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HUT Communications Laboratory

S-72.3340 Optical Networks Course

Lecture 6: MultiService Optical Networks

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Lecture Outline

- Introduction
- Data-Centric Client Layers
  - ATM
  - IP
  - Ethernet
  - SAN
- Next-Generation SDH
- OTN Standard
- Conclusion

1. Introduction

- Last week
  - Focused on optical TDM-based circuit switched networks (PDH, SDH/SONET)
  - Optimized for voice communications
- But…
  - Non-voice traffic now dominates in quantity (80/20% reverse)
  - Voice revenues are dwindling
  - Uncertainty on non-voice revenues
  - Operators need reliable revenue streams
    - Broaden service offering ⇒ "One-stop shopping" for customers
    - Reduce operating expenditure by being more flexibility to meet demand all service types

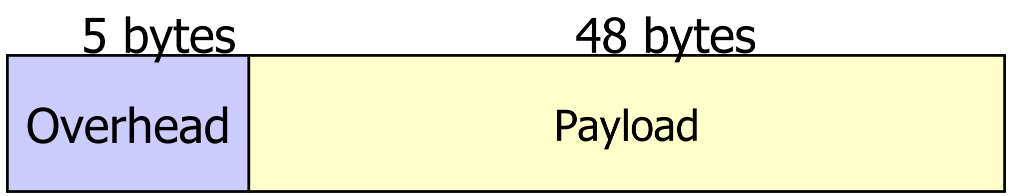
1. Introduction

- Increased use of buzz words (e.g. “triple play” services for home users) and business models (e.g. “multiservice provisioning”)

- Need for multiservice networks
  - Networks that provide more than one distinct communications service type over a common physical infrastructure (optical, wireless, copper etc.)

2. ATM

- Asynchronous Transfer Mode (ATM)
  - Main goal was the integration of voice (SDH, PDH) and data (e.g. IP, frame relay) networks
  - Uses fixed length cells of 53 bytes
    - Fixed packet size enable development low-cost high-speed ATM switches



  - Length is compromise between conflicting requirements of voice and data
    - Small packet size good for voice since delay is short
    - Large size good for data since overhead is small fraction of cell

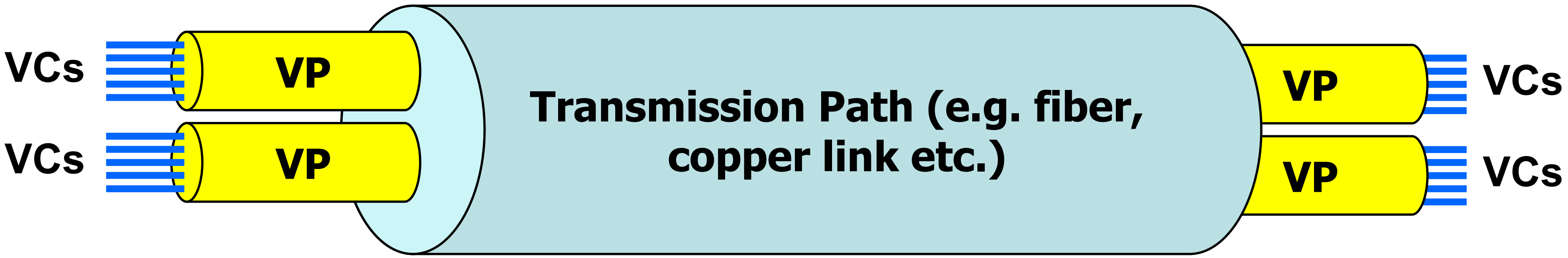
2. ATM

- Main motivation for use of ATM is the quality-of-service (QoS) guarantees it provides

- QoS guarantees in form of bounds on cell loss, cell delay and jitter (delay variations)
  - "Traffic contracts" offered to different service classes (constant bit rate [CBR], unspecified bit rate [UBR] etc.)
  - Enforcing of the traffic contracts
    - Admission control to maintain existing QoS guarantees
    - Traffic shaping at entry points
    - Continuous traffic policing for contract adherence

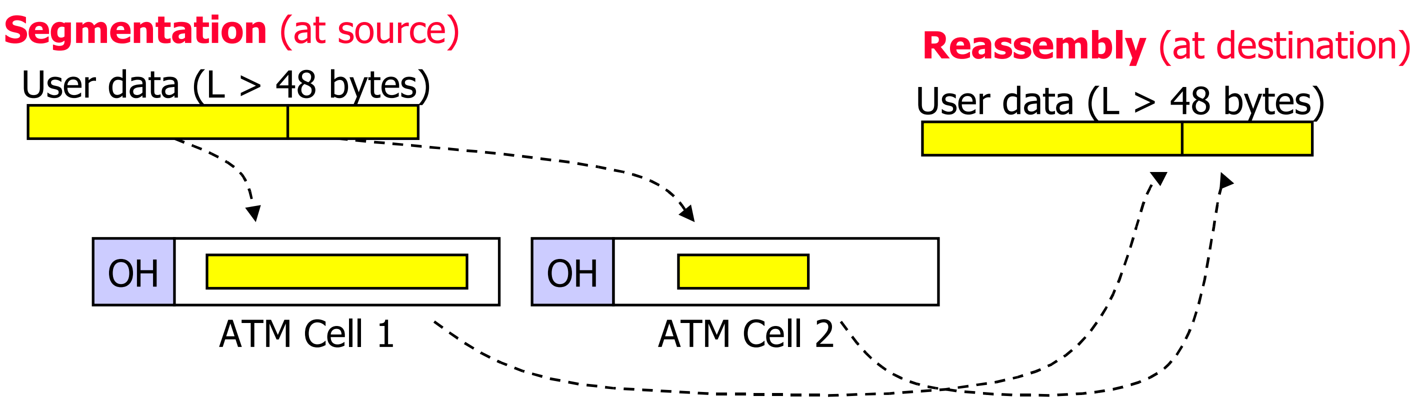
2.1 Functions of ATM

- ATM connections are termed virtual circuits (VC) and these are bundled into virtual paths (VP) on common links
  - Cell headers have VC identifier (VCI) and VP identifier (VPI) labels for addressing
  - Two level labels (VPI and VCI) simplifies cell forwarding and ATM switch designs
  - Switches maintain routing tables and read VCI/VPI to determine outgoing link for forwarding cells and enable rewriting of VCI/VPI fields on header



2.2 ATM Adaptation Layer

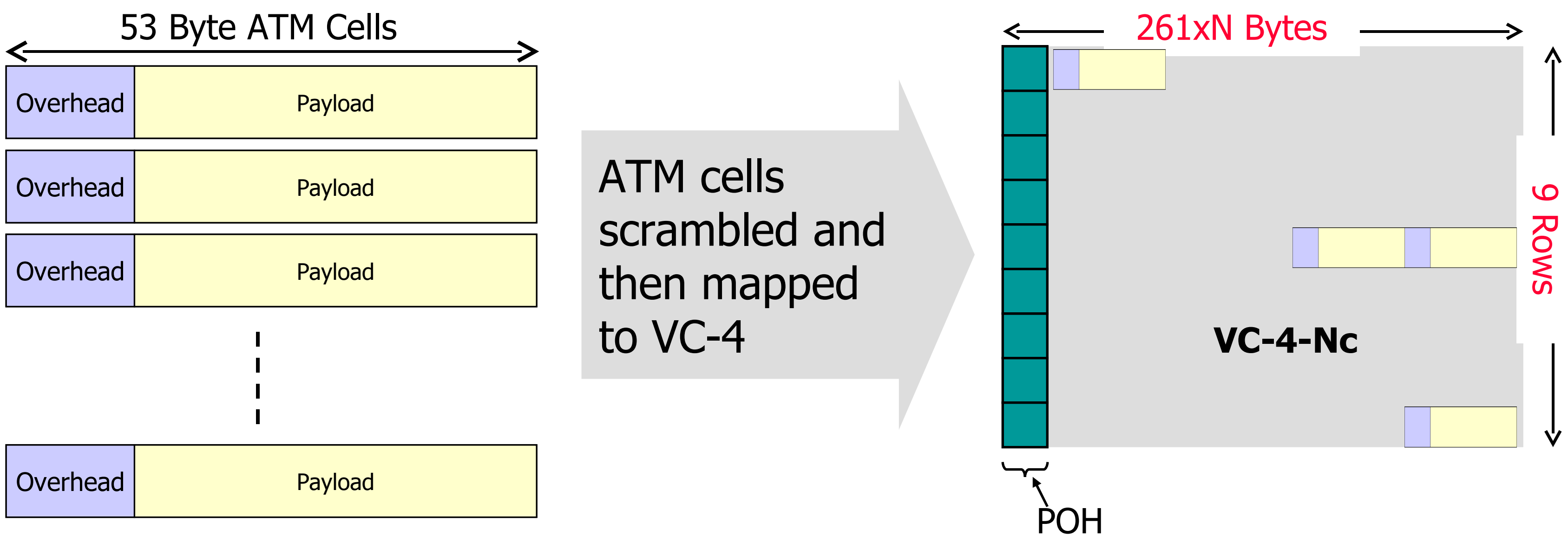
- Services/applications using ATM (e.g. video, IP) usually have variable packet sizes
- ATM adaptation layer (AAL) for mapping user data into ATM cells by segmentation and reassembly (SAR) of user data



- ITU defines the following AALs depending on service type
  - AAL-1 ⇒ for CBR connection-oriented services e.g. E1 circuit emulation
  - AAL-2 ⇒ for CBR real-time data e.g. video, voice etc.
  - AAL-3/4 (merged) ⇒ for VBR data traffic e.g. frame relay
  - AAL-5 ⇒ for VBR variable packet size traffic e.g. classic IP over ATM

2.3 ATM Optical Physical Layer Interfaces

- Optical interfaces originally defined by the ATM Forum
  - Enables interfacing to SDH/SONET terminal equipment
  - Defines framing structure for the transport of ATM cells over SDH
    - Uses VC-4-Nc frames with a concatenated or locked payload, where N=1 for 155.52 Mb/s, N=4 for 622.08 Mb/s and N=64 for 10 Mb/s interfaces



2.3 ATM Optical Physical Layer Interfaces

- Example: 622.08 Mb/s Physical Layer Specification (AF-PHY-0046.000, Jan. 1996) parameters

	Link length	Transmitter	Wavelength window	Receiver sensitivity	Dispersion
Singlemode Fiber	2 km (SR) 15 km (IR)	LED (SR) MLM (IR)	1310 nm 1310 nm	-23 to -28 dBm	13 ps/nm (SR), 74 ps/nm (IR)
Multimode Fiber	300 m	LED	1310 nm	-26 dBm	_
Multimode Fiber	300 m	Short λ laser	850 nm	-16 dBm	_

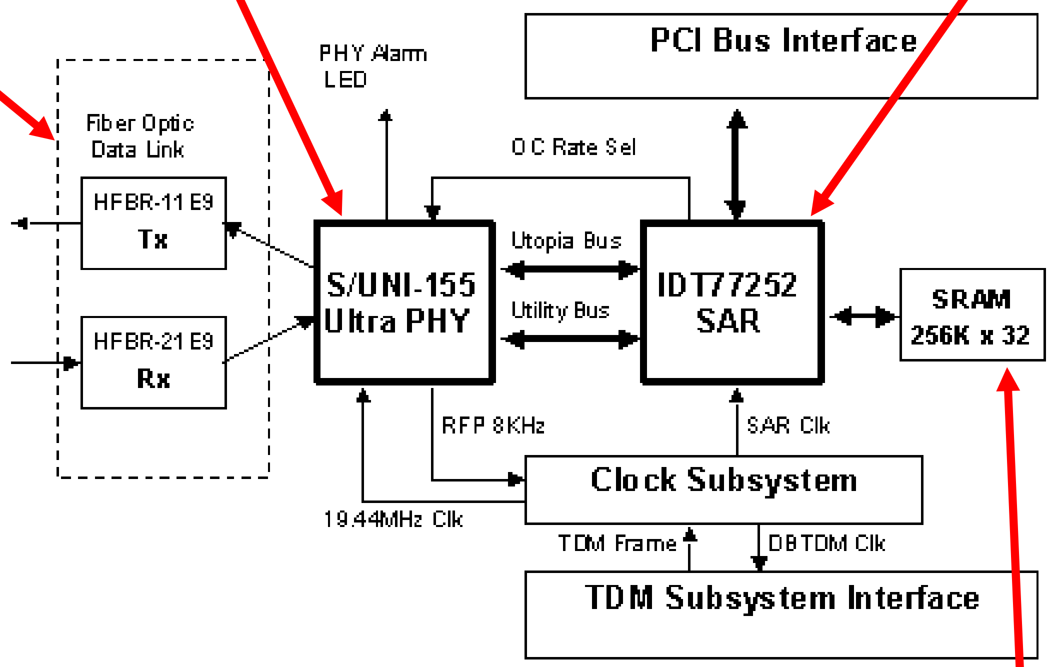
SR: Short Reach, IR: Intermediate Reach

2.3 ATM Optical Physical Layer Interfaces

1300 nm Transmitter and Receiver, 155 Mb/s rate, Multimode fiber

Optical transceiver interface, Clock recovery, SDH/SONET and ATM framing

AAL-3/4 and AAL-5 cell processing



Cell forwarding, Routing table, Transit cell buffering

Example: An OC-1/OC-3/STM-1 ATM-SDH/SONET interface module (by Communication Automation Corporation)

3. Internet Protocol (IP)

- Most widely used wide-area networking technology
  - Underlying networking protocol used in the Internet and private intranets
  - Flexible as it is designed to work above variety of data link layers e.g. Ethernet, ATM, ISDN

- IP is a network layer protocol (routing functions etc.)
  - Therefore IP does not guarantee reliable data delivery
  - Relies on transmission control protocol (TCP) or user datagram protocol (UDP) to keep track of packets and retransmit if needed

3. Internet Protocol (IP)

- IP layer increasingly generates the majority of traffic on existing networks

and…

  - Optical systems provide largest traffic carrier pipes

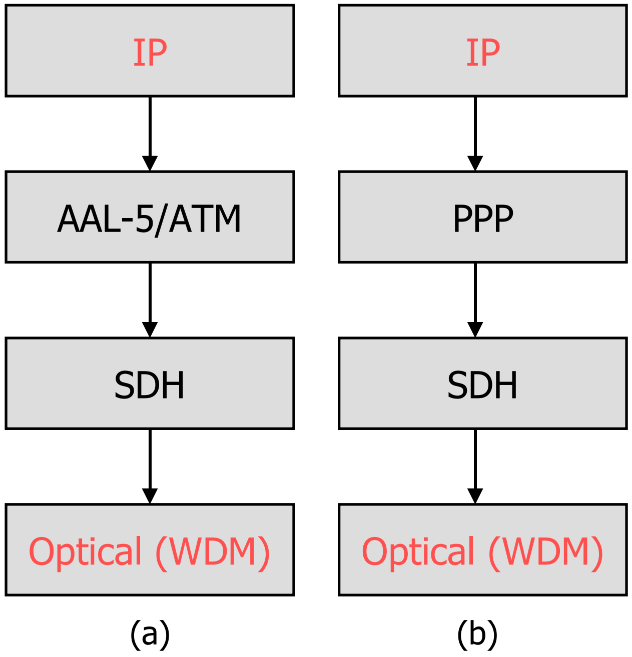
- A recurring theme is how best to transmit IP traffic over the optical (WDM) layer?
  - Also referred to as IP over WDM

3. Internet Protocol (IP)

- Several layering structures possible for mapping IP to optical layer

  - Traditional Implementation: IP packets ⇨ AAL-5 ⇨ ATM cells ⇨ SDH/SONET framing (up to 25% bandwidth wasted on overhead!)

  - IP directly over SDH or "packet-over-SONET": IP packets ⇨ PPP (variable length) frames ⇨ SDH/SONET framing



3.1 IP QoS

- IP provides only a “best-effort delivery” service
- Arriving IP packets may be:
  - Damaged
  - Out of sequence
  - Duplicated
  - Dropped entirely
- If an application requires solid QoS assurances, it is provided by other means e.g. MPLS

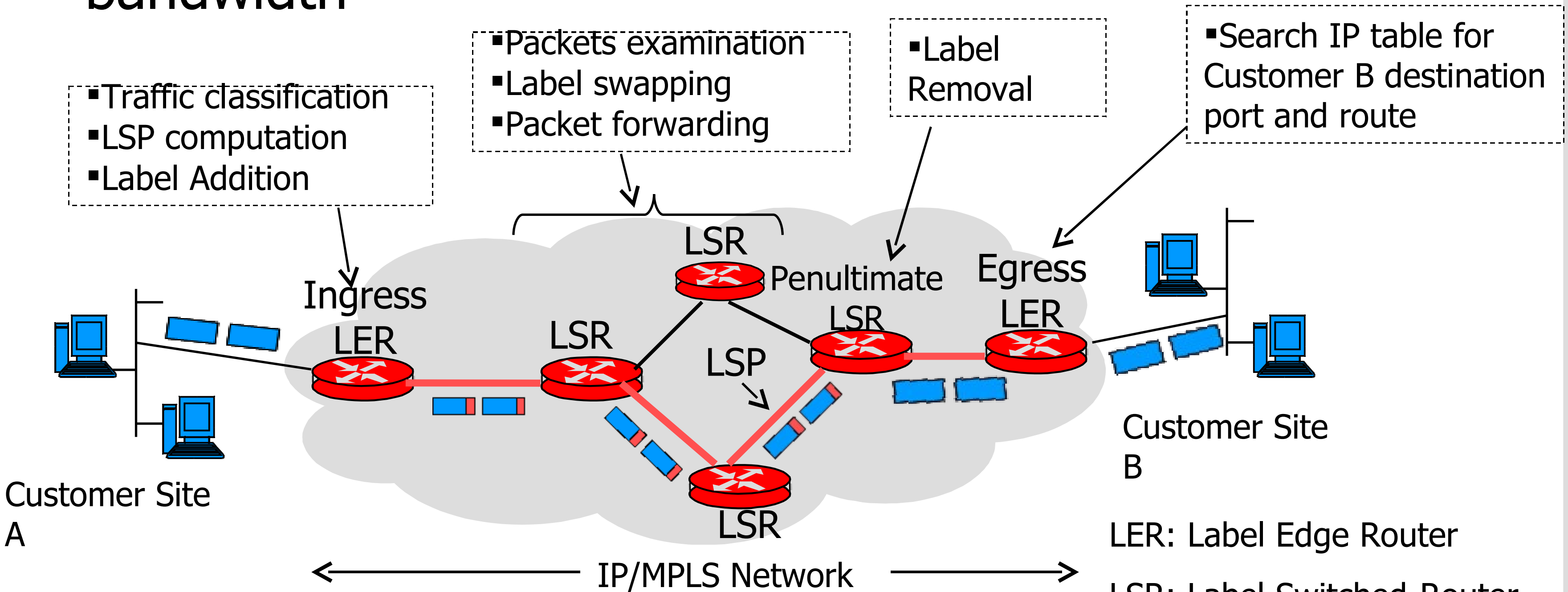
3.2 IP/MPLS

- MPLS ⇒ Multiprotocol Label Switching
  - Originally a Cisco proprietary proposal then adapted by IETF for open standardization
  - Combines IP Layer 3 service opportunities with traffic management control of Layer 2 switching
  - MPLS label set and routing tables used for setting up label switched path (LSP) between nodes in networks
    - MPLS pushed or imposed between IP and layer 2 headers
    - Or in Layer VPI/VCI fields if IP packet is being carried in ATM cells

L2 header	MPLS label	IP header	IP data

3.2 IP/MPLS

- IP/MPLS enable connectionless IP networks to operate in a more connected and managed way
  - Allows LSPs to be setup by different criteria
  - Able to provide QoS assurances e.g. guaranteed bandwidth



LER: Label Edge Router

LSR: Label Switched-Router

3.2 IP/MPLS

- Today providers pursuing IP/MPLS infrastructure as convergence mechanism
  - ATM, Frame Relay, Ethernet etc. networks folded into edges of IP/MPLS core
- Also MPLS virtual private networks (VPNs) are of great interest

3.3 Wither ATM?

- ATM initially viewed as replacement for IP because of its QoS capabilities
  - ATM has suffered because of slow development of standards
  - ATM also has complex provisioning and high cost interfaces
  - IP has survived due to its ubiquity and service creation capabilities

3.3 Wither ATM?

- MPLS now provides IP networks with QoS capabilities similar to ATM
  - MPLS better optimized for larger data packets (~1500 bytes)
  - Running IP packets through AALs increases overhead (inefficient)
  - IP/MPLS is expected to gradually displace ATM in the network core
- ATM still employed in various areas
  - Wireless backhaul
  - Multiplexing in DSL networks
  - Some LAN backbones

4. Optical Ethernet

- Widespread use of 10 Mb/s Ethernet and 100 Mb/s Ethernet (Fast Ethernet)
  - The de facto Layer 2 standard for local area networks (LANs)
- Numerous devices now shipped with Ethernet ports
  - PCs, servers, switches, routers, WiFi access points, VoIP equipment etc.
  - Example: Broadcom shipped 2 billion Ethernet ports between 1995 and June 2006 (Source: PRNewswire)

4. Optical Ethernet

- Now Ethernet deployments extend from LANs into access networks, MANs and WANs
- Advantages of Ethernet/IP compared to SDH/SONET and ATM implementations
  - A mature well understood technology
  - Low cost technology in terms of equipment and operations costs
  - Easier to provision connections
  - Dynamic bandwidth usage and sharing
  - Adaptible to any topology type (ring, star, mesh etc.)
  - Flexible capacity scaling with standards now existing for Gigabit Ethernet and 10 Gigabit Ethernet

4.1 Optical Ethernet PHY

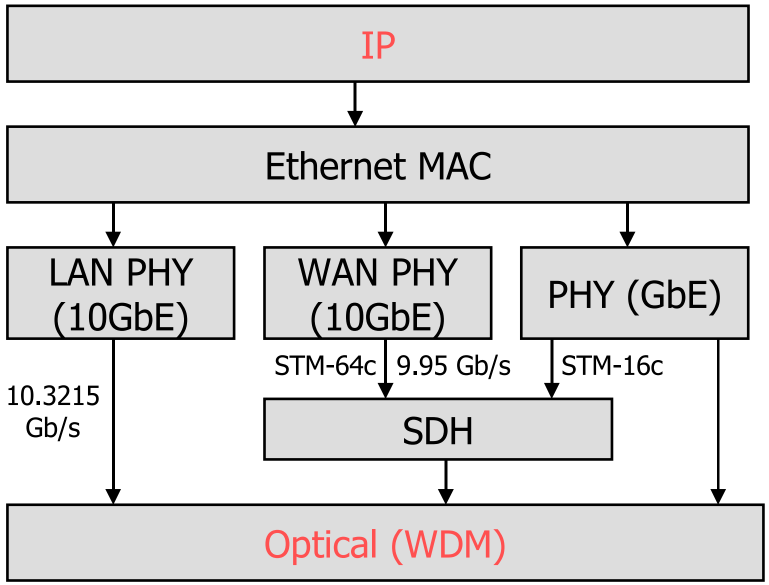
- Gigabit Ethernet or GbE (IEEE 802.3z)
  - Offers nominal 1 Gbit/s rate in both directions
  - Backward compatible with 10 Mbit/s and 100 Mbit/s Ethernet technologies
- Transmission media used for GbE
  - Category 5e (or higher) unshielded twisted copper pairs (1000Base-T)
  - Singlemode and multimode fibers, 1000Base-x, where x depends on the physical layer interface used
    - Example: 1000Base-SX for 850 nm operation over a short-reach multimode fiber

4.1 Optical Ethernet PHY

- 10 Gigabit Ethernet or 10GbE (IEEE 802.3ae)
  - 10 Gbit/s in both directions
  - Backward compatible with previous Ethernet standards
- 10GbE mostly fiber only technology
  - 10GBase-x, where x depends on the physical layer interface used (SR: short reach etc.)
  - Copper interface (10G BASE-T) recently proposed for very short (<30m) links

4.1 Optical Ethernet PHY

- Physical layer (PHY) of GbE and 10GbE defined to move Ethernet traffic:
  - Across SDH networks (WAN PHY for 10GbE)
  - Directly over single wavelength channel or WDM networks (LAN PHY for 10GbE)

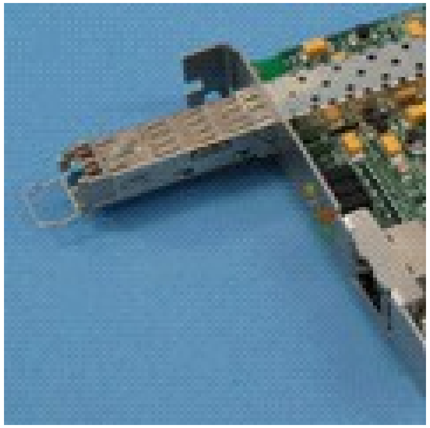


4.2 Pluggable Optics

- GbE initially proposed for LANs with range of about 2km over multimode fibers
- The move into MAN/WANs requires Ethernet optical transcievers suitable for:
  - Long range singlemode fiber transmission
  - WDM (either CWDM or DWDM) operation
  - Optical amplification
- But operators also need to extend useful life of existing GbE and 10GbE switching products

4.2 Pluggable Optics

- Use pluggable optical transceivers to adapt GbE for operation in access networks, MANs or WANs
  - Converts electrical signals within Ethernet switch port into optical signals
  - Could also provided measurements of optical signal power, wavelengths etc. for monitoring purposes

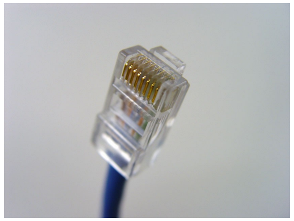

Source: Endace

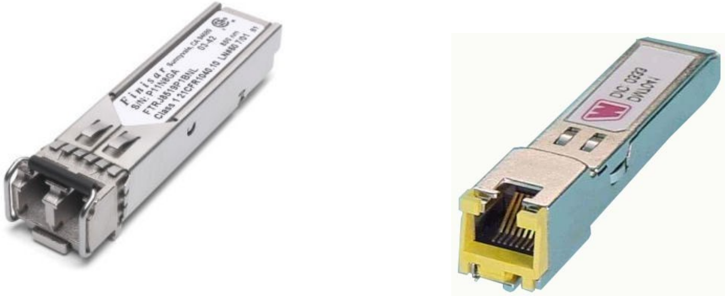
4.2 Pluggable Optics

- Pluggable optics for GbE
  - Gigabit Interface Converters (GBICs)
    - Plug-and-play
    - Hot-swappable
    - About 3cm width

Source: Extreme Networks, Asante

  - Small Form-factor Pluggable (SFP)
    - Plug-and-play
    - Hot-swappable
    - Width about 13 mm ⇒ better port density
    - Just wider than RJ-45 connector

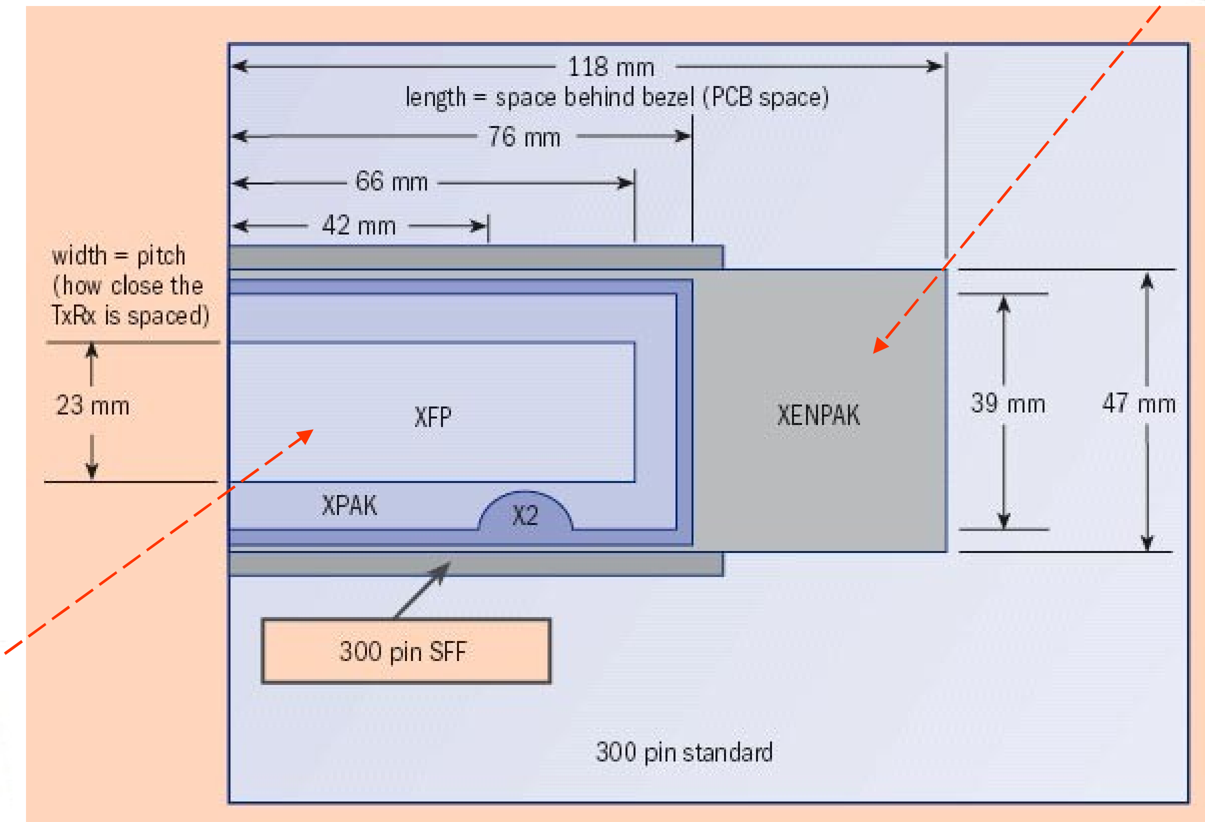




Source: Finisar

4.2 Pluggable Optics

- Pluggable optics for 10GbE
  - 10G Small Form-factor Pluggable (XFP)
  - XENPAK
  - X2
  - XPAK



Evolution of 10GbE pluggable transceivers (Source: FiberSystems Europe)

5. Storage Area Networks (SAN)

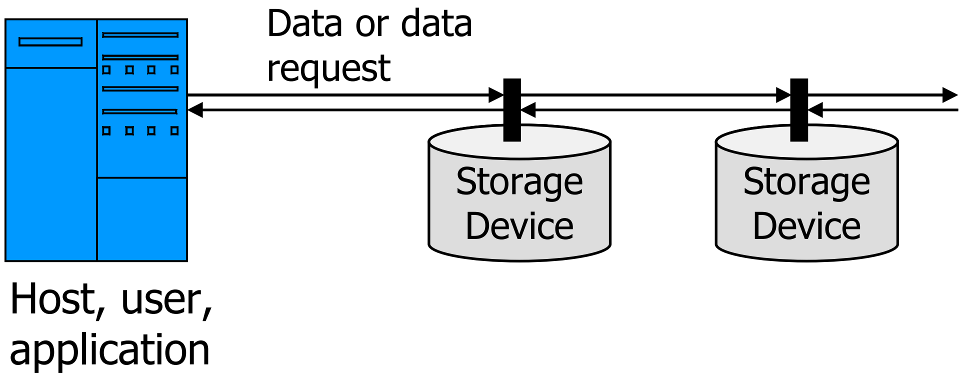
- Enterprises, Government agencies and public sector organizations
  - Discarding paper in favour of electronic data
  - Migrating some of their main business operations (customer care, billing, e-filing etc.) online
  - 24hr × 365days availability requirement for data and applications
    - Always open web storefront, outsourced care, globalization

5. Storage Area Networks (SAN)

- Disaster recovery planning to rescue or recover mission-critical data is now absolutely essential
  - Example 1: 93% of companies that had data outage for 10 days or more filed for bankruptcy within a year (Source: US National Archives and Records…)
  - Example 2: Basel II Accords (June 2004) providing international standardized measure of banks credit rating ⇒ data-backup strategy one of the considered factors
  - Example 3: Average revenue loss per hour caused by data unavailability for different business types:
    - €53,300/hr for tele-ticket sales
    - €5m/hr for brokerage operations (Source: Dataquest)

5.1 SAN Architecture

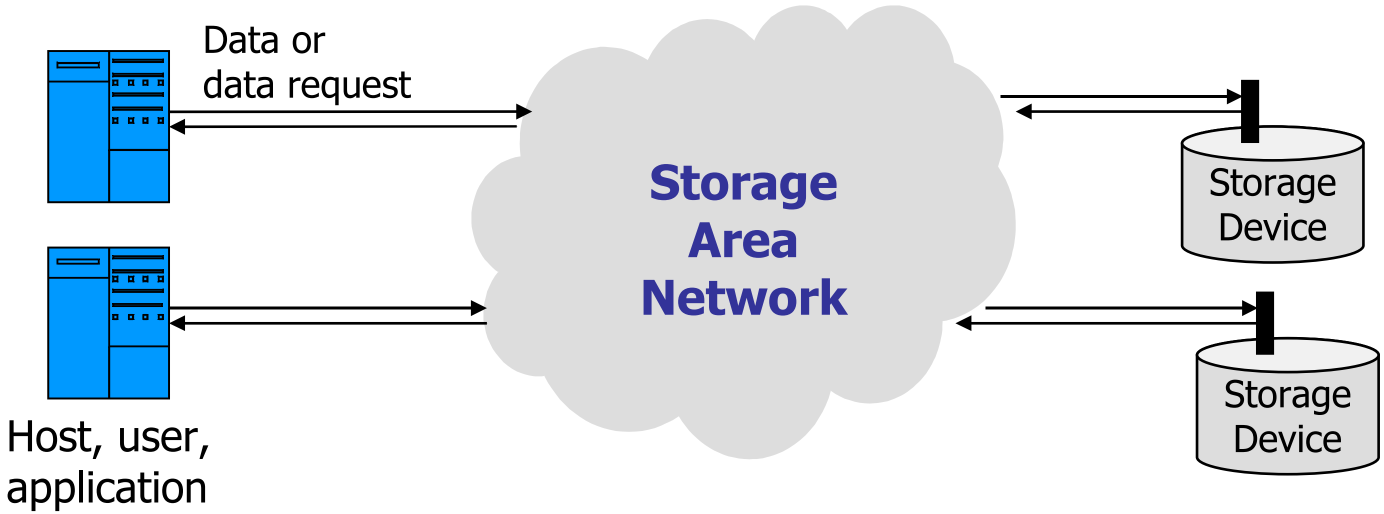
- Previously data exchange and backup confined to enterprise LAN (likely in the same building)
  - Traffic congestion commonplace
  - No redundancy by directly attaching storage devices to LAN servers
  - Little or nothing to recover if disaster hits the enterprise's site



Directly or network attached storage devices

5.1 SAN Architecture

- LAN-free backup using SANs necessary
  - Dedicated high speed links for data recovery
  - Shared storage ⇒ reduced cost
  - Storage capacity and resources can be added without shutting down LAN servers or networks
  - Could employ two (primary and secondary) data centers for increased redundancy



Storage area networks (SANs)

5.1 SAN Architecture

- Now fashionable to move SANs to very distant locations from enterprise sites
  - Secondary data centers 10s or 100s km from enterprise site
  - Provides more resilience against disasters e.g. earthquakes
  - Allows company to locate large peripherals in cheaper suburban areas

Hurricane Katrina, 2005

Kobe Earthquake, 1995

5.2 SAN Standards

- SAN data rates (usually expressed in Bytes/second) should be easily scalable for future growth
  - Amount of electronically stored data growing at a rate of 40%-80% per year
  - Data from remote storage site should appear like its coming from a local source
- Storage connectivity earlier used copper links
  - Insufficient capacity and unreliable
- Now mostly use high capacity optical systems
  - Fiber links (multimode and singlemode)
  - Low cost optical components e.g. LEDs, multilongitudinal mode (MLM) lasers, GBICs etc.
  - SDH/SONET, GbE/10GbE, DWDM or CWDM transmission

5.2 SAN Standards

❒ Various optical SAN proprietary technologies and standards exist

Technology	Developer / date	Profile	Max. Rate (MByte/s)	Physical Interface
ESCON: Enterprise Systems Connection	IBM/ 1980s	▪Serial interface, half duplex ▪I/O switches capable of providing dynamic connectivity for up to 60 fiber optic links	17	LED/MMF, MLM/SMF
HIPPI: HIgh Performance Parallel Interface	ANSI/ 1980s	▪Widely deployed in supercomputer installations ▪Uses switches like ESCON	200	MLM/SMF
FC: Fiber Channel	ANSI/ Early 1990s	▪Initially used for supercomputers, now a popular SAN standard ▪Deployed in point-to-point, arbitrated loop and switched topologies ▪Runs other protocols e.g. HIPPI, ESCON ▪FC over TCP/IP (FCIP) and internet FC protocol (iFCP) allows FC to use IP networks and routers	800 2400 (not backward compatible)	MLM/SMF SLM/SMF
FICON: Fiber Connection	IBM	▪Takes the ESCON protocol and maps it onto FC transport ▪Improves ESCON by increasing distance, rates, concurrent connections etc.	400	MLM/SMF SLM/SMF
iSCSI: Internet Small Computer System Interface	IETF/ 2003	▪SCSI protocol popular storage access protocol ▪iSCSI is SCSI protocol over a TCP/IP network ▪Main competitor of the FC protocol	IP network capacity limit	Installed fiber base

5.2 SAN Standards

- Example: Time to recovery 60 terabytes (60×10^3 GB) of data across a metro area
  - Using STM-1 connection ⇒ 49 days
  - Using ESCON connection ⇒ 45 days
  - Using 200 MB/s FC connection ⇒ 8 days
  - Using 400 MB/s FC over 64 wavelength channel DWDM system ⇒ 1.5 hours
- If recovery durations longer than several days
  - May be better to use PTAM or "Pick-up truck access method"
  - Manually transport storage devices from data center

5.2 SAN Standards

- Enterprise IT departments decision making on SAN solutions
  - Recovery Time Objective ⇒ how long an enterprise can wait before systems are recovered, resynchronized and back in service
  - Recovery Point Objective ⇒ amount of data an enterprise can afford to have lost once operations are restored

STORAGE SERVICES: SOMETHING FOR EVERYONE

Service	RTO	RPO	Number of sites	Technology Storage/server	Technology Network
Business continuity	zero to minutes	zero to minutes	2 to 3	server clusters with synchronous disk mirroring and stand-by servers	DWDM/CWDM
Fast data recovery	hours	minutes	1 to 2	synchronous disk mirroring and stand-by servers	DWDM/CWDM Fibre Channel over IP SONET/SDH
Slow disaster recovery	day	hours	1 to 2	asynchronous disk mirroring or electronic tape vaulting	CWDM Fibre Channel over IP SONET/SDH
Off-site backup	day(s)	day(s)	1 to 2	tape and "safe"	PTAM (Pick-up truck access method)

Source: FibreSystems Europe

6. Next Generation SDH/SONET

- Conventional SDH/SONET has several limitations
  - Traffic carried in streams with fixed speeds (e.g. STM-16, E4 etc.)
  - Lack of built in capability to dynamically alter speed of streams according to usage
- SDH/SONET originally designed for circuit-switched voice traffic
  - Unsuitable for asynchronous packet-switched bursty data traffic
  - Four-fold capacity increase increments (e.g. from STM-1 to STM-4) $\Rightarrow$ Inflexible provision of capacity to users
- Facing competition from data-centric standards (e.g. Ethernet)

6. Next Generation SDH/SONET

- Carrier choices
  - Invest in a new parallel data-centric network infrastructure?
  - …or maximize reuse of existing SDH/SONET networks
    - Tried and tested
    - Excellent management features
    - Resilient design configurations (e.g. SNCP rings)
    - Reduce capital expenditure
    - Extending network's lifespan

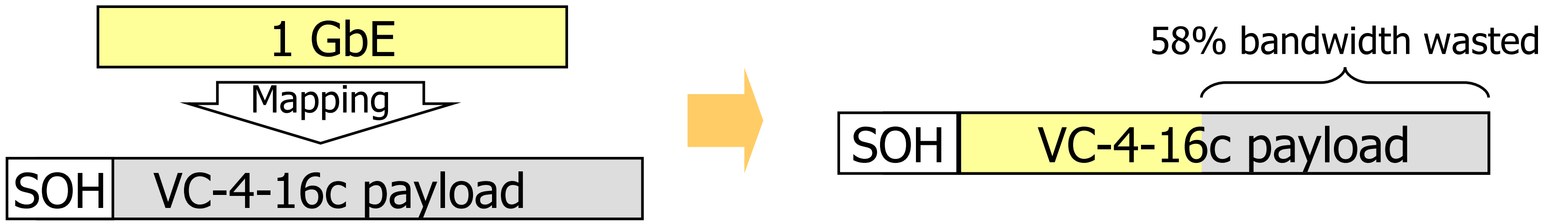
6. Next Generation SDH/SONET

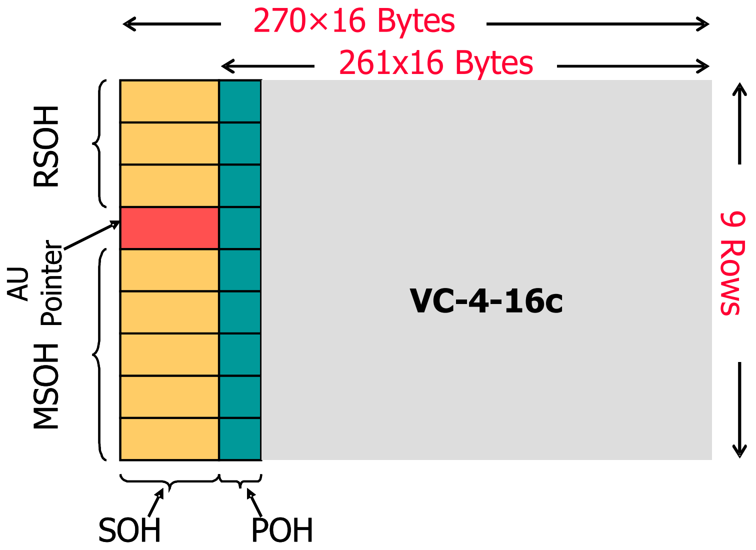
- Upgrade current systems with next-generation SDH/SONET (NG-SDH) solutions
  - Virtual Concatenation (ITU-T G.7043)
  - Link Capacity Adjustment Scheme (ITU-T G.7042)
  - Generic Framing Procedure (ITU-T G.7041)

- These upgrades only needed at source and destination terminal equipment of required service
  - Intermediate equipment do not need to be aware and can interoperate with upgraded equipment
  - Enables operater to make only partial network upgrades on as-needed basis

6.1 Virtual Concatenation (VCAT)

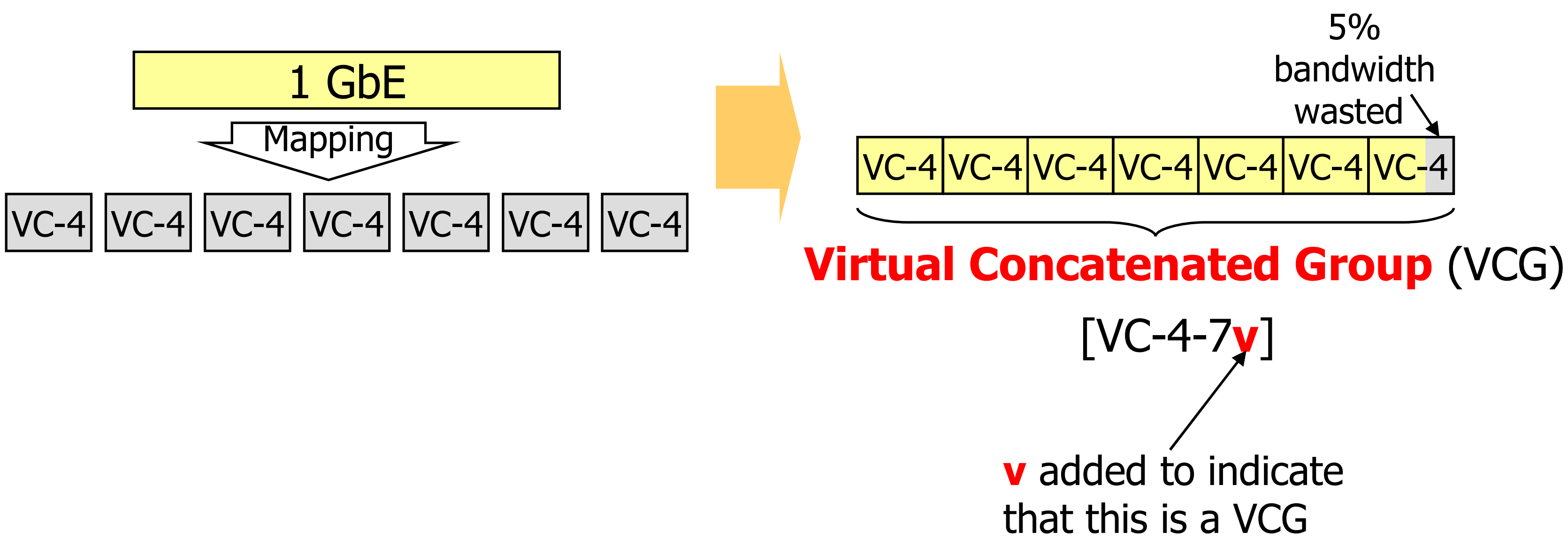
- Fixed and contiguous rates leads to waste of bandwidth
  - Example: Mapping 1 GbE (1 Gbit/s) to VC-4-16c payload of an STM-16c (2.5 Gbit/s) frame





6.1 Virtual Concatenation (VCAT)

- VCAT ⇒ improve bandwidth efficiency by fragmenting streams and placing in many smaller containers
  - Example: Mapping 1 GbE to payload of seven basic VC-4 containers



6.1 Virtual Concatenation (VCAT)

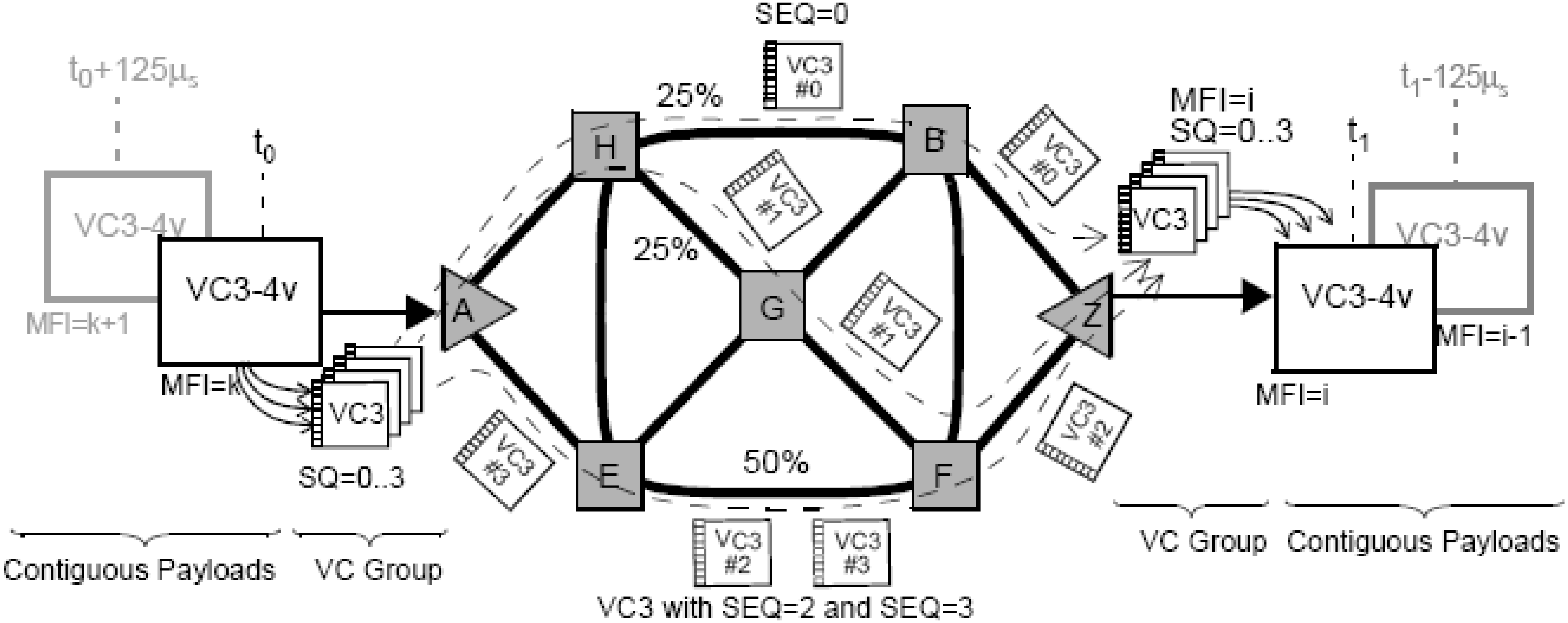
- Low-order (LO) VCGs for low-speed applications e.g. network edges
- High-order (HO) VCGs for higher-speed applications e.g. core networks

	SDH VCAT type	Component Signal	X range	Capacity (kb/s)	
LO VCG	VC-11-Xv	VC-11	1 to 64	1600 to 102 400	e.g. X=16 for 25 Mbit/s ATM
LO VCG	VC-12-Xv	VC-12	1 to 64	2176 to 139 264	e.g. X=5 for 10 Mbit/s Ethernet
LO VCG	VC-2-Xv	VC-2	1 to 64	6784 to 434 176	
HO VCG	VC-3-Xv	VC-3	1 to 256	48 348 to 12.5 Gb/s	e.g. X=4 for 200 MB/s ESCON
HO VCG	VC-4-Xv	VC-4	1 to 256	149 760 to 38.3 Gb/s	e.g. X=7 for GbE

Source: IEEE Communications Magazine, Vol 44, No 5, May 2006.

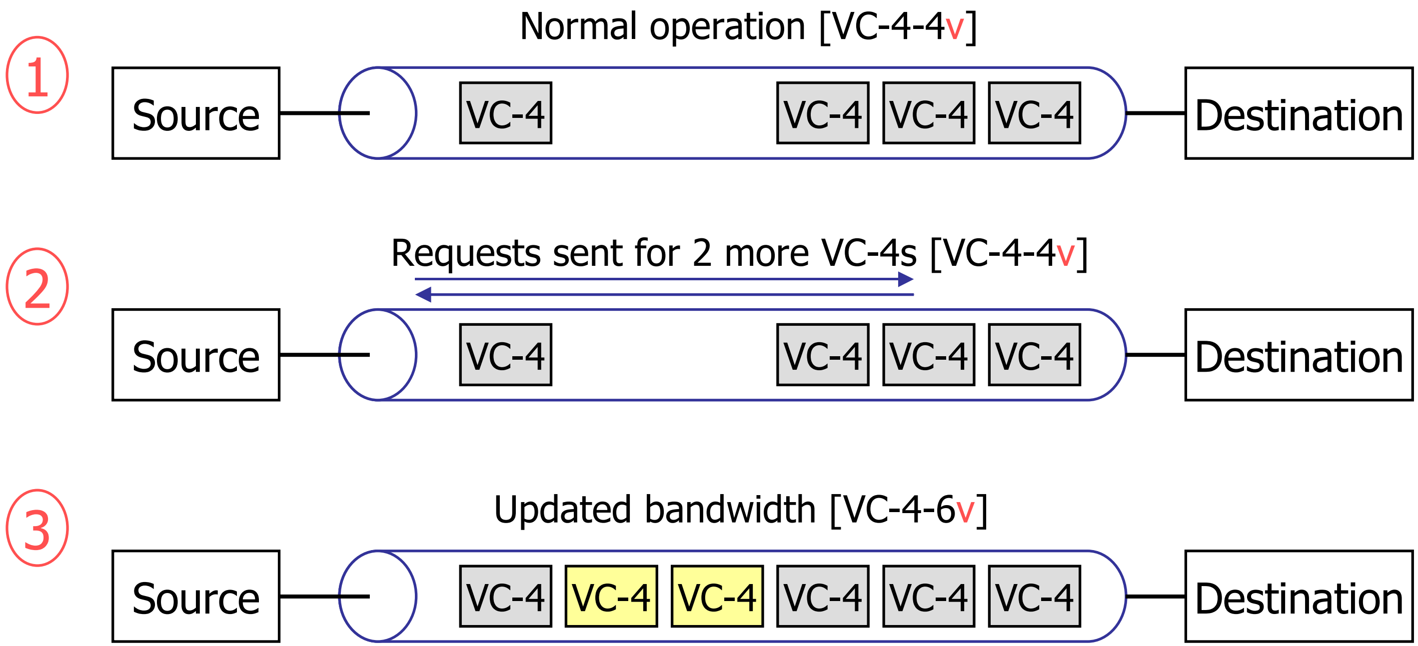
6.1 Virtual Concatenation (VCAT)

- VCG members routed and transported independently over SDH network
  - VCG recombined at destination VCG receiver
  - If a link fails only a fraction of the VCG is lost



6.2 Link Capacity Adjustment Scheme (LCAS)

- LCAS ⇒Enable increase and decrease VCG capacity on increments of member container bandwidths
  - Without affecting or taking down the entire VCG service (hitless)
  - Once a VCG is defined, the source and destination (sink) equipment are responsible for agreeing which members will carry traffic



6.2 Link Capacity Adjustment Scheme (LCAS)

- Capacity control is unidirectional
  - Forward LCAS VCG capacity can differ to that of the reverse direction
  - Both can change without coordination

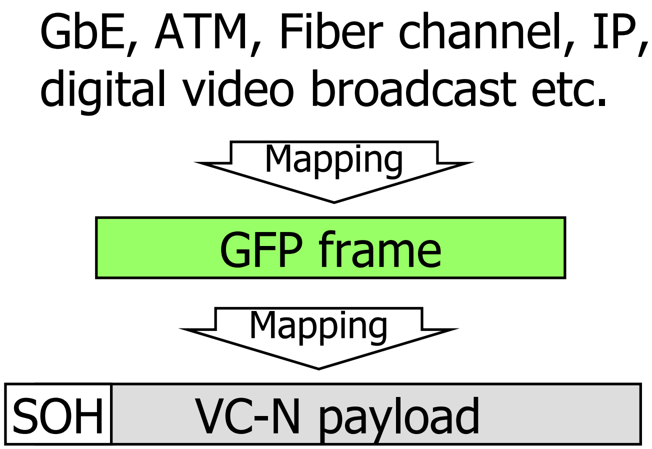
- Note that VCAT can be used without LCAS, but LCAS only possible with VCGs therefore requires VCAT

6.2 Link Capacity Adjustment Scheme (LCAS)

- LCAS flexibility has several practical benefits
  - Allows bandwidth-on-demand provisioning
    - Time-of-day demands
    - Special events
    - Pay-as-you-grow
    - Introducing new service granularities
  - Enables removal of failed VCG members and eventual member reinstatement without affecting services
  - Could be used to enhance other functions
    - Load-sharing
    - Congestion-avoidance
    - QoS differentiation

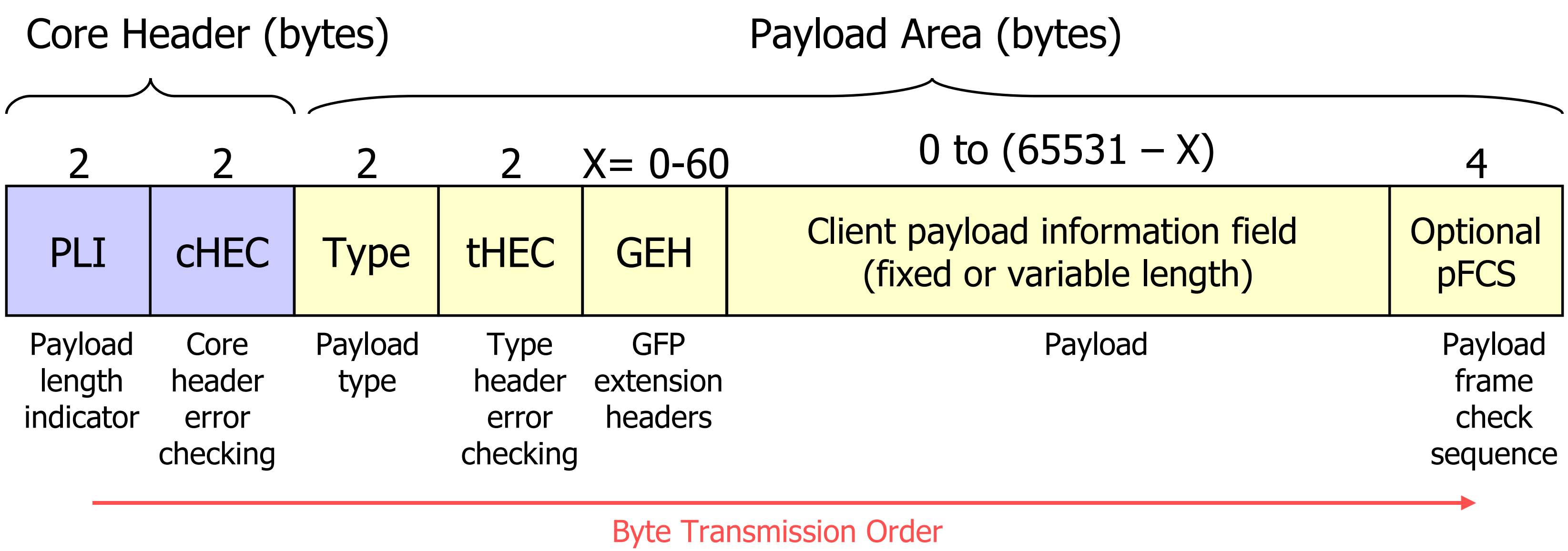
6.3 Generic Framing Procedure (GFP)

- GFP provides mechanism for mapping packet and circuit-switched data traffic to SDH frames
  - Traffic mapped onto general purpose GFP frames
  - GFP frames then mapped to SDH VCs
  - Only needed at source and destination equipment



6.3 Generic Framing Procedure (GFP)

- GFP defines different length frames and different client-specific frame types for payload and management

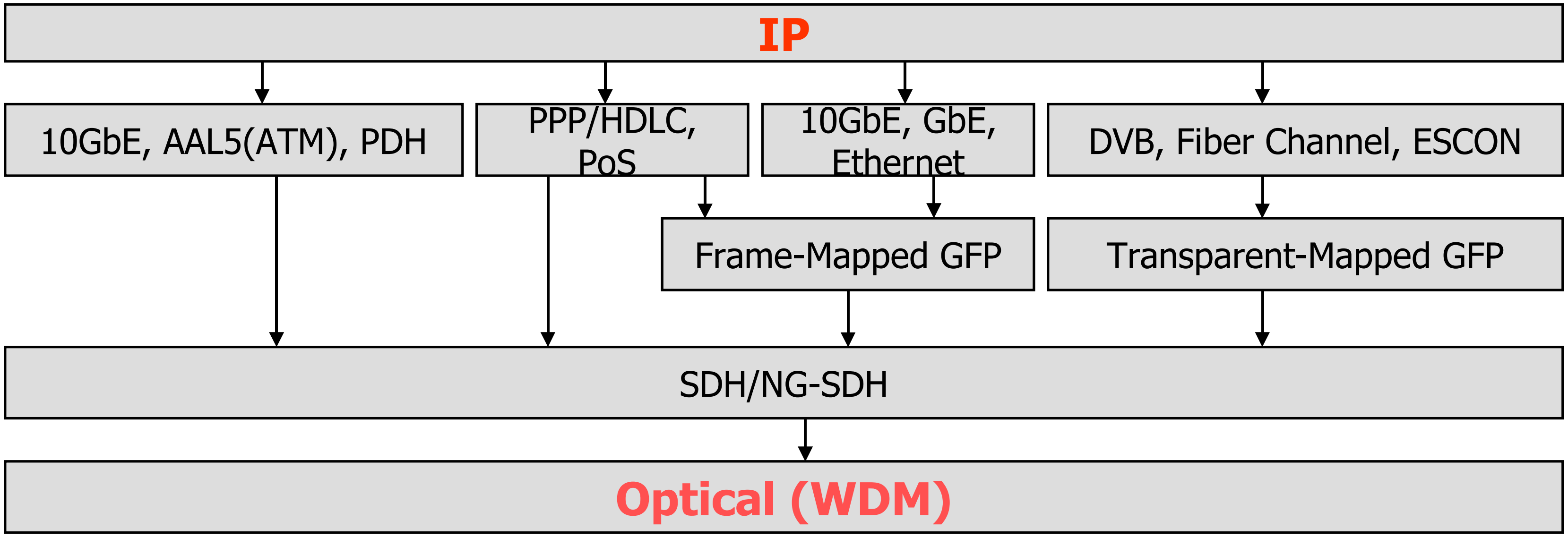


6.3 Generic Framing Procedure (GFP)

- GFP specification allows 2 different transport modes
  - The frame-mapped GFP (GFP-F): optimized for framing variable length packets (e.g. Ethernet, IP/MPLS)
    - Whole data frames mapped in its entirety
    - Variable GFP frame length depending on client packet or frame size
  - The transparent-mapped GFP (GFP-T): optimized for services that require bandwidth efficiency and are delay sensitive (e.g. DVB)
    - Data mapped byte by byte
    - May span multiple GFP frames
    - Fixed length GFP frame

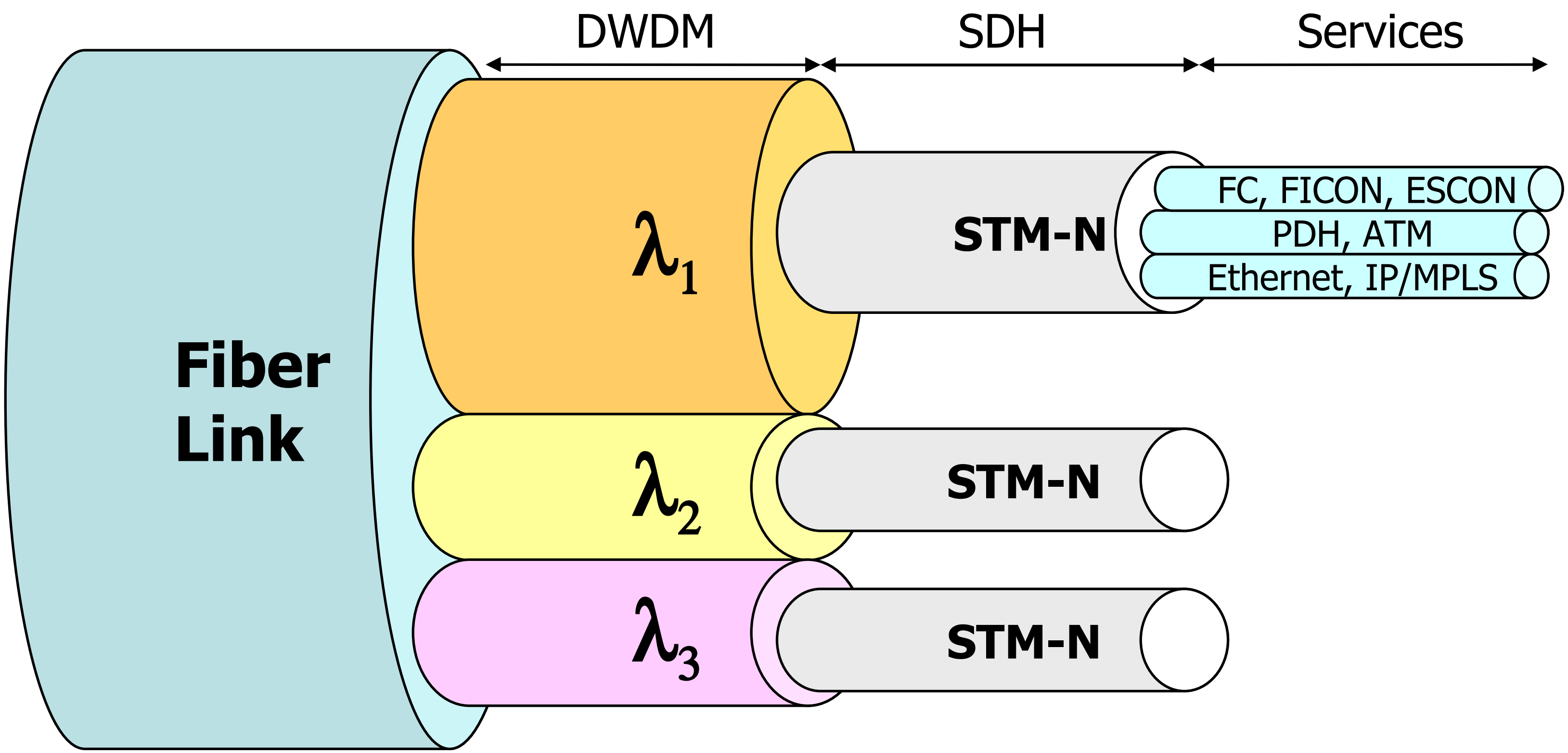
6.3 Generic Framing Procedure (GFP)

- Example ways of transporting IP packets over optical (WDM) networks



7. Optical Transport Network (OTN)

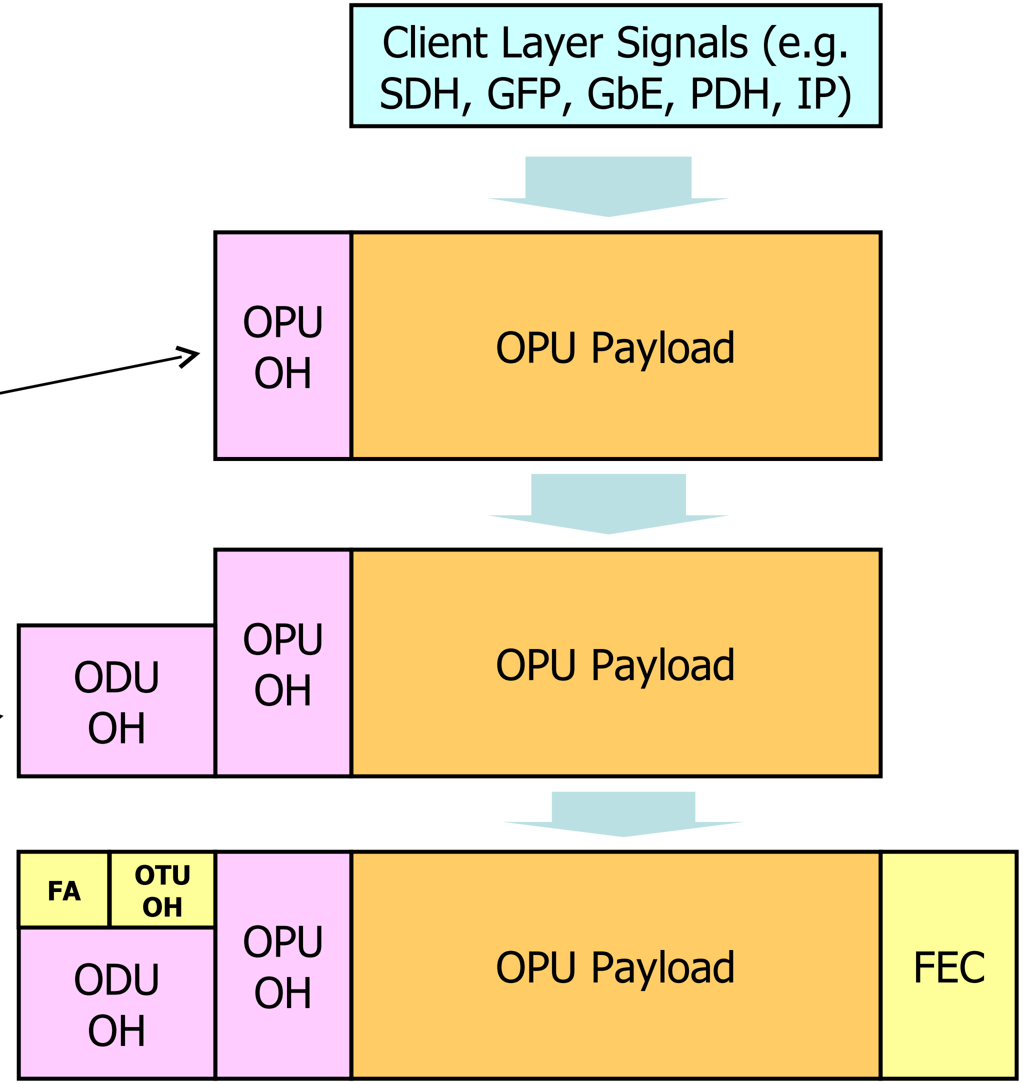
- DWDM has significantly increased fiber capacity for SDH
  - But also introduced new network elements (e.g. wavelength MUX/DEMUX) that require monitoring to ensure reliability
  - SDH monitoring and management only available for SDH sublayers



7. Optical Transport Network (OTN)

- OTN ⇨ a relatively new standard (ITU-T G.709, G.872)
  - Truly global standard unlike SDH/SONET
  - Enables SDH-like Operations, Administration, Maintenance and Provisioning for WDM networks
    - Reduces the requirement to run every service through SDH/SONET to benefit from the management features
  - More efficient multiplexing, provisioning, and switching of high-bandwidth ($\geq$ 2.5 Gbit/s) services
  - Improved multivendor and inter-carrier interoperability
  - Forward error correction (FEC) from the beggining
  - Less complex than NG-SDH ⇒ easier to manage

7.1 OTN Framing and Multiplexing



Optical Payload Unit (OPU)

OPU OH for identifying and mapping client signals adaptation

Optical Data Unit (ODU)

ODU OH for end-to-end path supervision, TCM

Optical Transport Unit (OTU) or Digital Wrapper

FA: Frame Alignment, FEC: Forward Error Correction RS(255,239)

7.1 OTN Framing and Multiplexing

- OTU frame size is fixed but duration changes with order k where k=1, 2 or 3
  - In SDH, STM-N frame duration fixed (125 µs due to legacy 8 kHz digital voice sampling rate) but size varies with N

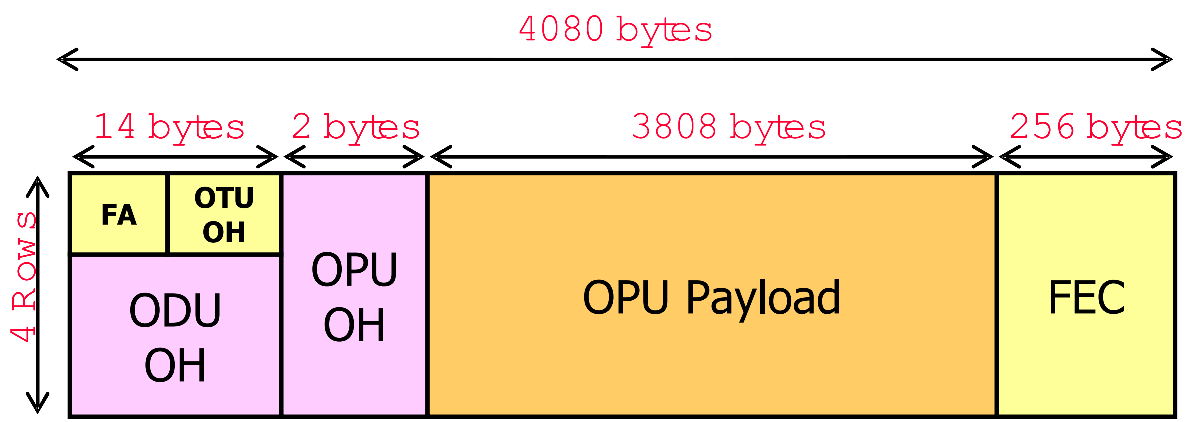


Figure: Dimensions of an k order OTU frame (OTU-k)

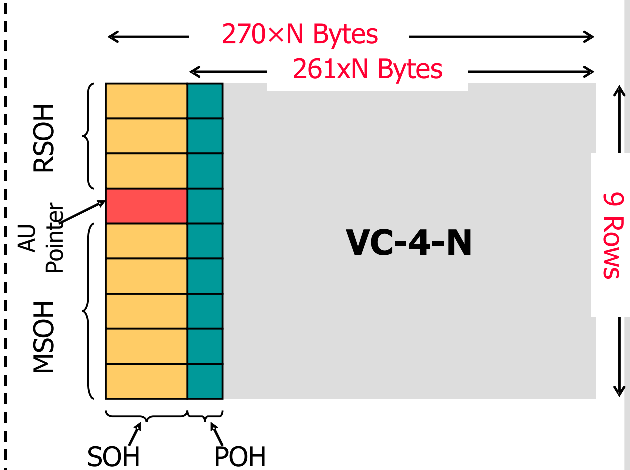


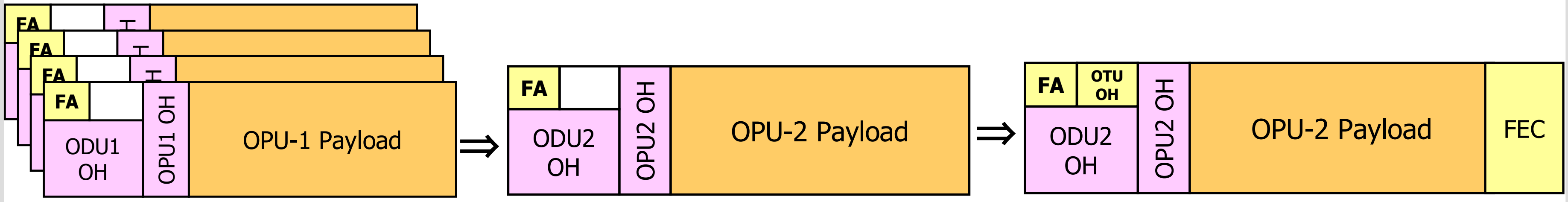
Figure: STM-N frame structure

7.1 OTN Framing and Multiplexing

Table: Date rates and durations for standardized k order ODU and OTU frames

ODU-k	Data rate	OTU-k	Data rate	Order	Duration (μs)
ODU-1	2.5 Gb/s	OTU-1	2.67 Gb/s	k=1	48.971
ODU-2	10 Gb/s	OTU-2	10.7 Gb/s	k=2	12.191
ODU-3	40 Gb/s	OTU-3	43 Gb/s	k=3	3.035

- Low k order ODU frames interleaved to form higher order frames



Example: 4 × ODU-1 ⇒ 1 × ODU-2 ⇒ 1 × OTU-2

7.1 OTN Framing and Multiplexing

- Virtual concantenation also available for OTN
  - Realized by concatenating OPUk frames into OPUk-Xv groups
  - Enables very flexible support of line rates ≥ 2.5 Gbit/s
  - Rates over 10 Tbit/s possible (OPU3-256v) for future!

OTN VCAT type	Component signal	X range	Capacity (kb/s)
OPU1-Xv	OPU1	1 to 256	2,488,320 to 637,009,920
OPU2-Xv	OPU2	1 to 256	~9,995,277 to ~2,558,709,902
OPU3-Xv	OPU3	1 to 256	~40,150,519 to ~10,278,532,946

TABLE 3. OTN component and VCAT signals.

Source: IEEE Communications Magazine, Vol 44, No 5, May 2006.

7.2 Optical Channel (OCh)

- OTU-k is an electric signal ⇒ converted to an optical channel (OCh) signal for fiber transmission
  - OCh transports an OTU-k between electronic transponders in an OTN
  - OCh overhead transported on an out-of-band wavelength channel ⇒ optical supervisory channel (OSC)

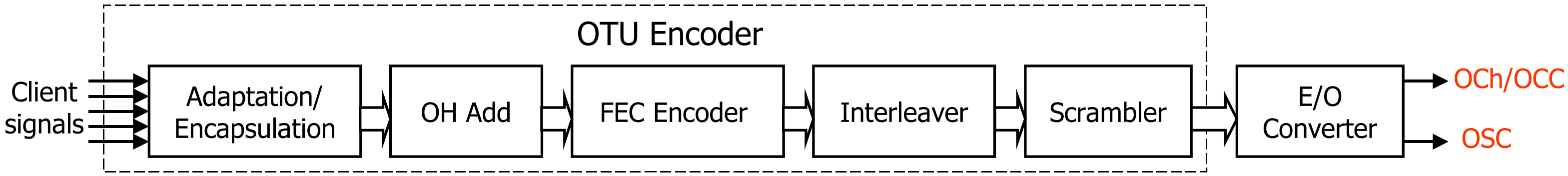
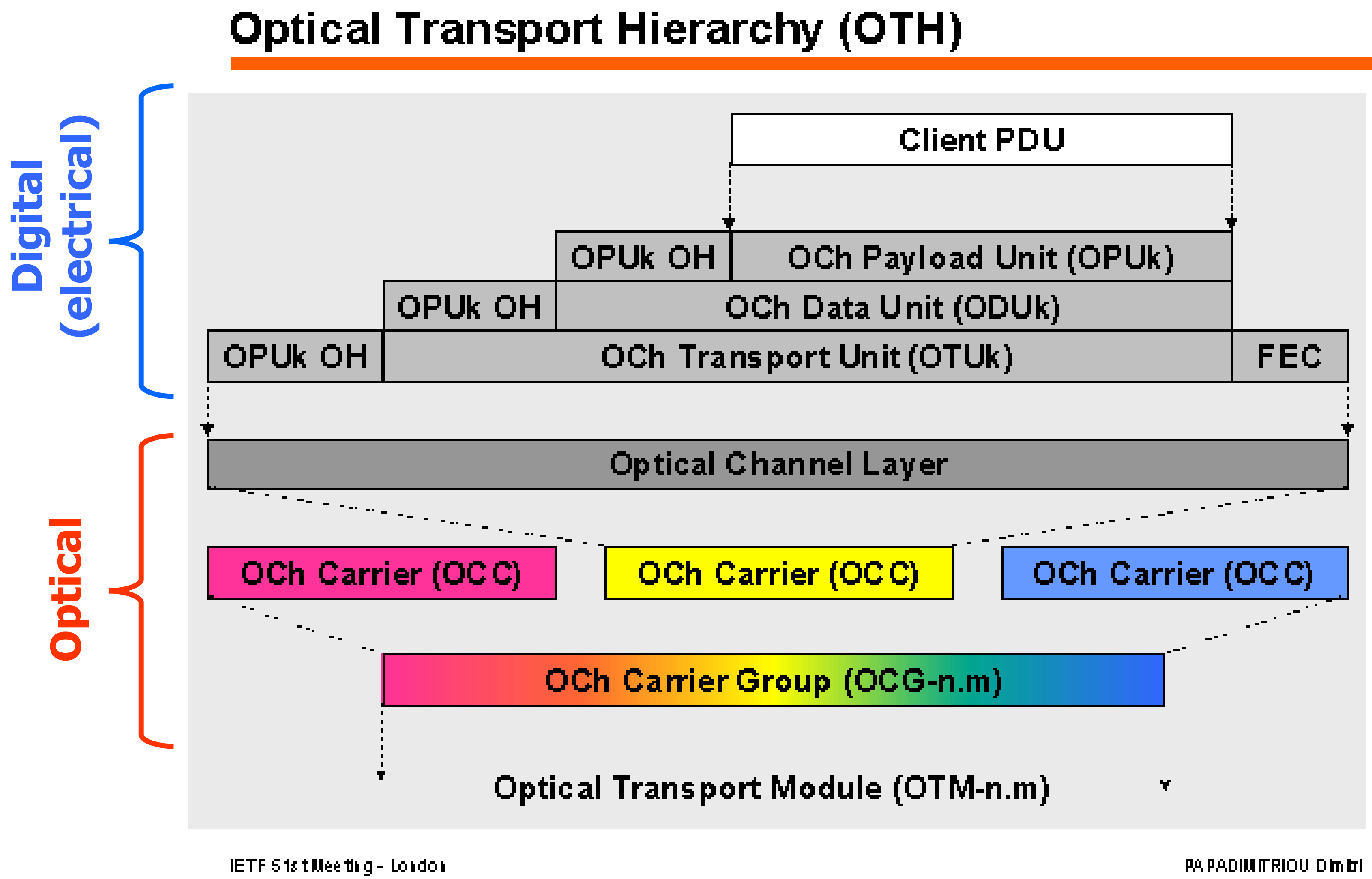


Figure: Block diagram of OTN transmitter

  - n distinct OCh carriers (OCC) of bit rate index m can be multiplexed (using WDM) to form an OCC group (OCG-n.m) to share a common fiber

7.2 Optical Channel (OCh)



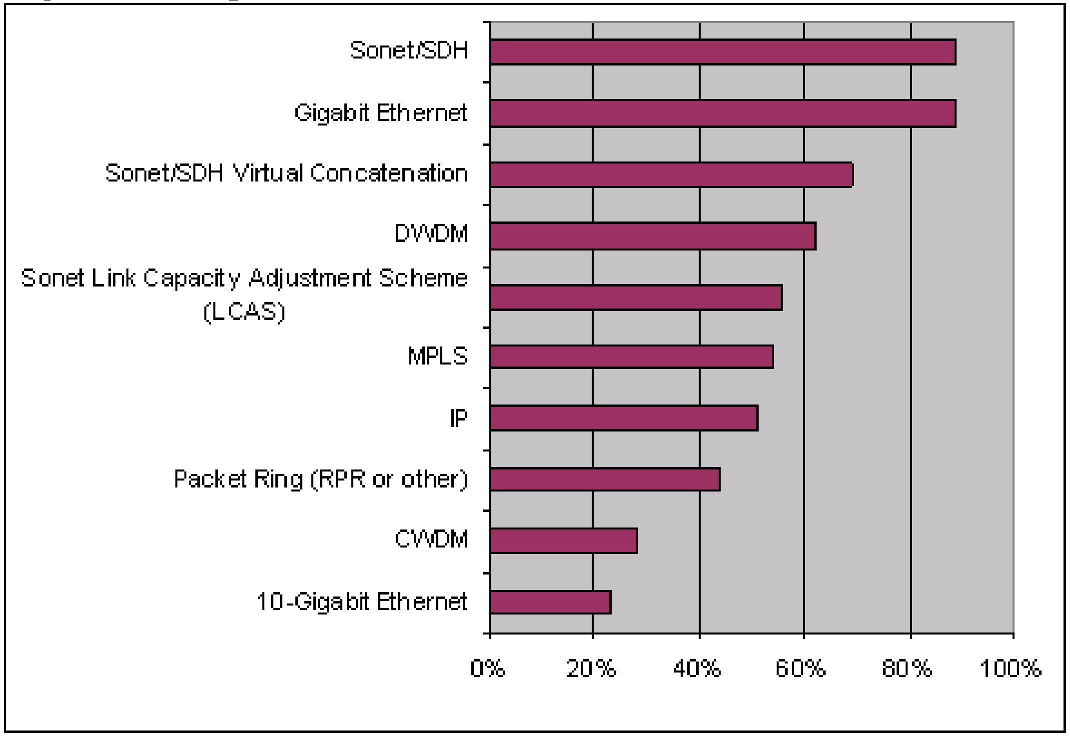
8. Multiservice Platforms

- Optical network operators now faced with a difficult choices to make among a multitude of standards
- How to build new networks or evolve existing network?
  - NG-SDH
  - Ethernet
  - OTN
  - IP/MPLS
  - CWDM or DWDM
  - etc.

8. Multiservice Platforms

- Multiservice provisioning platform (MSPP)
  - Multiservice provisioning using NG-SDH features
  - Diverse optical and electrical interfaces (GbE, SAN, IP, OTN etc.)
  - Support for CWDM or DWDM transmission

Major Technologies Used in MSPPs



Source: *Heavy Reading*

8. Multiservice Platforms

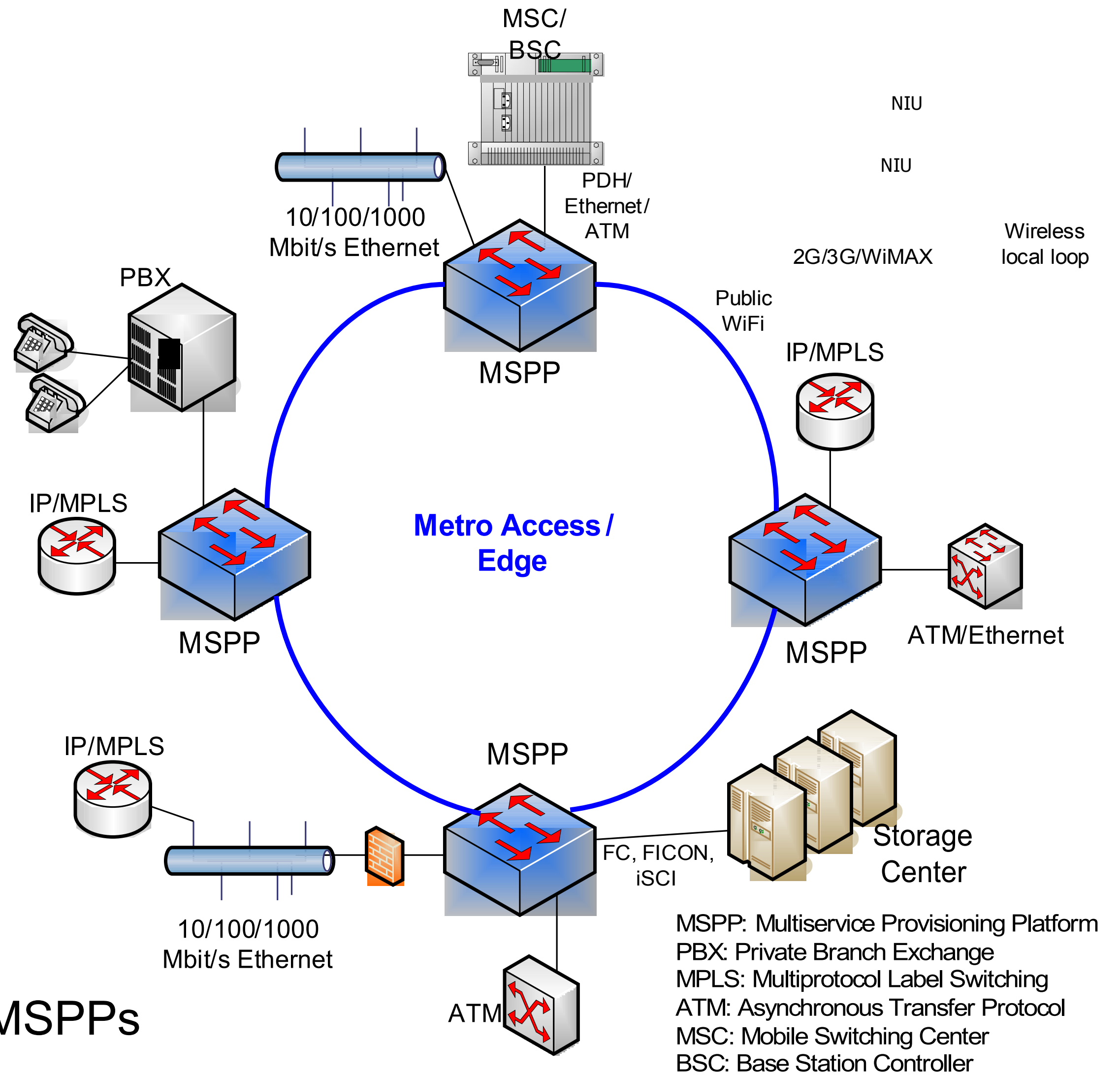
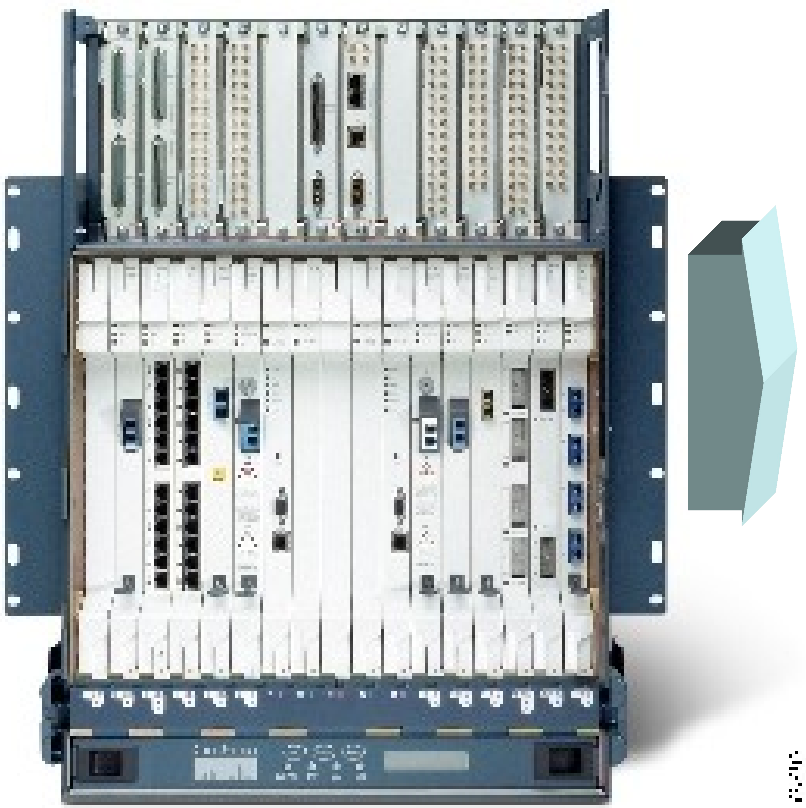


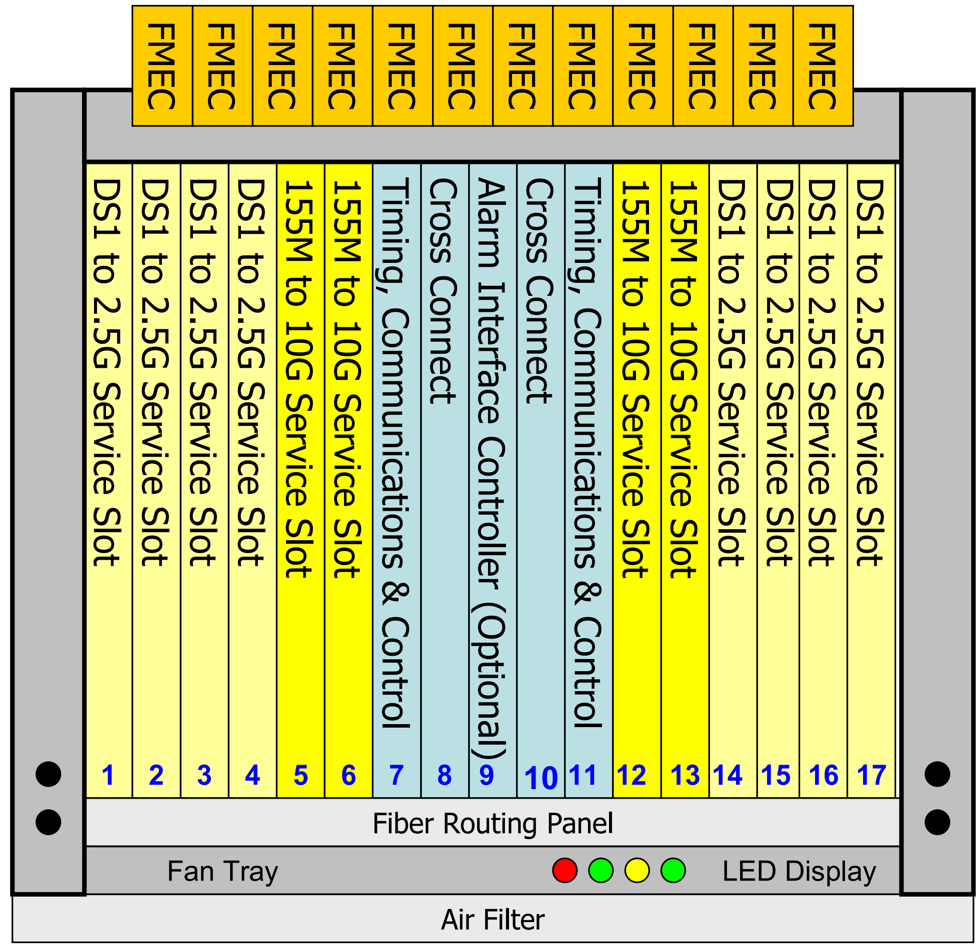
Figure: Example service mix supported by deployment of MSPPs

8. Multiservice Platforms

- Example MSPP: Cisco ONS 15454



Cisco ONS 15454



8. Multiservice Platforms

Cisco ONS 15454

- Supported interfaces
  - Electrical (DS1, E1, E3, STM-1E etc.)
  - SDH (up to STM-64)
  - CWDM and DWDM (OTN)
  - Ethernet (up to GbE)
  - SAN (Fiber Channel and FICON)
  - Video (D1 video, HDTV)
- Cross-connection levels
  - DS1/E1 up to STM-64

Conclusions

- This week
  - Discussed various client layers (PDH, IP, SDH etc)
  - Multiservice provision capabilities are crucial for operators
  - OTN standards expected to play significant part in the future
- Next lecture
  - WDM network elements, design, management etc.

Thank You!

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