The Migration Toward the Optical Internet

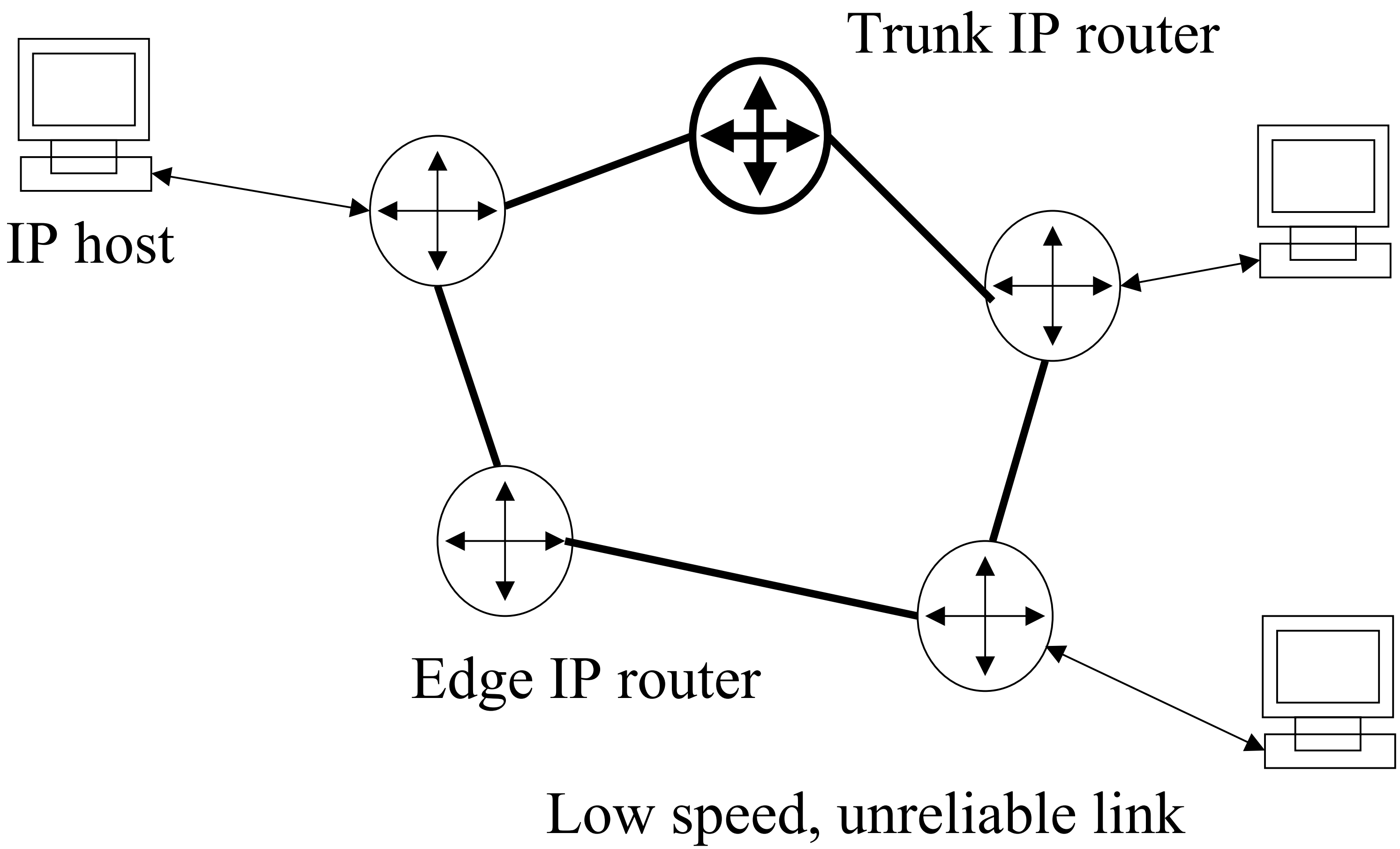
Lesson 6

Luca Valcarenghi

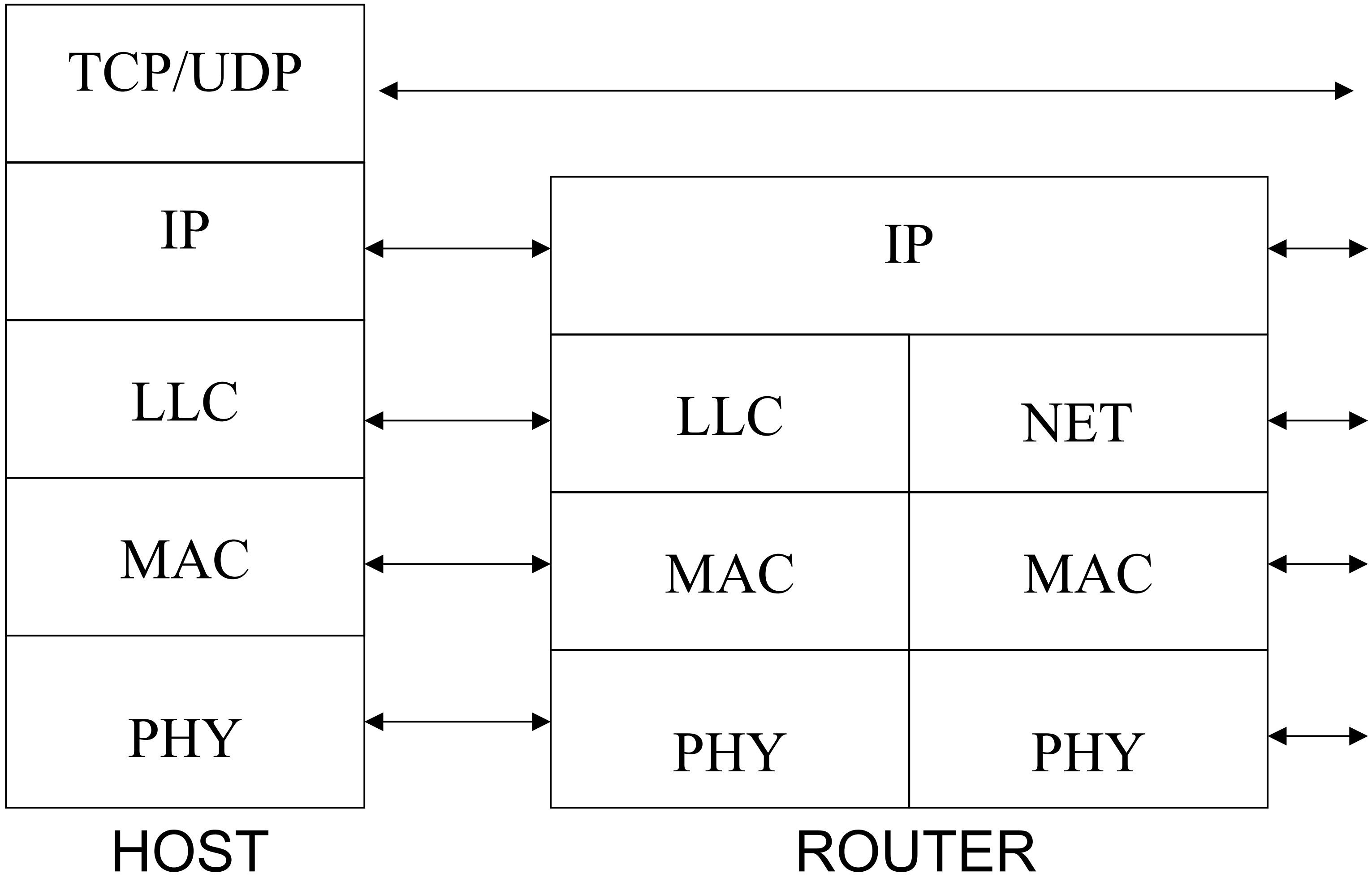
(part of these notes are taken from

A. Fumagalli and J.Aracil, “Optical Internet: Available Technologies and Challenges”, ICC 2002 Tutorial)

The Internet Origins



Protocol Architecture (I)



IP over Optical Networks

- A more realistic layered model for today's networks would employ multiple protocol stacks residing one on top of the other
- Each stack incorporates several sublayers, which may provide functions resembling traditional physical, link, and network layers

First Generation and Second Generation Optical Networks

- First Generation Optical Networks (FGON)
  - Optical signal O/E/O converted at each network node
  - SONET, Gigabit Ethernet (GbE), Point-to-Point WDM (Wavelength Division Multiplexing)
- Second Generation Optical Networks (SGON)
  - Enhanced (higher layer) capabilities
    - Networking
    - Multiplexing
    - Transport
  - Lightpath (static and dynamic)
    - All-optical circuit between non-adjacent network nodes
  - Optical Transport Network (OTN) (ITU-T Rec. G.872), also called Optical Layer (OL)

SONET/SDH History

- SONET = Synchronous Optical Network
  - current transmission and multiplexing standard for high-speed signals in North America
- SDH = Synchronous Digital Hierarchy
  - standard closely related to SONET, adopted in Europe and Japan and for most submarine links
- SONET/SDH predecessor was PDH (Plesiochronous Digital Hierarchy) mid 1960's
  - Primary focus of PDH (referred also as the asynchronous digital hierarchy by North American operators) was to multiplex digital voice circuits

Voice Circuit Multiplexing

- Analog voice circuit with 4kHz bandwidth can be
  - sampled at 8 kHz
  - quantized at 8 bits/sample
  - $\Rightarrow$ bit rate 64 kb/s of a digital voice circuit
- 64 kb/s circuit became accepted standard for digital voice
- Higher speed streams were defined as multiples of the basic 64kb/s stream

Transmission rates for Asynchronous (PDH) Signals

- PDH suffered from several problems ⇒ carriers and vendors developed new transmission and multiplexing standard in late 1980's ⇒ SONET/SDH

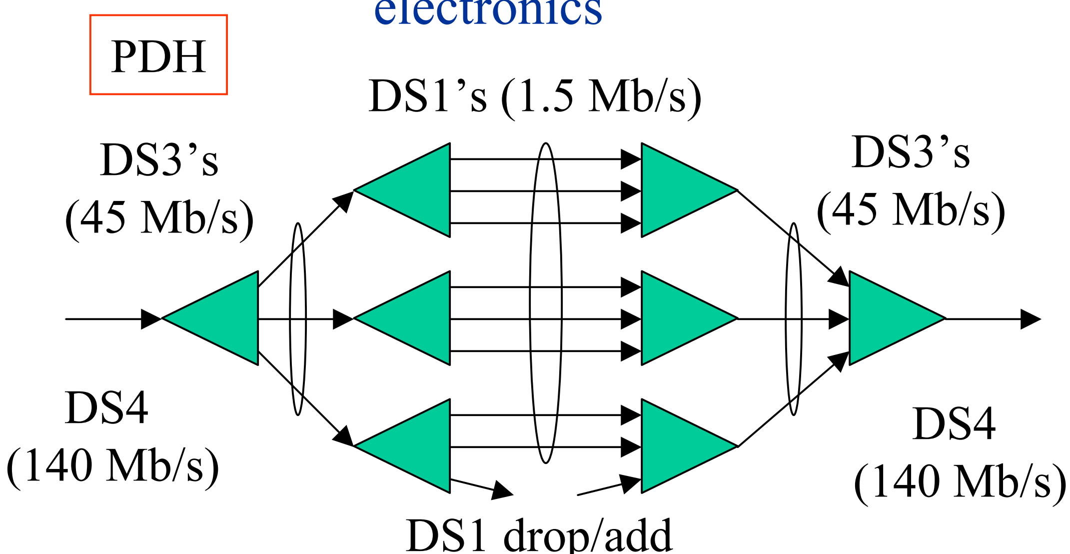
Level	North America (DS-x)	Europe (E-x)	Japan
0	0.064 Mb/s	0.064 Mb/s	0.064 Mb/s
1	1.544 Mb/s	2.048 Mb/s	1.544 Mb/s
2	6.312 Mb/s	8.448 Mb/s	6.312 Mb/s
3	44.736 Mb/s	34.368 Mb/s	32.064 Mb/s
4	139.264 Mb/s	139.264 Mb/s	97.728 Mb/s

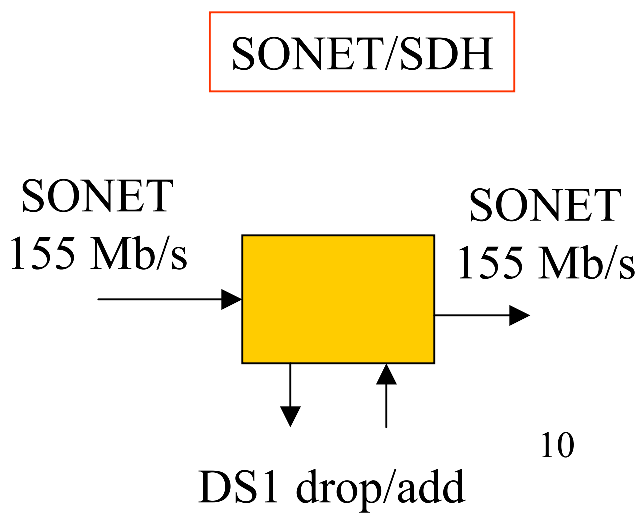
Benefit of SONET/SDH with respect to PDH

- Multiplexing Simplification
  - Asynchronous (PDH) multiplexing each terminal in the network runs its own clock
  - There can be significant differences in actual rates even if a nominal clock is specified
    - Example: in DS3 a 20 ppm (parts per million) variation in clock rate $\Rightarrow$ bit rate difference of 1.8 kb/s between two signals
    - When lower-speed streams are multiplexed by interleaving their bits, extra bits may need to be stuffed in the multiplexed stream to account for differences between the clock rates
    - Bit rates in PDH not integral multiple of basic 64 kb/s rates but slightly higher to consider bit stuffing
    - 1.544 Mb/s > 24 x 64kb/s = 1.536 Mb/s

Benefit of SONET/SDH with respect to PDH (2)

– In PDH very difficult to pick out a low-bit-rate stream (e.g., DS1 from DS3) without completely demultiplexing the higher-speed stream down to its individual component streams
  - Need for stacked-up multiplexers (“multiplexer mountains”) each time a low-bit-rate stream needs to be extracted
  - Expensive
  - Might compromise network reliability due to large amount of electronics





Benefit of SONET/SDH with respect to PDH (3)

- SONET clocks are perfectly synchronized to a single master clock
  - Links for network clock synchronization
    - http://www.ncs.gov/n2/content/tibs/files/tib99_4.pdf
    - http://phaidra.ascom.com/digitalasset-DLFiles/322/file175993_0_/DLFileName/Ascom_Synkronointiseminaari.pdf
- SONET/SDH rates are integral multiples of the basic rate
- no bit stuffing is needed when multiplexing streams together
- Lower speed signals can be extracted from a multiplexed SONET/SDH stream in a single step by locating the appropriate position of the bits in the multiplexed signal
- Easier design of SONET multiplexers and demultiplexers

Benefit of SONET/SDH with respect to PDH (4)

- Management
  - SONET/SDH incorporate extensive management information
    - extensive performance monitoring
    - identification of connectivity and traffic type
    - identification and reporting of failures
    - a data communication channel for transporting mangement information between the nodes

Benefit of SONET/SDH with respect to PDH (5)

- Interoperability
  - PDH did not define standard format on the transmission link
  - Interoperability problems among vendors
  - SONET/SDH defines standard optical interfaces
    - This enables interoperability between equipment from different vendors on the link

Benefit of SONET/SDH with respect to PDH (6)

- Network Availability
  - SONET/SDH evolved to incorporate
    - specific network topologies
    - specific protection techniques
    - associated protocols to provide high availability services
  - SONET/SDH restoration time < 60 ms (typically 50 ms)
  - PDH restoration time several seconds to minutes

SONET/SDH Signal Rates

SONET Signal	SDH Signal	Bit Rate (Mb/s)	Optical Interface
STS-1		51.84	OC-1
STS-3	STM-1	155.52	OC-3
STS-12	STM-4	622.08	OC-12
STS-24		1244.16	
STS-48	STM-16	2488.32	OC-48
STS-192	STM-64	9953.28	OC-192
STS-768	STM-256	39,814.32	OC-768

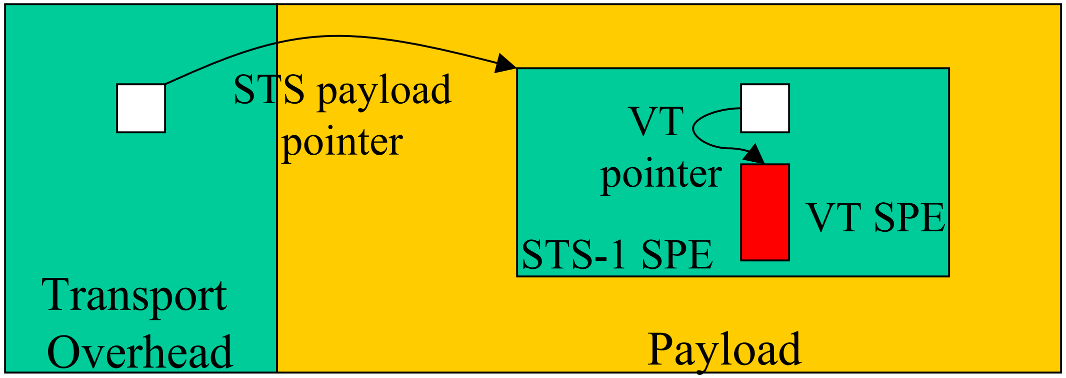
SONET/SDH Acronyms

- SONET
  - STS-N = Synchronous Transport Signal level-N
    - STS-N obtained by interleaving the bytes from N frame-aligned STS-1s
    - STS signal is an electrical signal and it may exist only inside the SONET equipment
    - The interface to other equipment is usually optical and is essentially a scrambled version of the STS signal in optical form
    - The SONET bit rate was chosen to accommodate the commonly used asynchronous signals DS1 and DS3
- SDH
  - STM-N= Synchronous Transport Module-N
    - SDH bit rate was chosen to accommodate the commonly used PDH signals which are E1, E3, and E4
- Optical interface $\Rightarrow$ OC-N = Optical Carrier-N

SONET Frame

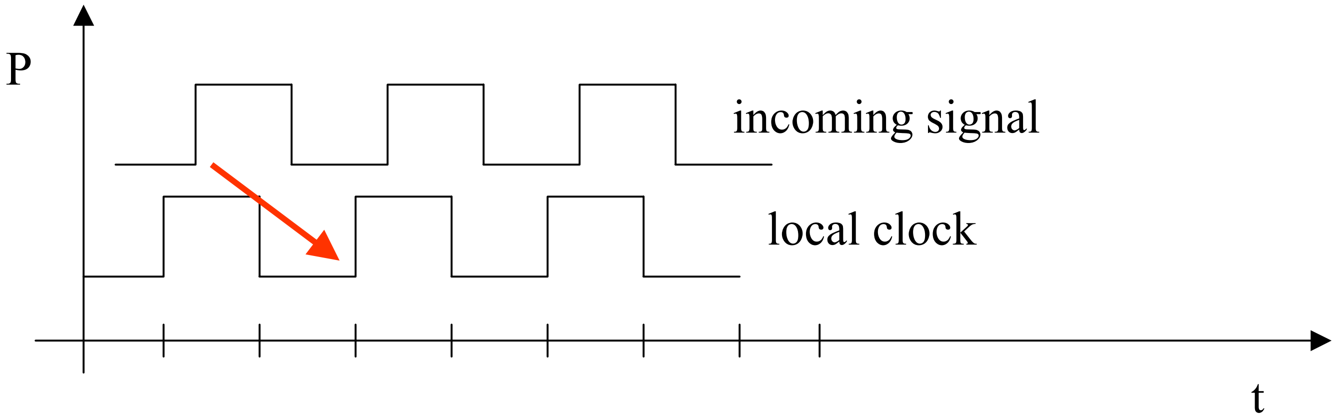
- Transport Overhead = overhead bytes
- Payload = payload bytes
- SPE = Synchronous Payload Envelope
  - part of the payload carrying data
  - SPE includes
    - Path overhead = additional overhead bytes insertyed at the source node and extracted at the destination node
      - One of these bytes is PATH TRACE byte which identifies the SPE and can be used to verify network connectivity

STS Frame



Use of Pointers in the STS Frame

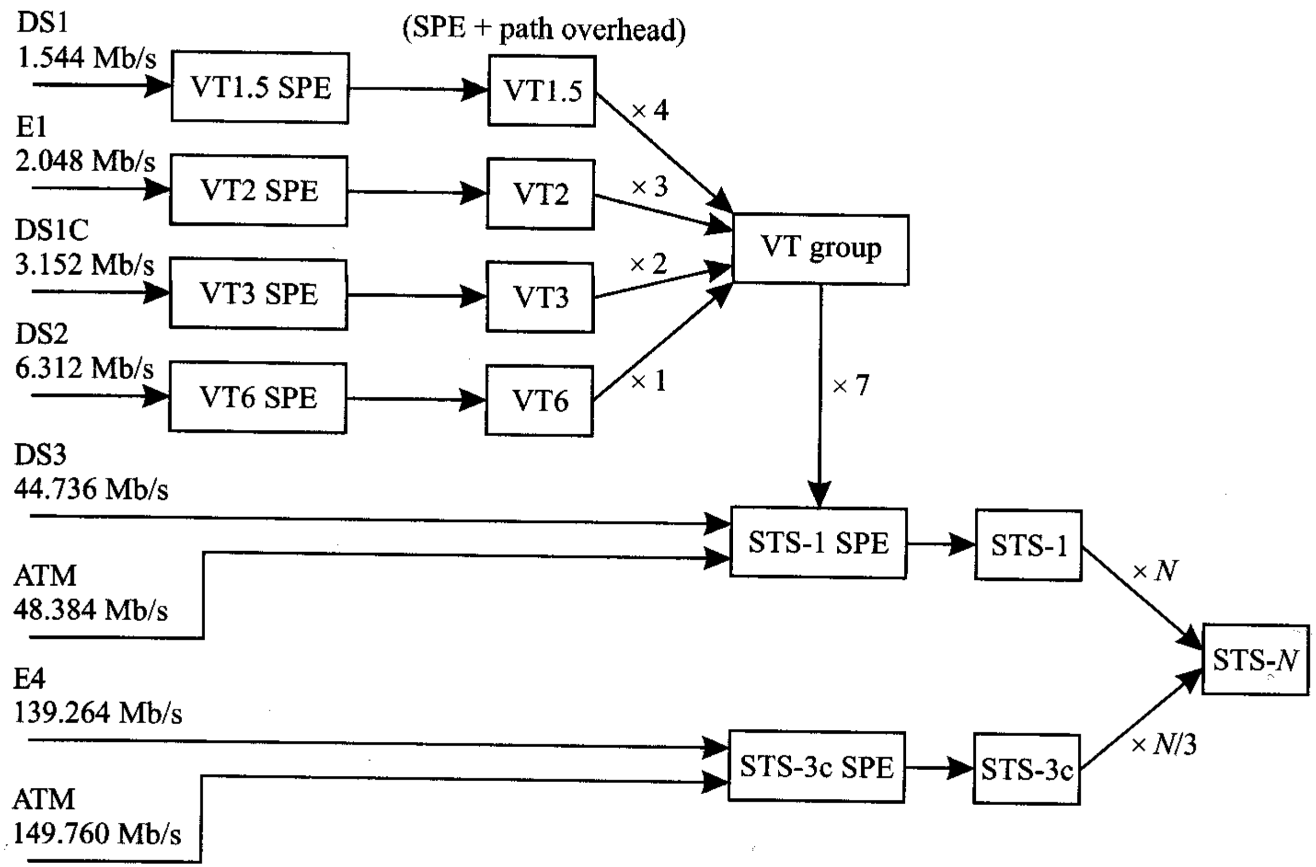
- SPE does not have a fixed starting point within a frame
  - SPE starting point is indicated by a pointer in the line overhead
  - This help in compensating slight phase differences between incoming signal and local clock
    - Payload is allowed to be shifted earlier or later in a frame and indicating this by modifying the associated pointer



SONET Multiplexing

- Lower-speed non-SONET streams below the STS-1 are mapped into Virtual Tributaries (VTs)
- In SONET VT have been defined in four sizes
  - VT1.5 → 1.5 Mb/s
  - VT2 → 2 Mb/s
  - VT3 → 3 Mb/s
  - VT6 → 6Mb/s
- VTs carry asynchronous/plesiochronous streams
- A VT group consists of 4 different VT multiplexing
  - 4 x VT1.5
  - 3 VT2
  - 2 VT3
  - 1 VT6
- Seven such VT groups are byte interleaved along with a set of paths overheads to create a basic SONET SPE
- As an SPE floats within a SONET frame the VT payload (VT SPE) can also float within the STS-1 SPE
- A VT pointer is used to point to the VT SPE
- The pointer is located in two designated bytes within each VT group

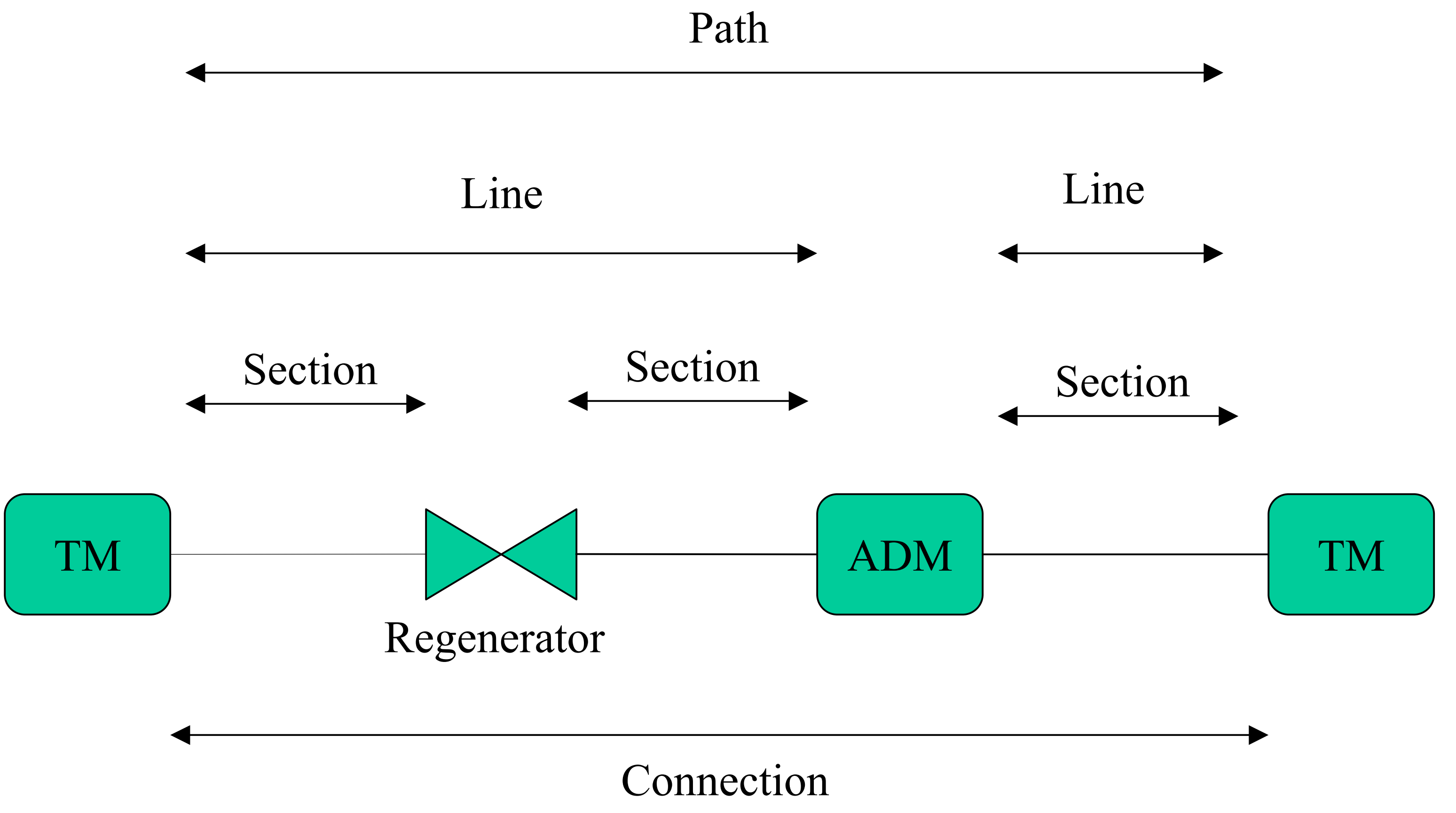
SONET Multiplexing (2)



SONET Multiplexing (3)

- To map higher-speed non-SONET signals can be mapped for transport over SONET
- Most common examples high-speed packet streams from IP routers or ATM switches
- For this purpose STS-Nc signal are used
- STS-Nc signal has a locked payload and “c” stands for concatenated
- The concatenated or locked payload implies that this signal cannot be demultiplexed into lower-speed streams
- Example
  - 150 Mb/s ATM signal is mapped into an STS-3c signal

SONET/SDH Layers



SONET/SDH Layers (2)

- The SONET layer consists of four sublayers
  - Path
  - Line
  - Section
  - Physical
- Each layer, except for the physical layer, has a set of associated overhead bytes used for several purposes
- Overhead bytes are added whenever the layer is introduced and removed whenever the layer is terminated in a network element

SONET/SDH Path Layer

- Responsible for end-to-end connections between nodes
- It is terminated only at the ends of a SONET connection
- Intermediate nodes can do performance monitoring
- Path bytes are not modified by intermediate nodes

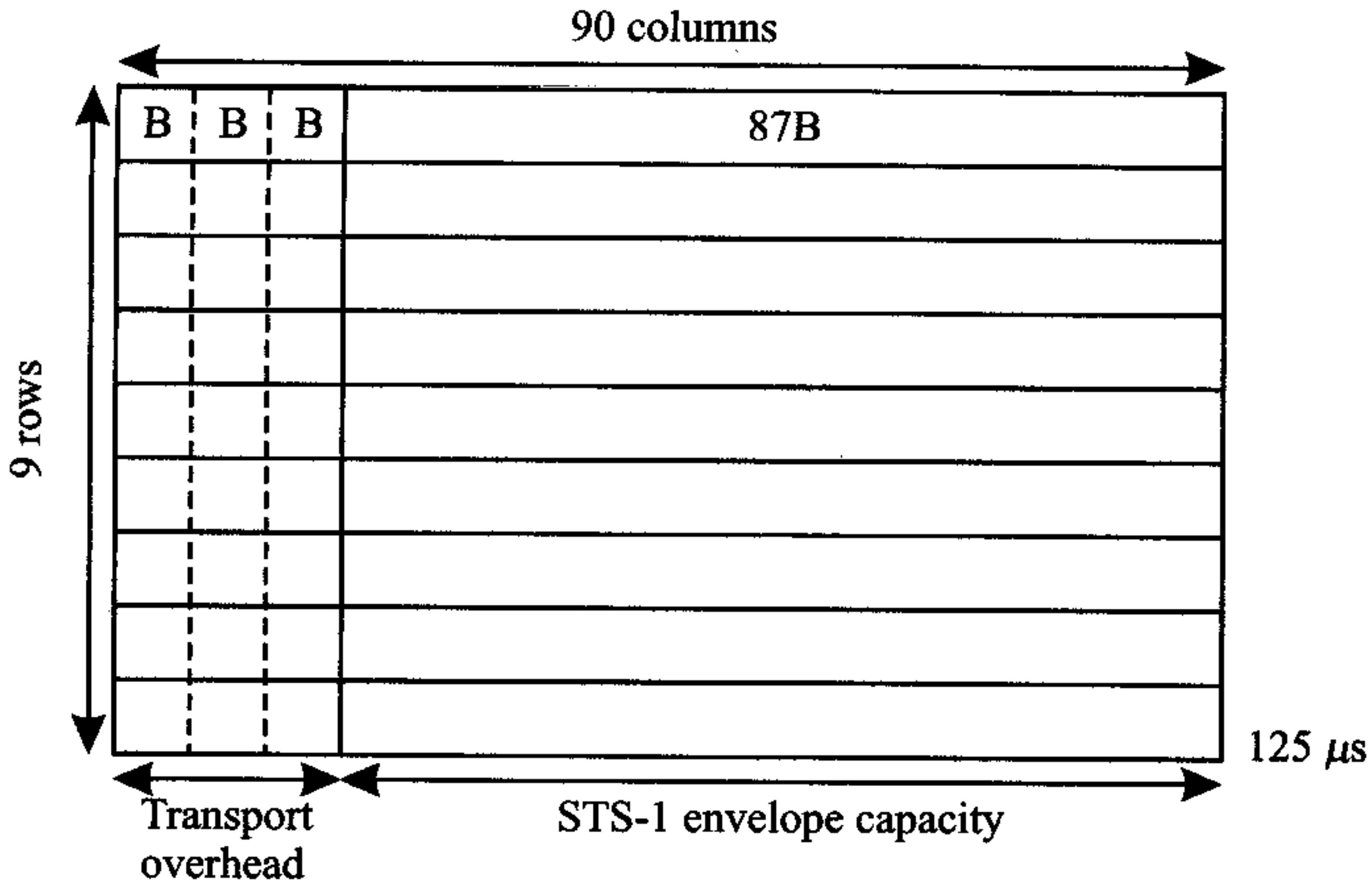
SONET/SDH Line Layer

- Multiplex Section layer in SDH
- It multiplexes a number of path-layer connections onto a single link between two nodes
- Liine layer is terminated at each intermediate line Terminal Multiplexer TM or add/drop multiplexer (ADM) along teh route of a SONET connection
- Line layer responsible for performing certain types of protection switching

SONET/SDH Section Layer and Physical Layer

- Section Layer
  - Regenerator-section layer in SDH
  - Section layer correspond to to link segments between regenerators
  - Section layer is terminated at each regenerator in the network
- Physical Layer
  - Responsible for actual transmission of bits across the fiber

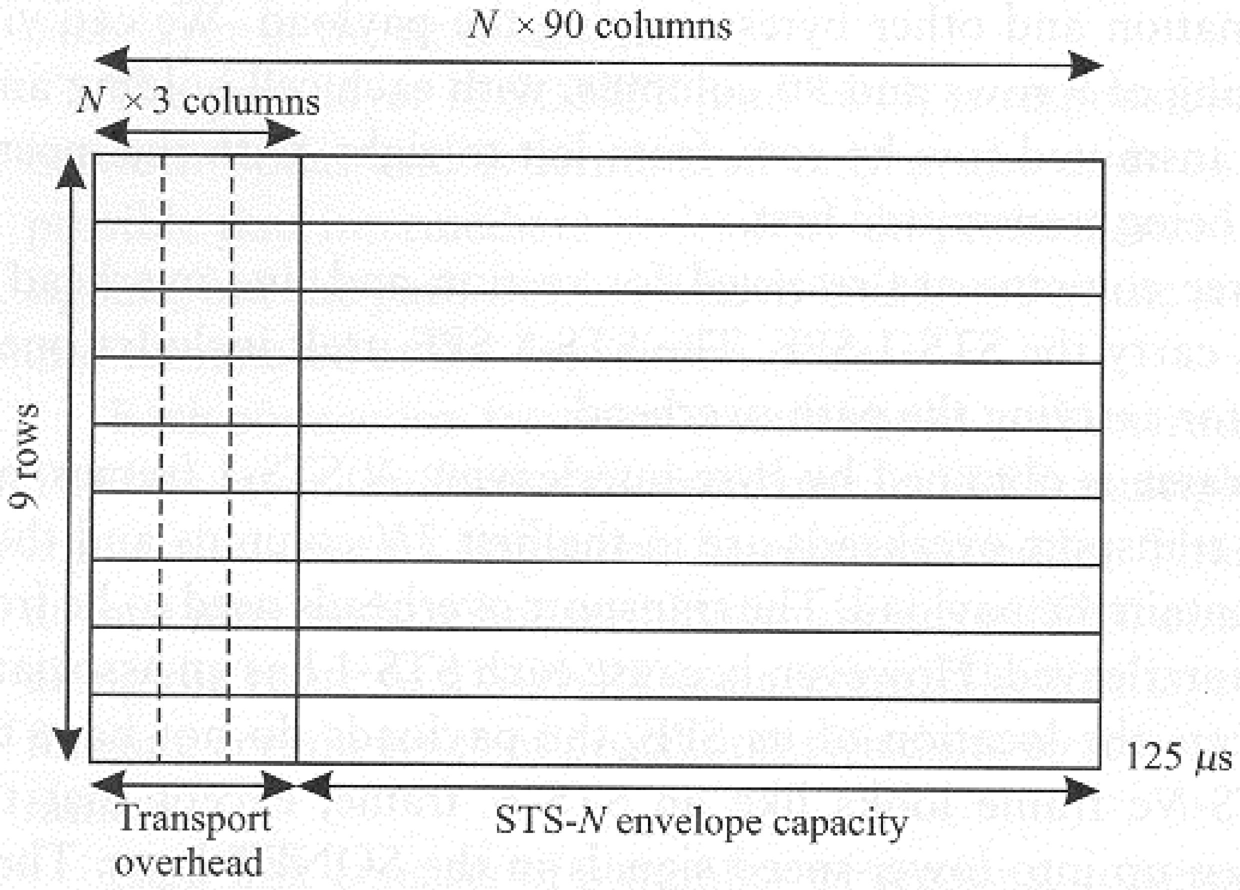
SONET Frame Structure



SONET Frame Structure (2)

- A SONET frame is 125μs in duration regardless of the bit rate of the SONET signal
- It corresponds to a rate of 8000 frames/s
- The SONET frame duration time is set by the 8kHz sampling rate of the voice circuits
- Frame is a specific sequence of 810 bytes
  - bytes allocated to carry overhead information
  - other bytes carrying the payload
- SONET frame can be visualized a consisting of 9 rows and 90 columns, with each cell holding an 8-bit byte
- Bytes are transmitted row by row, from left to right, with the most significant bit in each byte being transmitted first

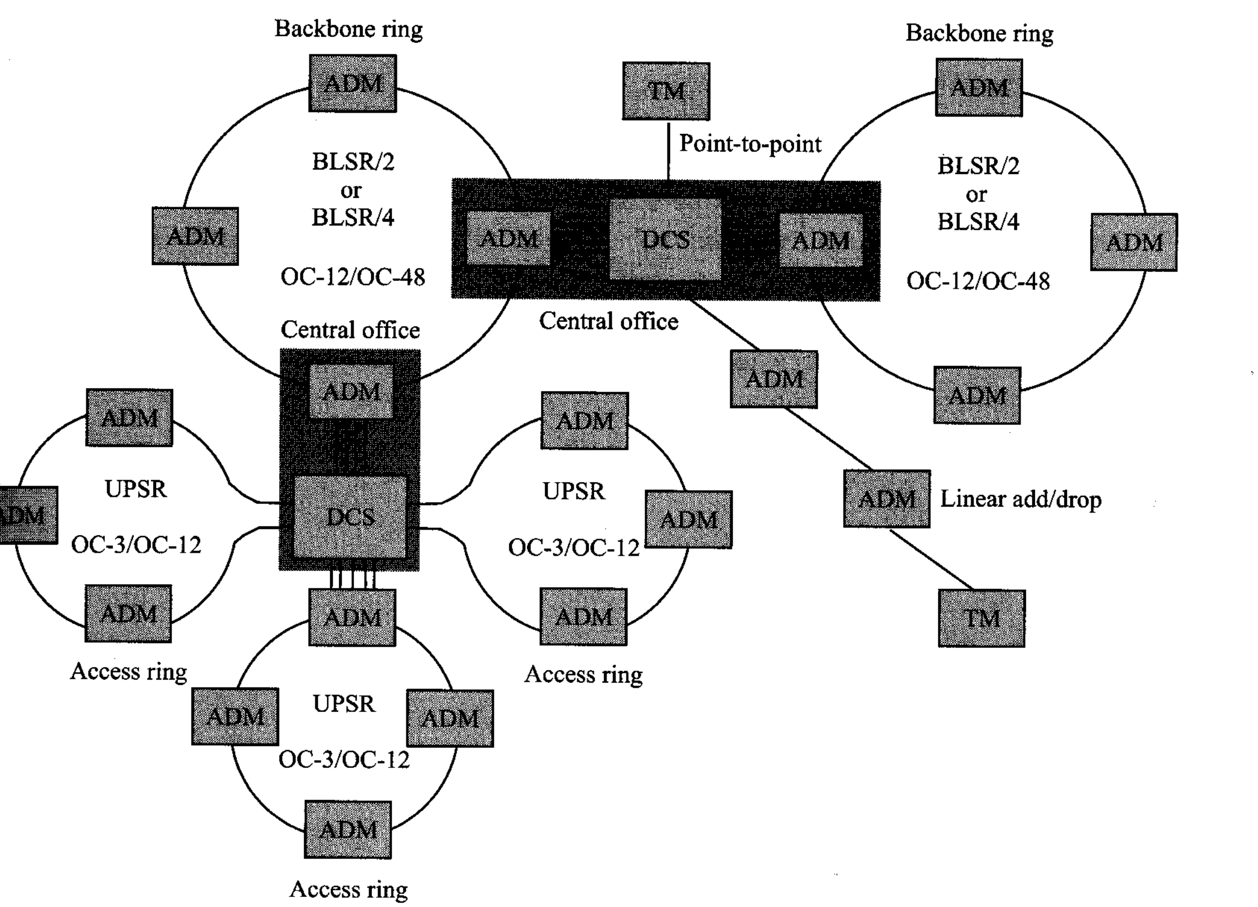
SONET Frame Multiplexing



SONET Frame Multiplexing (2)

- An STS-N frame is obtained by byte-interleaving N STS-1 frames
- The transport overheads are in the first 3N columns
- The remaining 87N columns contain the payload
- The transport overheads need to be frame aligned before they are interleaved
- The payloads do not need to be frame aligned because of the presence of the SPE pointer
- An STS-Nc frame looks like an STS-N frame
  - The same 87N columns contain the payload
  - Special values in the STS-payload pointers are used to indicate that the payload is concatenated

SONET/SDH Architetural Elements



SONET/SDH Architectural Elements (2)

- SONET is deployed in three types of network configurations
  - Rings
  - Linear
  - Point-to-point links

SONET/SDH Point-to-Point Links

- Early deployment of SONET/SDH
- Nodes at the ends of the link are called terminal multiplexers (TM)
- TMs are also sometimes called line termintaing equipment (LTE)
- Add/Drop Multiplexer (ADM)
  - add/drop one or more low speed streams to a high-speed stream
  - Example an OC-48 ADM can drop/add OC-12 or OC-3 streams from/to and OC-48 stream
  - ADM can be used in a point-to-point link as linear add/drop element

SONET/SDH Rings

- Most common topology for guaranteeing service availability in the presence of failures
- Rings provide an alternate path to reroute traffic in the event of link or node failures
- Rings are made up of ADMs
- Ring ADM
  - perform mutliplexing and demultiplexing operations
  - incorporate protection mechanism
- Two types of ring architectures
  - Unidirectional Path-Switched Ring (UPSR)
  - BidirectionalLine Switched Ring (BLSR)
    - using two fibers → BLSR/2
    - using 4 fibers → BLSR/4

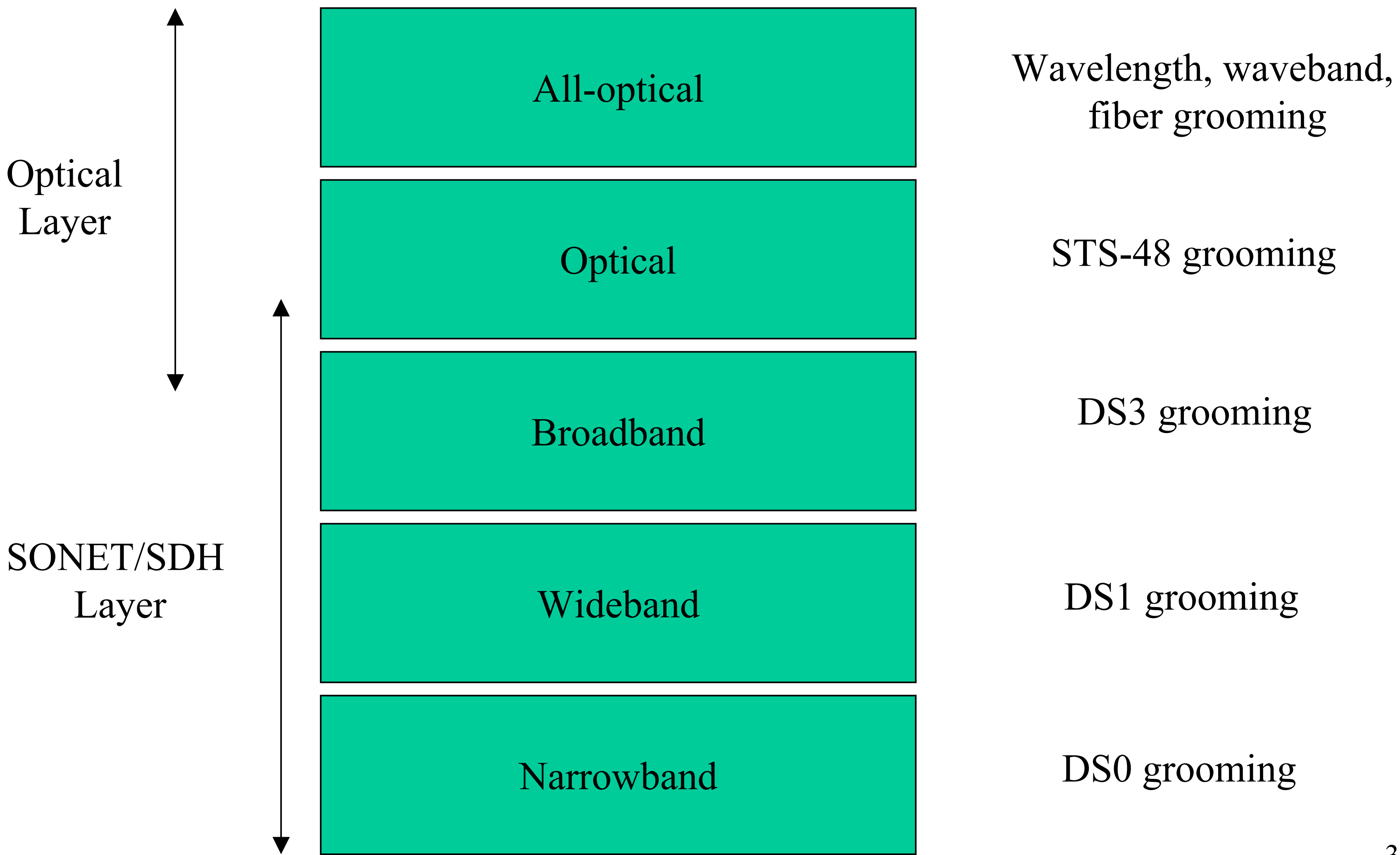
SONET/SDH Digital Crossconnect

- A Digital Crossconnect (DCS) is used to interconnect multiples rings
- DCS replaces path panels by crossconnecting the individual streams under software control
- DCS started out handling only PDH streams but have evolved to handle SONET streams as well
- Although the overall network topology including the DCS is a mesh only rings have been standardized so far

Grooming and DCS Types

- Grooming is the grouping together of traffic with similar destinations, quality of service, or traffic type
- The type of grooming a DCS performs is directly related to the granularity at which it switches the traffic
- Narrowband DCS
  - grooms traffic at the DS0 level
- Wideband DCS
  - grooms traffic at the DS1 level
- Broadband DCS
  - grooms traffic at the DS3/STS-1 rates
- Optical crossconnect
  - groom at DS3 rates and above with primarily high-speed optical interfaces
- Optical crossconnect with purely optical switch fabric (Photonic Crossconnects (PXC))
  - groom traffic in unit of wavelengths or more

Grooming and DCS Types (2)



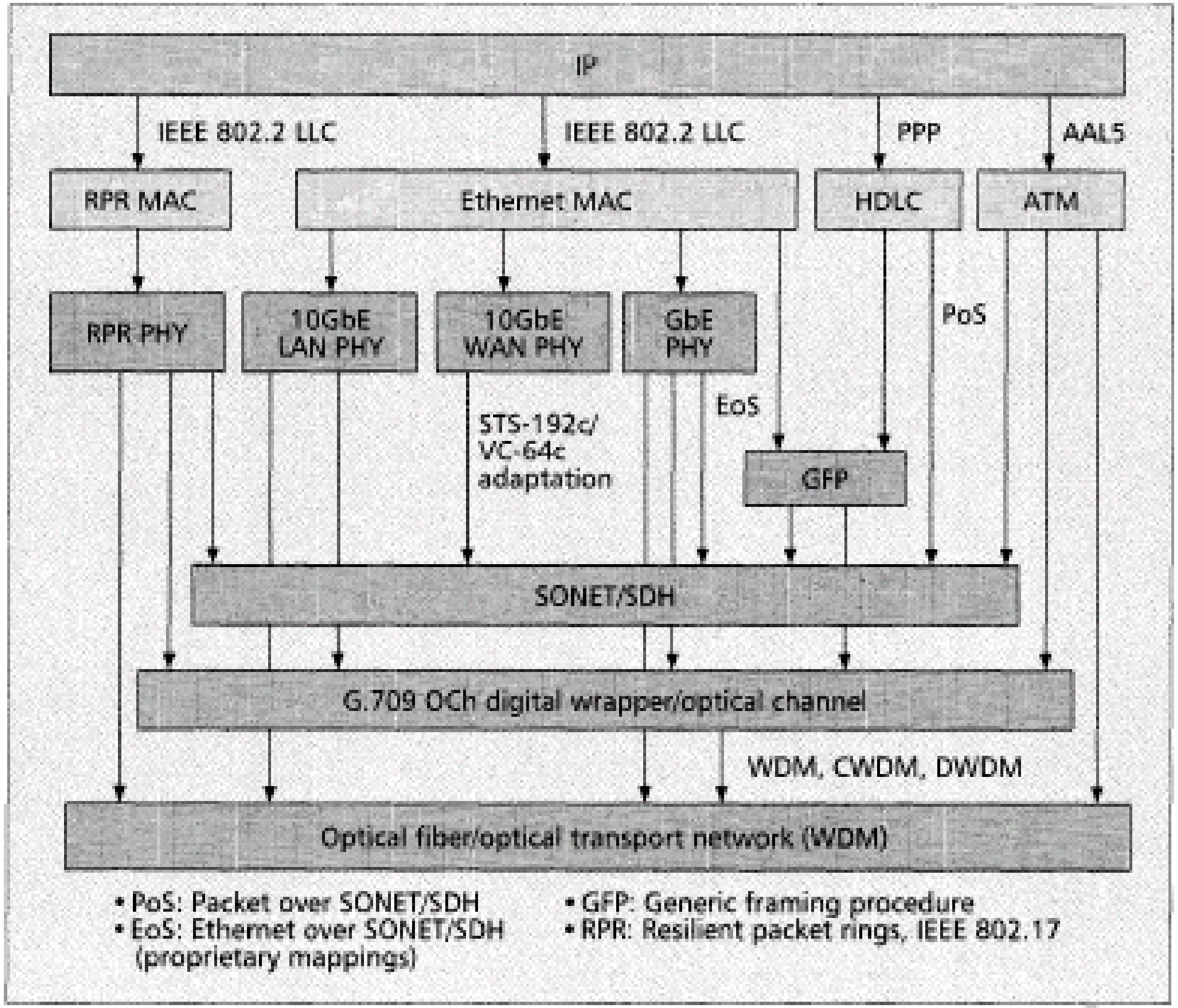
First and Second Generation Optical Internet

- First Generation Optical Internet (FGON)
  - Internet Protocol (IP) over FGON (IP/FGON)
  - Point-to-Point static or semi-static optical channels
  - IP/SONET
  - IP/GbE
- Second Generation Optical Internet (SGON)
  - IP over SGON (IP/SGON)
  - Lightpaths form logical topology for IP routers (similar to IP/ATM)
  - IP/OTN, IP/OL, IP/WDM (Wavelength Division Multiplexing)

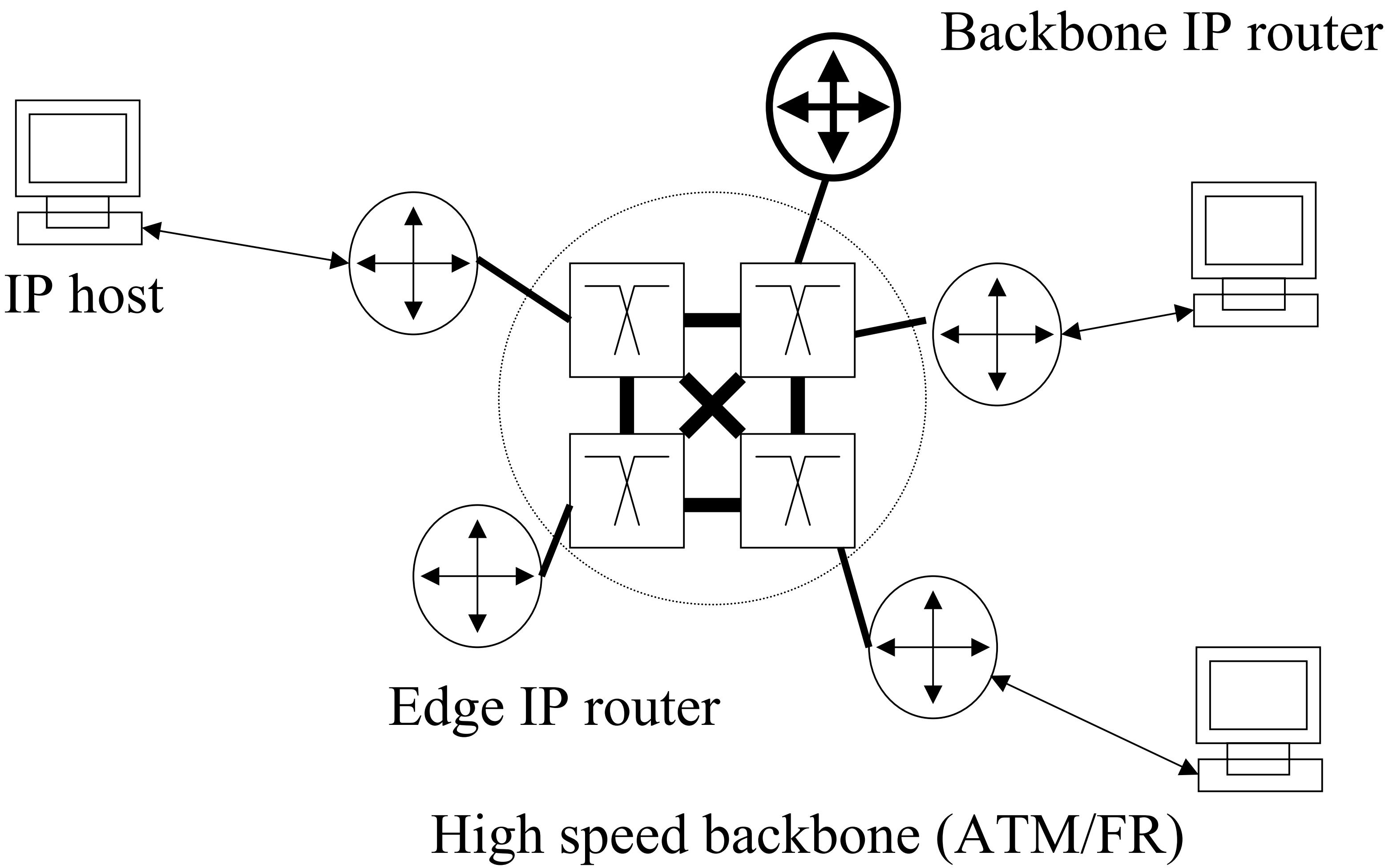
Framing IP over OL

- Optical Layer (fiber optics) offer a service to continuous data stream
- IP datagrams cannot be constructed as continuous data streams
- To map IP onto an optical wavelength requires the intermediate step of encapsulation
  - the IP packets must be encapsulated
  - the encapsulation must be inserted into the wavelength's modulation fromat

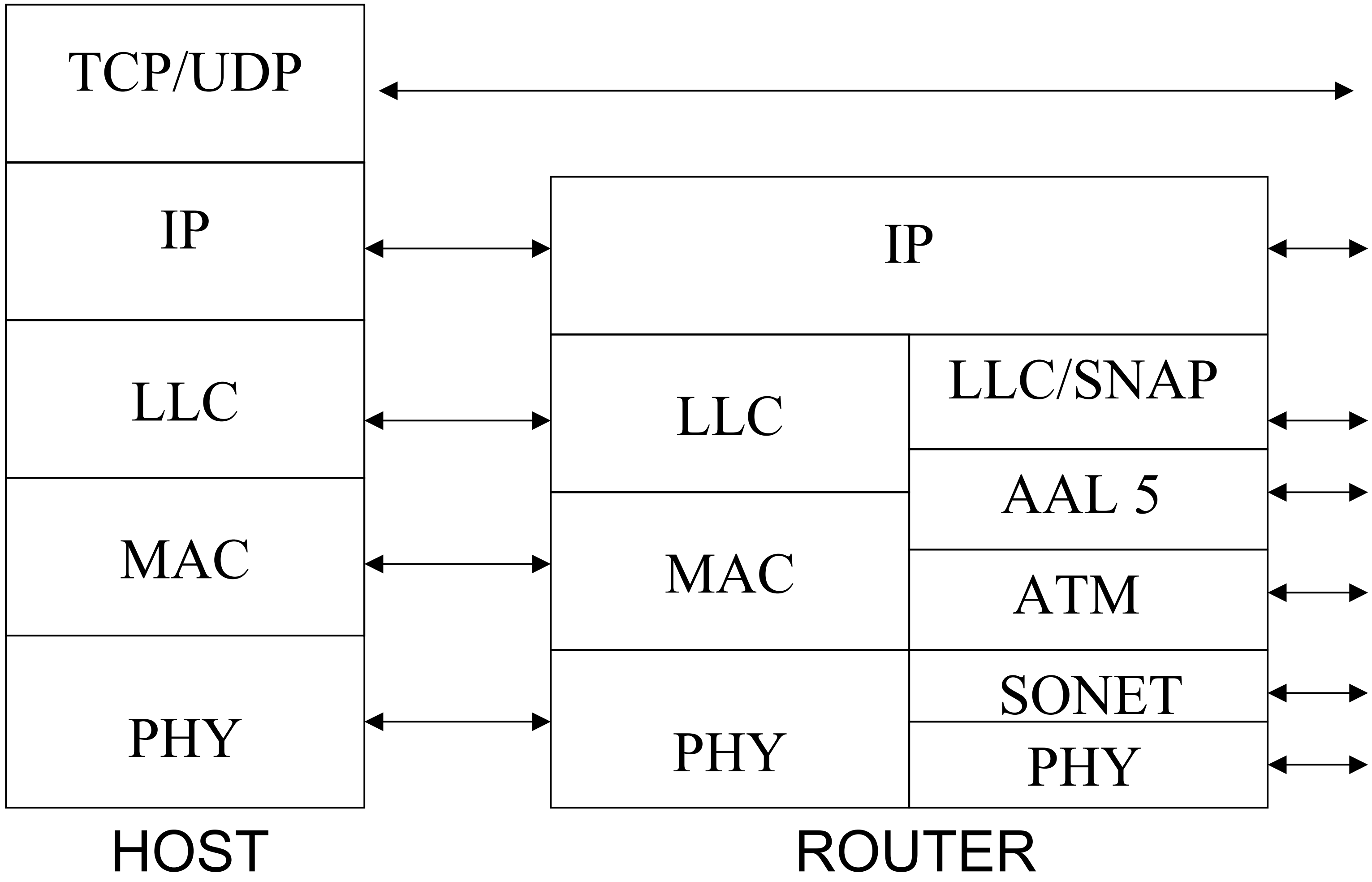
Framing for IP over OL (2)



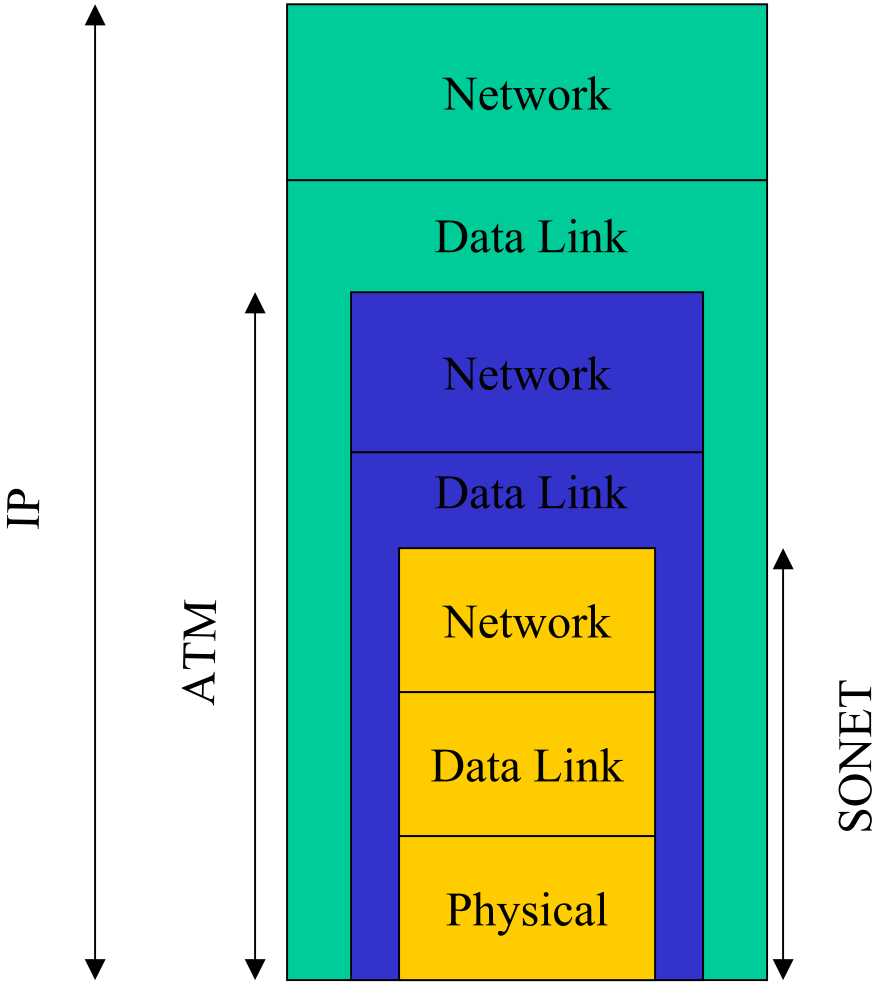
The Current Internet



Protocol Architecture (III)



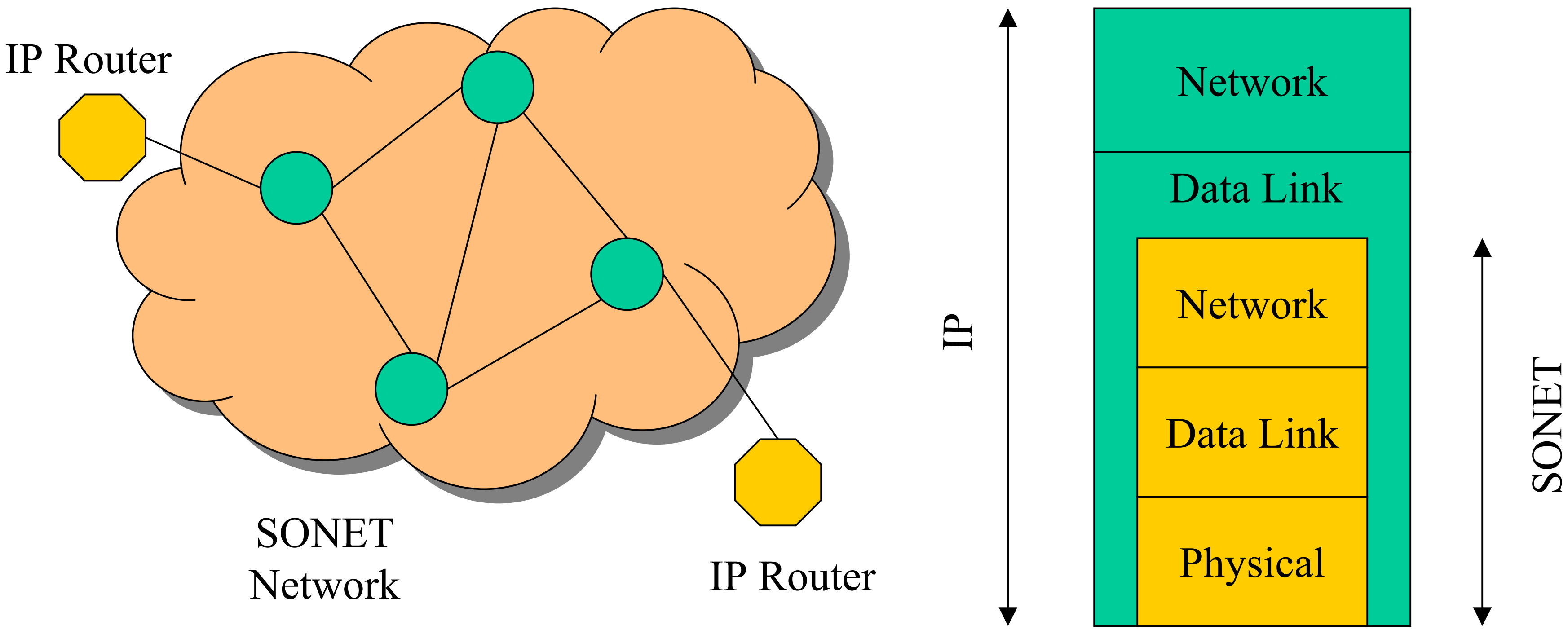
IP over ATM over SONET



IP over ATM over SONET (2)

- IP packets are converted to ATM cells at the periphery of the network
- The ATM switches are connected through a SONET infrastructure
- The IP network treat the ATM network as its link layer
- The ATM network uses SONET as its link layer

IP over SONET (Packet over SONET - POS)



POS (2)

- IP network treats the SONET network as providing it with point-to-point links between IP routers
- SONET layer itself internally
  - routes and switches connections
  - incorporates layers
    - link
    - physical
    - network

POS (3)

- Standardized mapping for IP into SONET use Point-to-Point Protocol (PPP)/High-Level Data Link Control (HDLC)
- IP datagrams are encapsulated into PPP packets
  - PPP provides multiprotocol encapsulation, error control, and link initialization control features
- The PPP encapsulated IP datagrams are then framed using HDLC
  - The main function of HDLC is to provide for delineation (demarcation) of the PPP encapsulated IP datagrams
- IP/PPP/HDLC frame are then mapped into the SONET SPE

POS (4)

- IP over SONET/SDH solution provides
  - robust transmission
  - path-level fault and performance management
  - protection switching with high bandwidth efficiency for rates uop to 2.5Gb/s (OC-48c) and 10Gb/s (OC-192c)

IP over Gigabit Ethernet

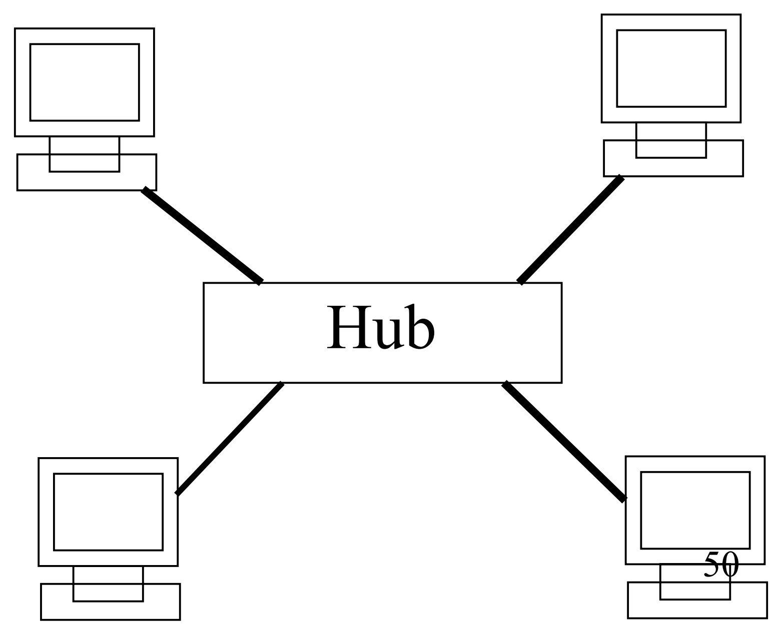
- Gigabit Ethernet is being considered for the access network (and the backbone)
- Full-duplex technology over single-mode, multimode and STP (1000BASE-X encoding 8B/10B)
- Simple and efficient but does not allow BW reservation (as SONET/ATM)

IP over Gigabit Ethernet (IP/GbE)

	50 µm MM	62.5 µm MM	10 µm SM
1000BASE-SX	525 m.	260 m.	N/A
1000BASE-LX	550 m.	550 m.	3000 m.

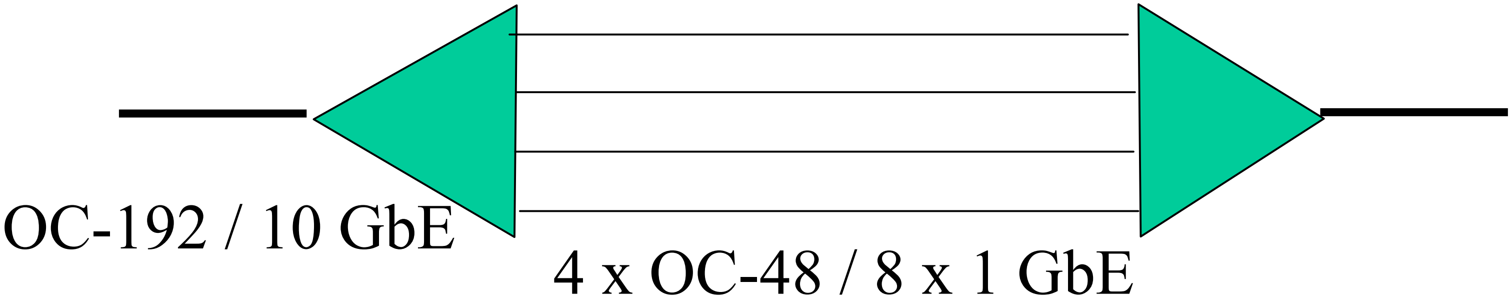
Limitations are physical and not MAC

Point-to-point



Gigabit Ethernet and DWDM

- "Inverse multiplexing" solutions provide 10 Gbps solutions



- Examples: Avici´s composite links, Lucent´s Gigachannel, HP´s SpectraLAN
- Work in progress for 10 Gigabit Ethernet (IEEE 802.3 Higher Speed Study Group)

Extending IP/GbE to WAN

- Simplest method of deploying a transport infrastructure for distances that cannot be covered directly by GbE consists of using bit/byte interleaving or SONET/SDH framing to incapsulate Ethernet packets ⇒
- ⇒ IP/GbE/SONET
- Nonstandard solution has been dubbed Ethernet over SONET/SDH (EOS)
- This generates problem for multivendor interoperability