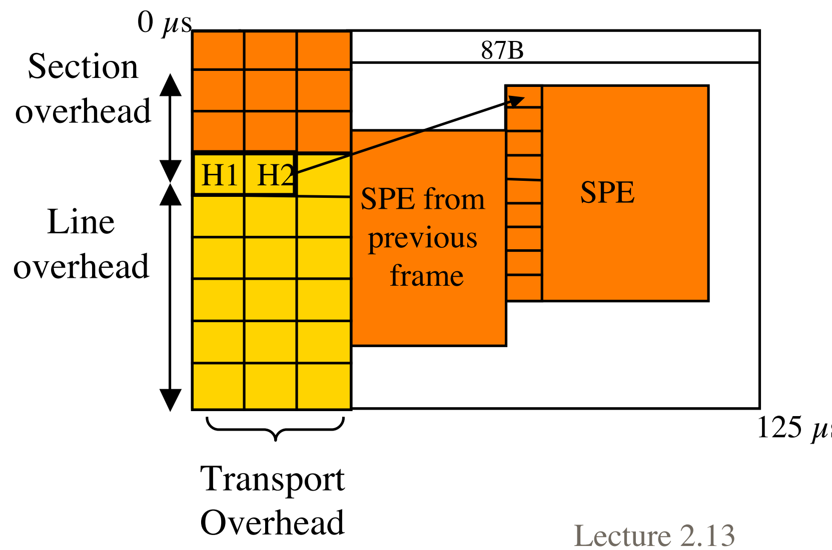
SONET Pointers

- Pointers are used to compensate for frequency and phase variations
- Pointers allow dynamic and flexible phase aligning of STS and VT payloads



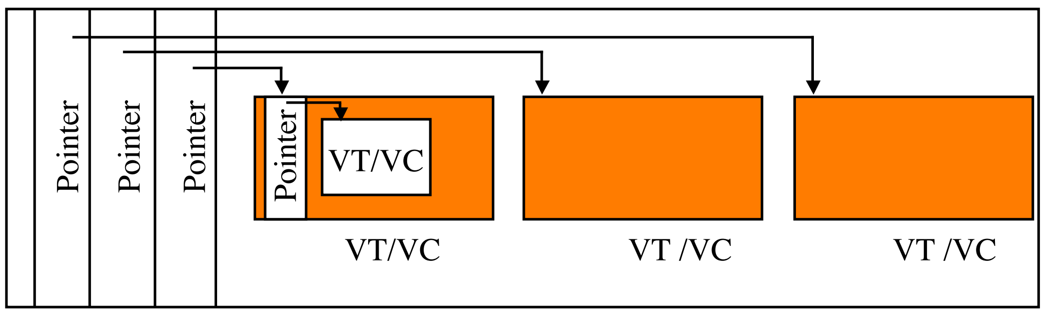
Bit Stuffing for Synchronization

- When the frame rate of the SPE is too slow relative to STS-1
  - An extra byte is stuffed for a "one-byte" delay
- When the frame rate of the SPE is too fast relative to STS-1
  - An extra byte is removed and place in the overhead capacity

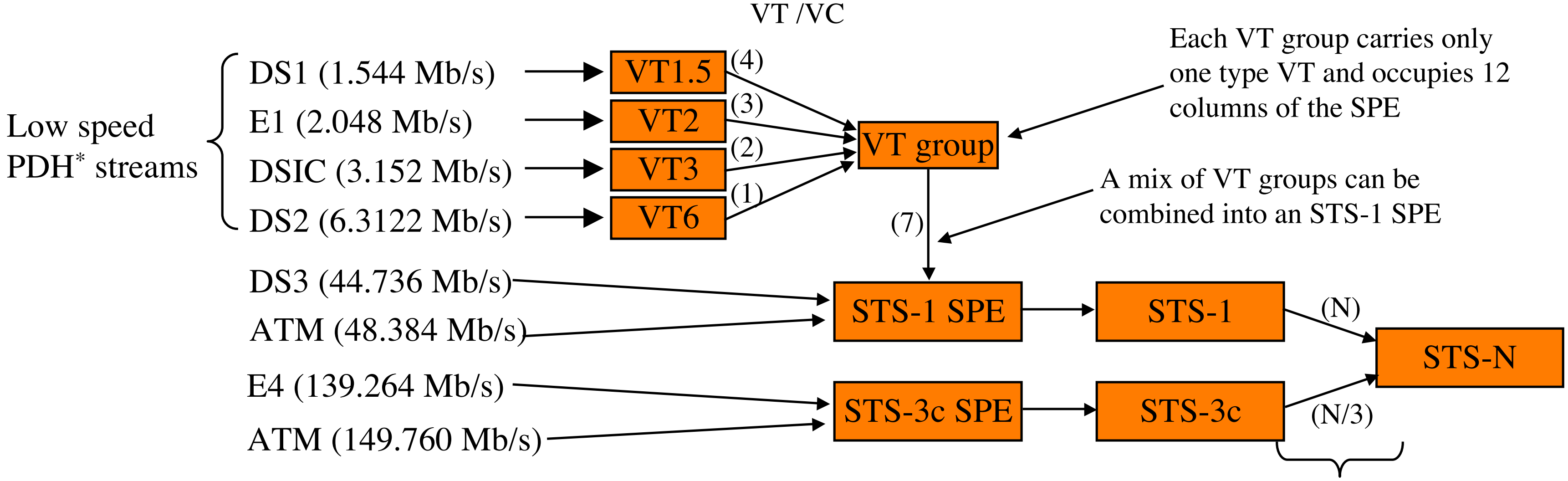


Virtual Tributary (VT)/Virtual Container (VC)

Multiplexing by VT/VCs makes it easier to extract low bit rate data from a high bit rate channel



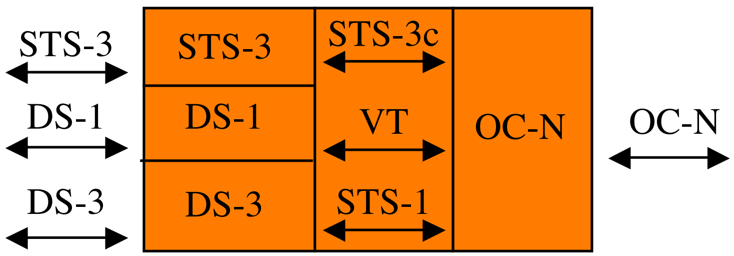
VT /VC



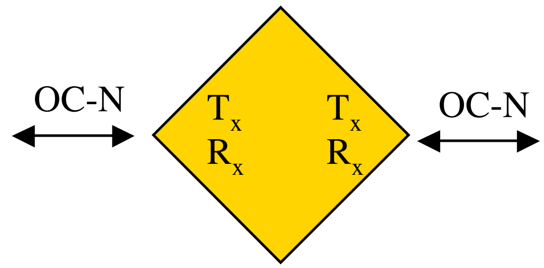
(*PDH: Plesiochronous Digital Hierarchy; DS is North American; E is European)

SONET Network Elements

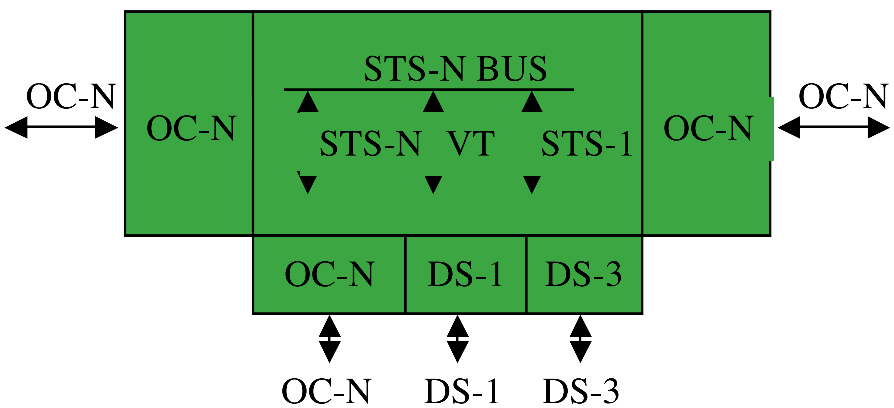
Terminal Multiplexer



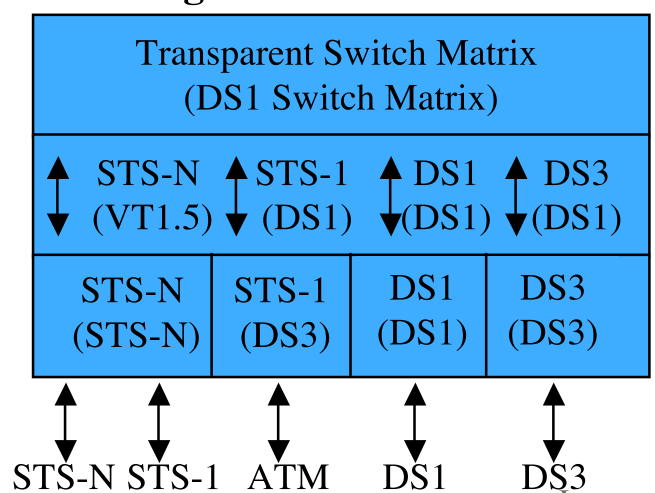
Regenerator



Add/Drop Multiplexer

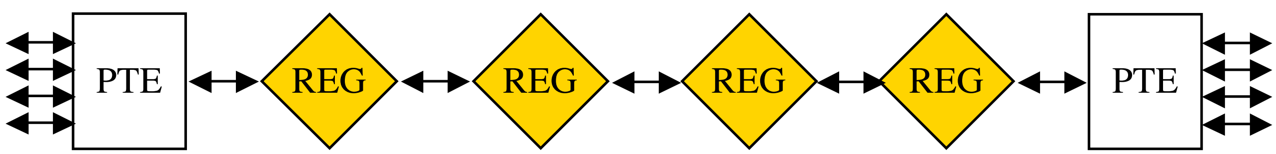


Broadband and (Wideband) Digital Cross-Connects



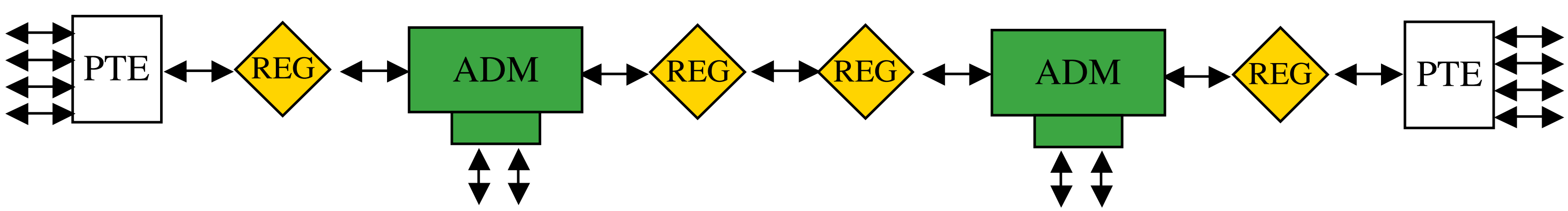
SONET Network Configurations

- Point-to-Point configuration
  - It is the simplest SONET network configuration
  - The point-to-point link starts and ends in the Path Terminal Equipments, which perform mud-demultiplexing of the input tributaries
  - No routing or demultiplexing is done along system
  - Regenerators are used to restore the signal



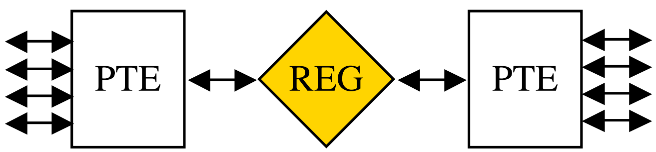
SONET Network Configurations

- Point-to-Multipoint configuration (add-drop)
  - It is still a linear topology
  - ADM (and regenerators) are placed along the network
  - The ADM element adds and drops tributary channels along the link
  - SONET ADM are specifically designed for this task, and have a significantly simpler structure than general SONET cross-connects

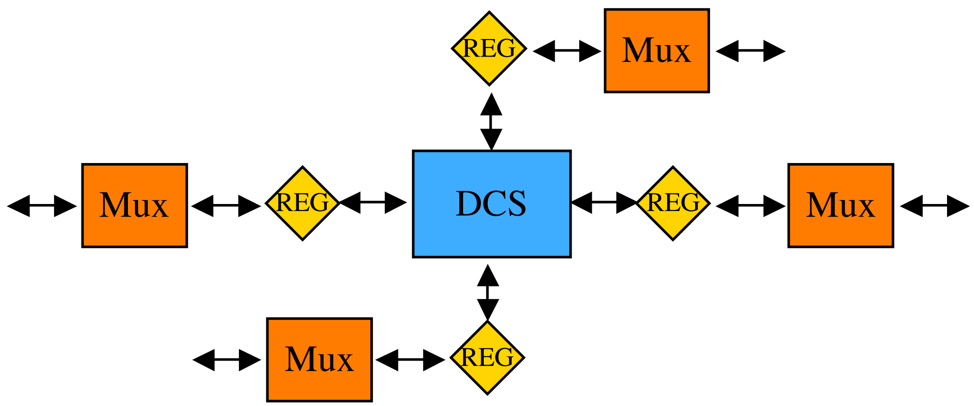


SONET Network Configurations

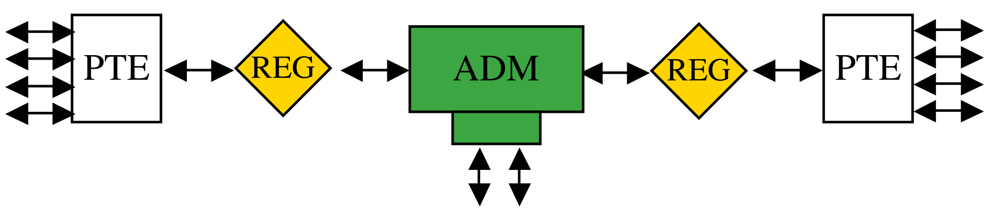
Point-to-Point



Hub Network

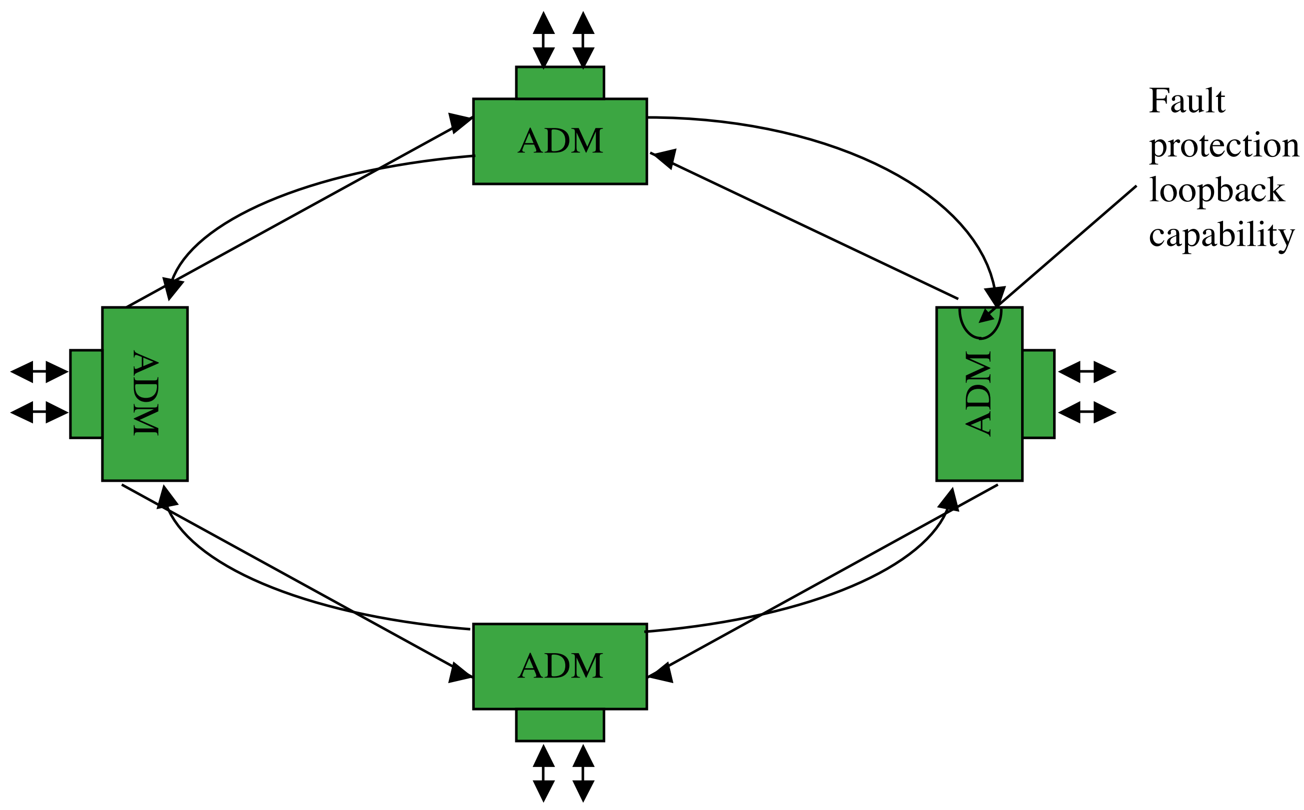


Add/Drop Mux



SONET Network Configurations

SONET Ring Architecture



SONET Physical Layer

- The SONET physical layer is totally based on optical fiber transmission
- The most important ITU 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
- The Recommendations cover several type of links, ranging from very short-haul interoffice links to ultra-long haul, WDM backbone links
  - Transmitter, receiver and link physical parameters are specified

SONET Physical Interface

- An extract from ITU G.691 for SONET OC-192 (or SDH STM-64) (10 Gbit/s)
  - Standard for inter-office terrestrial systems
- The systems are classified as follows

  Type - level . Suffix (like in V-64.2)

  - where:
- Type indicate the system length:
  - S- short-haul (up to 20-40 Km)
  - L- long-haul (up to 40-80 Km)
  - V- very long-haul (up to 80-120 Km)
  - U- ultra long-haul (up to 120-160 Km)
- Level indicate the bit rate, according to the SHH STM notation (for example V-64 is a very long haul system at 10 Gbit/s)

SONET Physical Interface

- .level indicates the fiber and wavelength used
  - .1 - 1300 nm sources, on standard fiber (ITU G.652)
  - .2 - 1550 nm sources, on standard fiber
  - .3 - 1550 nm sources, on dispersion shifted fiber (ITU G.653)
  - .5 - 1550 nm sources, on non-zero dispersion shifted fiber (ITU G.655)
- In conclusions, V-64.3 is a
  - very long haul system
  - at 10 Gbit/s
  - On dispersion shifted fibers

Example of the Standard for V-64.3

- Transmitter parameters
  - Operating wavelength range: 1530-1565
  - Mean launched power: 10-13 dBm
  - Minimum transmitter extinction ratio: 8.2 dB
- Path Parameters
  - Attenuation range: 22-33 dB (allowing a single span of 100-120 km)
  - Maximum accumulated dispersion: 400 ps/nm
  - Maximum accumulated PMD: 10 ps
- Receiver Parameters
  - Receiver sensitivity: -24 dBm
  - Receiver overload: -9 dBm
  - Maximum path-penalty: 1 dB

SONET SMF Optical Interface

- Must support RZ or NRZ
- Repeater spans of less than 25km and between 25 and 40km have been specified
- Repeater spans greater than 40km require specialized specifications

NRZ

0.95T ≤ Rise Time + On Time ≤ 1.05T

$$f_0 > \frac{2}{T}, \text{ OC-1 to OC-48}$$

RZ

Rise Time + On Time + Fall Time ≤ (2/3)T

$$f_0 > \frac{2}{T}, \text{ OC-1 to OC-18}$$

$$f_0 > \frac{3}{T}, \text{ OC-24 to OC-48}$$

$$\text{Rise time} \le \frac{T}{3}, \text{ OC-1 to OC-48}$$

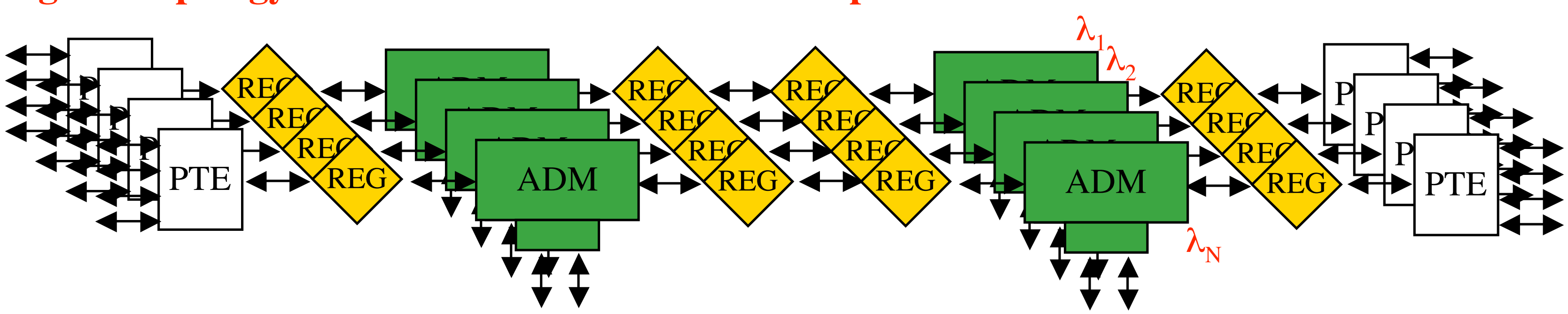
$$\text{Fall time} \le \begin{cases} T/3, & \text{OC-1 to OC-18} \\ T/2, & \text{OC-24 to OC-48} \end{cases}$$

SONET & WDM

- The standard SONET approach to WDM is to simply use wavelengths as totally separated channels
- Basically, with this approach, a fiber carrying *N* wavelengths is totally equivalent to *N* single channel fibers

Physical Topology

Logical Topology: N linear ADM SONET links in parallel



SONET & WDM

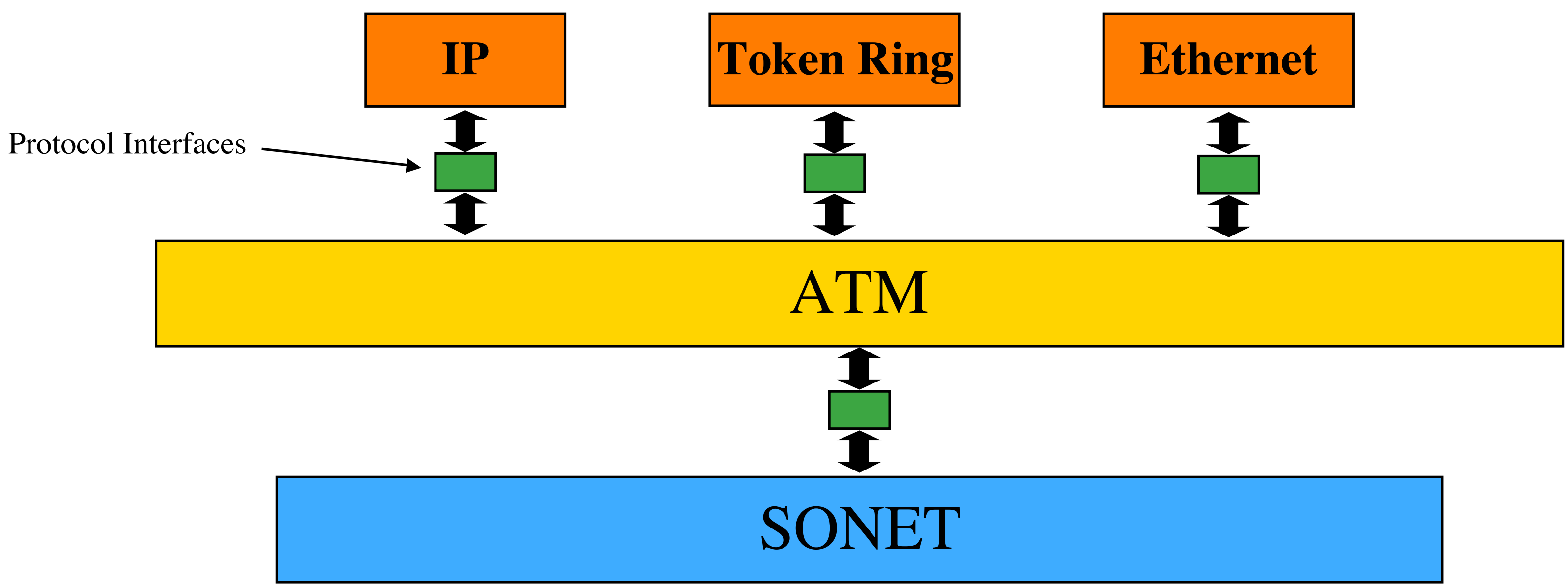
- An Add-Drop node receiving 40-80 channels at 10 Gbit/s has to handle in the electronic domain a throughput approaching the Terabit/s
- The situation is even more complex for a hub digital cross-connect
- The resulting SONET equipments are
  - Expensive
  - Have power dissipation problems
  - Have significant dimension
- Note that in both ADM and DCS, most of the traffic is just passing through the node, and would not need to be decoded
- Second Generation optical networks remove this complexity, by trying to keep the signal in the optical domain

IP and ATM over SONET

- Internet Service Providers (ISP) typically use ATM to build their Internet backbone networks
  - ATM links at 155 Mbit/s or 622 Mbit/s are typically used to connect IP backbone routers
- ATM links are then typically implemented over SONET
- IP over ATM over SONET (over WDM) is thus today current approach
- There are several proposal to build a simpler architecture, such as:
  - IP over SONET over WDM
  - IP "directly" over WDM (with some framing simpler than SONET)
- This approaches are often called "Optical IP", even though this may generate some misunderstandings

Classical IP over ATM

- The classical approach, defined in IETF, RFC 1577, use ATM for data transport
- Besides IP, other protocols are mapped into ATM
  - LAN emulation: allows to send standard LAN (Ethernet 802.3 or Token Ring/805.%) traffic over WAN
- ATM uses SONET for data transport

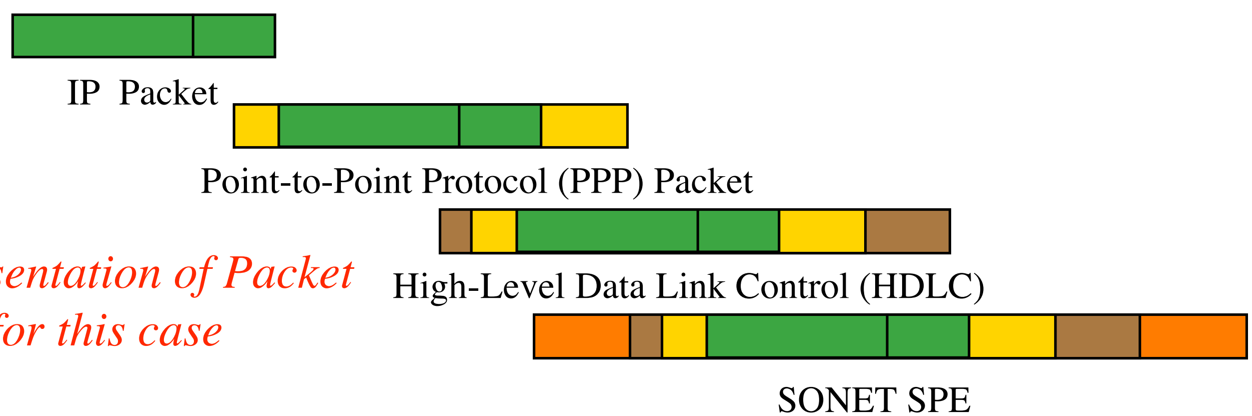


MPLS

- Intermediate nodes along the network are very complex
- Each node, on each IP packet to be forwarded to a following node, has to implement all the functions of the three protocols
- Some proposal, such as Multi Protocols Label Switching (MPLS), are focused on greatly simplifying the packet forwarding process
  - Short “Labels” are attached to packets
  - Forwarding is obtained by swapping labels according to fixed look-up tables
  - The IP router becomes more similar to a switch
- MPLS is gaining more and more interest as an efficient IP Traffic engineering protocol
  - As we will see later, it has an interesting counterpart in second generation optical networks, in the Multi Protocol Lambda Switching (MPλS)

IP over SONET

- Another approach is based on directly mapping IP over SONET through the Point-to-Point Protocol (PPP), standardized by the IETF in RFC 1661
- PPP is a protocol that can adapt IP over different other data transport (not only SONET). Functions:
  - Encapsulation and multiplexing from multiple network layer protocols over the same link
  - Establishment, configuration and test the link layer connection



Pictorial representation of Packet Encapsulation for this case

Homework #1, Due April 24th

- Problem 6.1 Ramaswami
- Problem 6.3 Ramaswami
- Problem 6.4 Ramaswami
- Problem 7.1 Ramaswami
- Problem 7.2 Ramaswami
- Problem 7.4 Ramaswami
- Problem 7.5 Ramaswami