Communication Networks II

BMEVITMA310 in English

Tibor Cinkler (**1.**) March 9, 2020

Monday 12:15 – 13:45 (QBF.11)

http://opti.tmit.bme.hu/~cinkler/TNS

Laboratory !!!

- Laboratory:
  - MPLS
  - VoIP
  - http://opti.tmit.bme.hu/~cinkler/KH2/English/LabMeasurements/
  - Register if not yet done!!!

Backbone / Transport Networks

Outline:

1.: PCM/PDH (http://www.hte.hu/hte2007/data/upload/File/online/THIS/2_en.pdf: 2.1.1.1, 2.1.1.2) (http://www.hte.hu/onlinebook)

2.: SDH/SONET(http://www.hte.hu/hte2007/data/upload/File/online/THIS/2_en.pdf: 2.1.1.3)

3.: ATM

4.: MPLS

5.: ngSDH/SONET (GFP, VCat, LCAS)

6.: OTN

7.: Optical Networks

Introduction

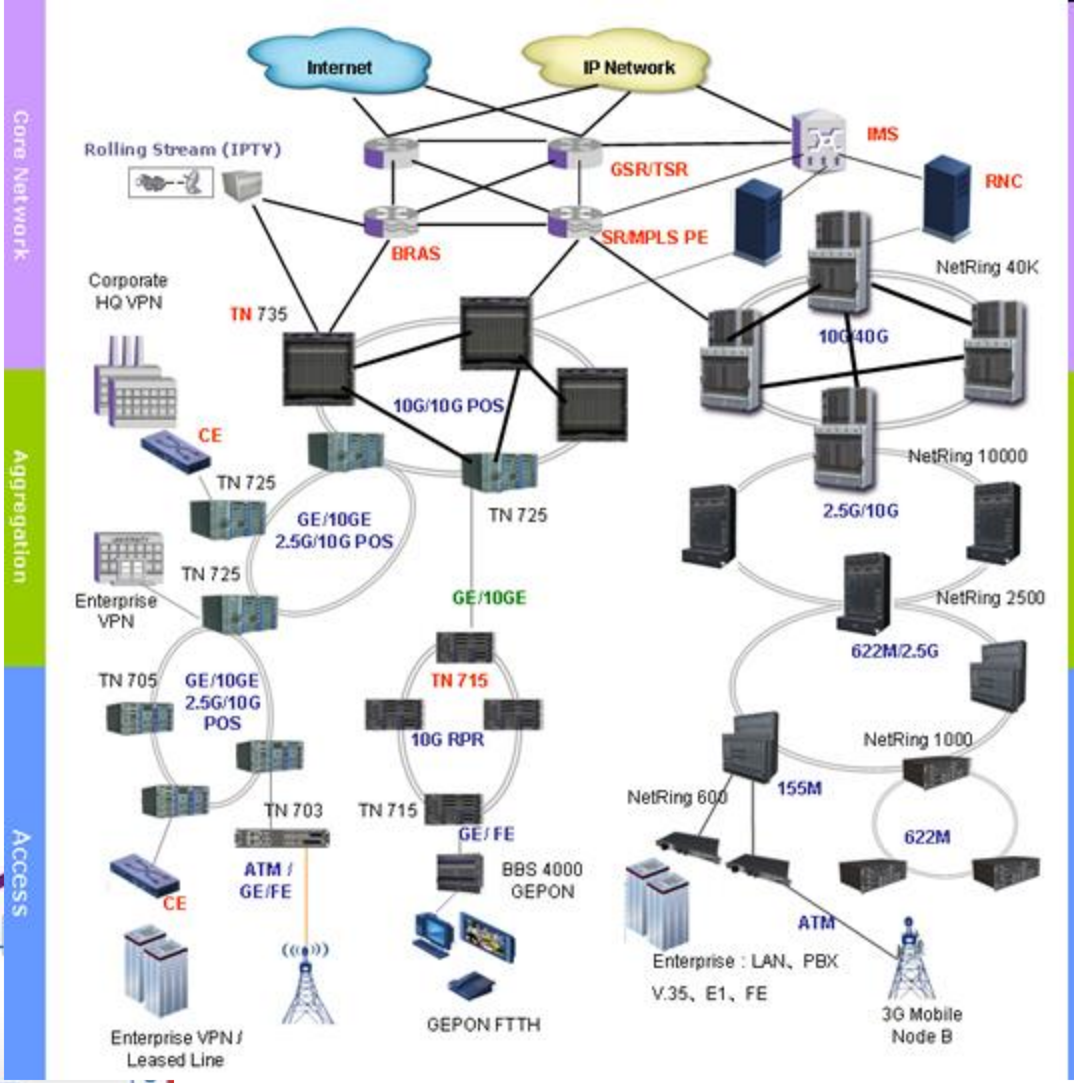
- Evolution of transmission techniques
  - 1915 New York - San Francisco telephony - copper/analog
  - 1936 coaxial cabel PSTN NY - Philadelphia
  - 1947 microwave links
  - 1962 telecom. satelite
  - 1980 fiber
  - 1988 SONET (ANSI) and SDH (CCITT → ITU) standard

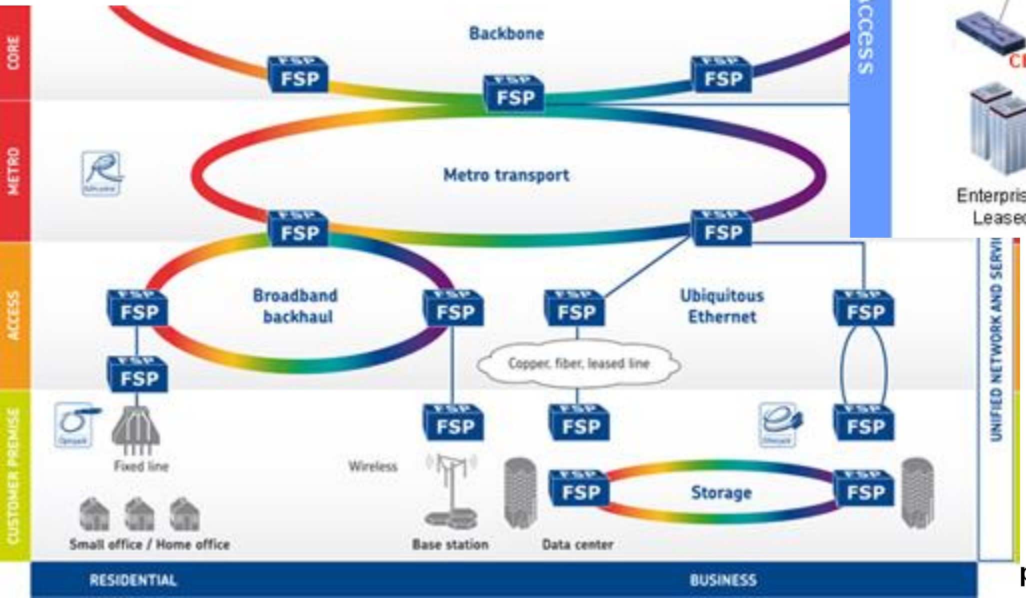
Analog -> Digital

PDH -> SDH

- Today
  - PCM/PDH, ISDN
  - SDH/ngSDH
  - ATM/MPLS
  - IP/Ethernet
  - DWDM
  - GMPLS
  - MPLS-TP

Access
Metro
Core





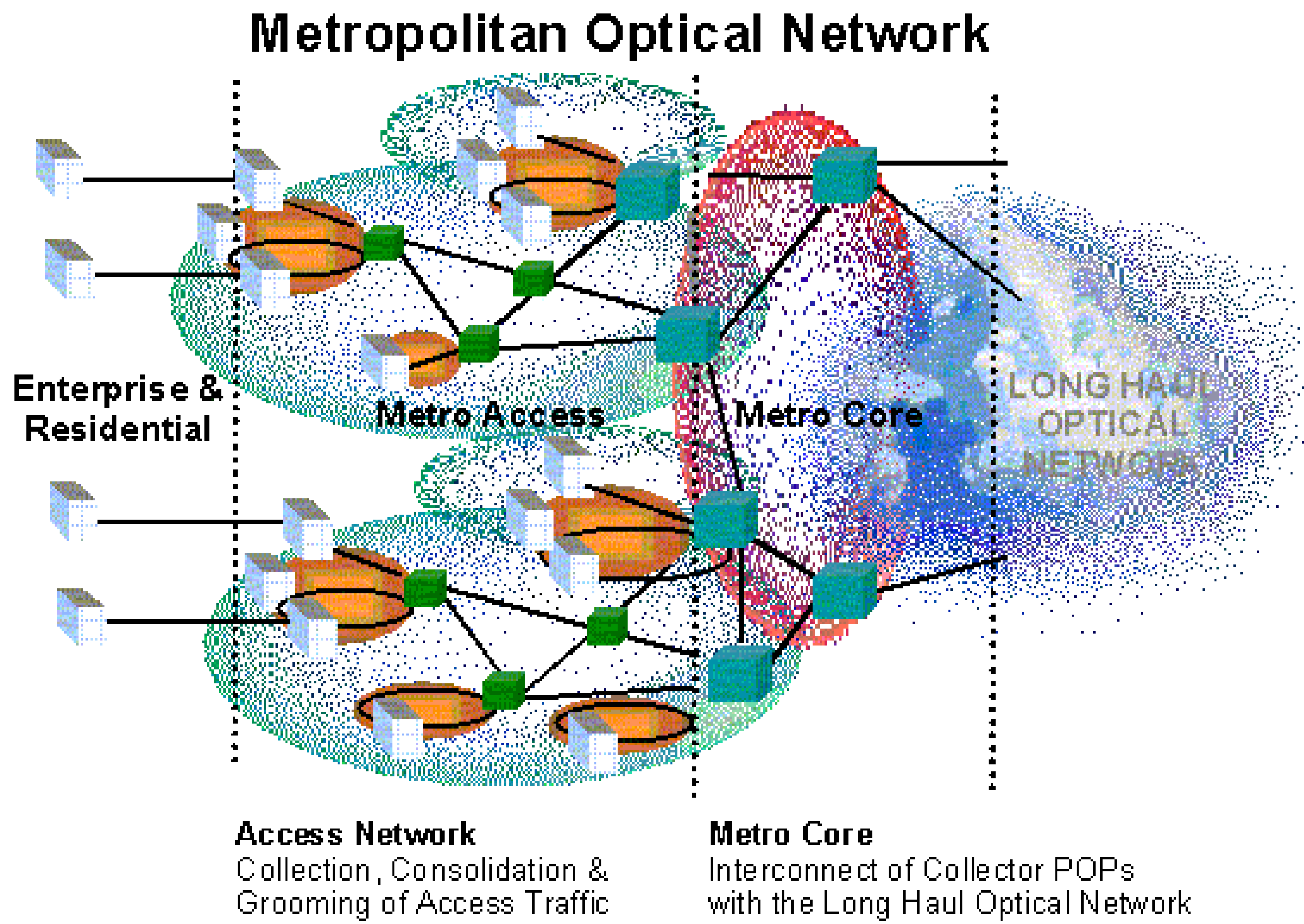
MON-LHON — Positioning

OR:

- Access
- Metro
    - Metro-Aggregation
    - Metro-Core
- Core or Backbone

OR:

- Metro Access
    - First mile access
    - Metro aggregation
- Core



Source: ITU-T: http://www.itu.int/itudoc/itu-t/com15/otn/index.html

Network Architectures

- Access/Aggregation:
  - LAN (Eth, GbE, 10GbE, 100GbE, TbE), xDSL, FTTx, PLC,…
  - DECT, GSM, HSCSD, GPRS, EDGE, 3G (UMTS), HSPA, LTE, 5G...
  - WLAN: WiFi (IEEE 802.11a,b,g,n,ac) (http://www.ieee802.org/11/)
  - Wireless MAN: WiMAX (IEEE 802.16) (http://www.ieee802.org/16/)
  - p2p microvawe, terrestrial, satelite (InMarSat, Iridium, Thuraya), free space optics, LiFi, etc.
  - PON (EPON, GPON, xPON, WDM PON…)
- METRO:
  - SDH, ngSDH, METRO Ethernet, (ATM), MPLS, optics …
  - METRO Access/Aggregation:
    - aggregate the traffic from access networks
    - classical approaches (SONET/SDH aggregation rings, RPR, Full Ethernet, Pt2Pt Optical Ethernet)
  - METRO Core: MROADM with CWDM or DWDM
- Transport (Backbone, Core)
  - DWDM, flexgrid, DW / OTN
  - (ng)SDH/SONET, ASON, GMPLS, ASTN
  - MPLS-TP

"Last Mile"/ "First Mile"

- Question of the point of view
  - "First Mile„ for the customer
  - "Last Mile„ for the operator
  - in practice it is the same…
- Becomes shorter and shorter:
  - Last mile, km, 100m, meters, etc
  - Wi-Fi a, b, g, n, ac… or mobile data
- Mostly wireless and mobile
  - Rarely wireline solution

Communication Satelite Systems

- GEO 36 000 km from Earth surface
- MEO (2 000-36 000 km)
- LEO (160-2 000 km)

- Inmarsat www.inmarsat.com
  - Voice, data, M2M
- Iridium www.iridium.com
  - Voice, data, IoT
- Thuraya www.thuraya.com
  - Voice, data, IoT/M2M
- Spacex Starlink Mission www.spacex.com
  - Internet services, VLEO → LEO (https://en.wikipedia.org/wiki/Starlink)
- Etc., etc., etc…

FTTx systems

- Fiber to the
  - Curb
  - Cabinet
  - Building
  - Home
  - Office
  - Desktop
- The closer the better!
- Point-to-point or point-to-multi-point systems
  - P2MP: PON (EPON, GPON,10xPON, WDM PON, CDMA PON, TWDM PON…)

Mobil data and voice

- 2G: **GSM**, HSCSD, GPRS, EDGE,
- 3G: **UMTS**, HSDPA, HSUPA, HSPA, HSPA+
- 4G: LTE, **VoLTE,** LTE Adavnced, LTE Advanced Pro
  - 4G to 3G FallBack for Voice
    - No voice service for 4G was available in the start
    - VoLTE solves this problem now
    - VoWiFi
- 5G

HomeWork

- Visit the homepages of the following organisations, that are most active in standardisation of Communication Networks:
  - IETF
  - ITU-T (and ITU-R)
  - 3GPP
  - IEEE
- Identify 2-3 standards (RFC, Recommendation, Release…) defined by the considered organisation.

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Tibor Cinkler (**2.**) March 30, 2020

Monday 12:15 – 13:45 (Online~~QBF.11~~)

http://opti.tmit.bme.hu/~cinkler/TNS

- One can recorded only in teams!
- I do it! I share it with you!
- Do not stop my teams recording, please!
- Do not start your teams recording, please!

- You can all interact with me any time, please, ask questions! This is a small group, can be interactive.
- Please, keep your microphone muted all the time, except when you want me to here you.

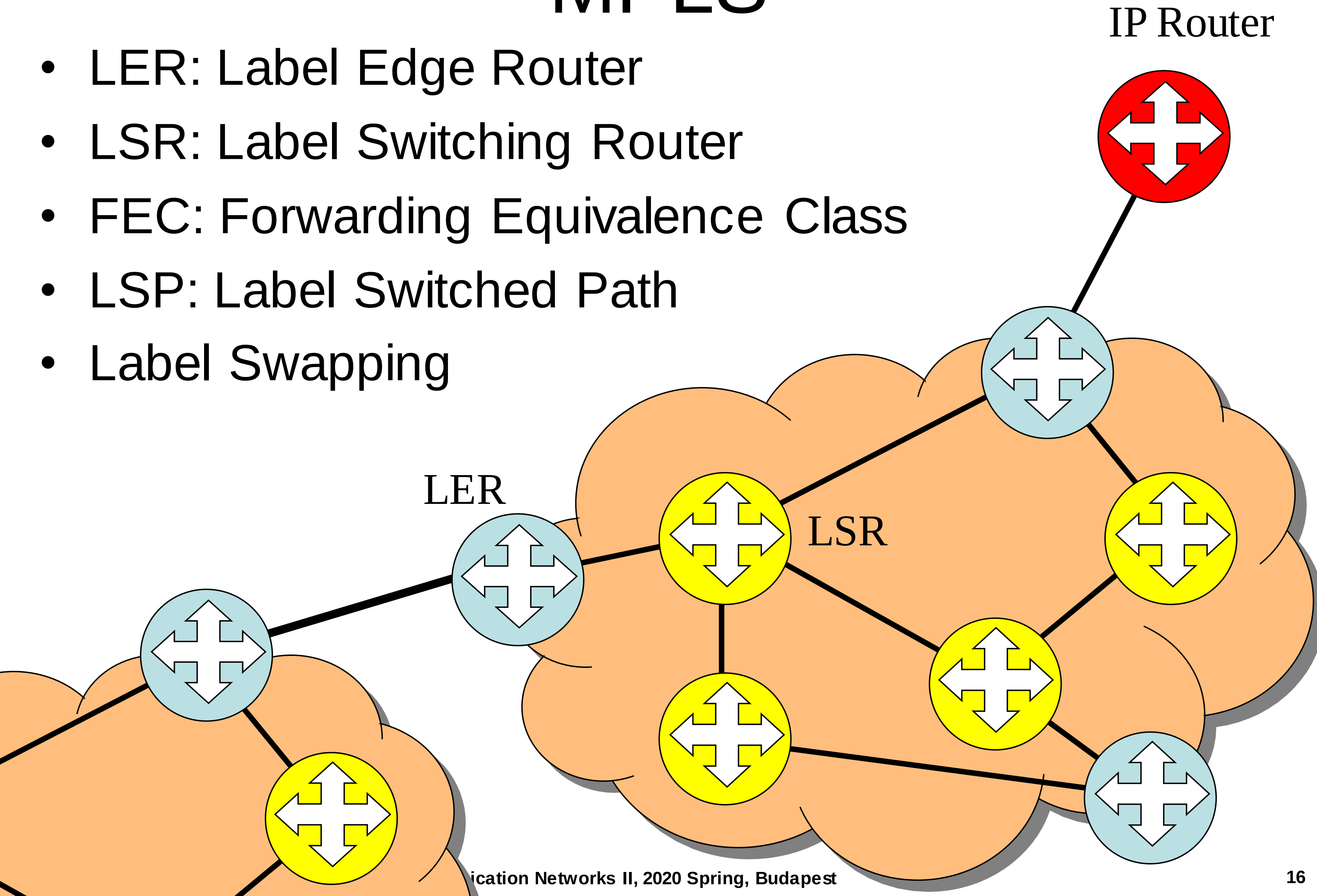
MPLS

MultiProtocol Label Switching:

- “Layer 2.5” protocol
  - between OSI Layer 2 (data link layer) and Layer 3 (network layer)
- Unified IP/MPLS control
- Simpler than ATM
- Reduced label space rquirement via FEC (Forwarding Equivalence Class)
- Label Swapping and Stacking
- Not much new compared to ATM ☺
- Topology or Traffic driven
- Some QoS issues still open
- TE and VPN support (Traffic Engineering and Virtual Private Networks)
- IPoMPLS: Peer Model !
  - RSVP-TE
  - CR-LDP

MPLS

- LER: Label Edge Router
- LSR: Label Switching Router
- FEC: Forwarding Equivalence Class
- LSP: Label Switched Path
- Label Swapping

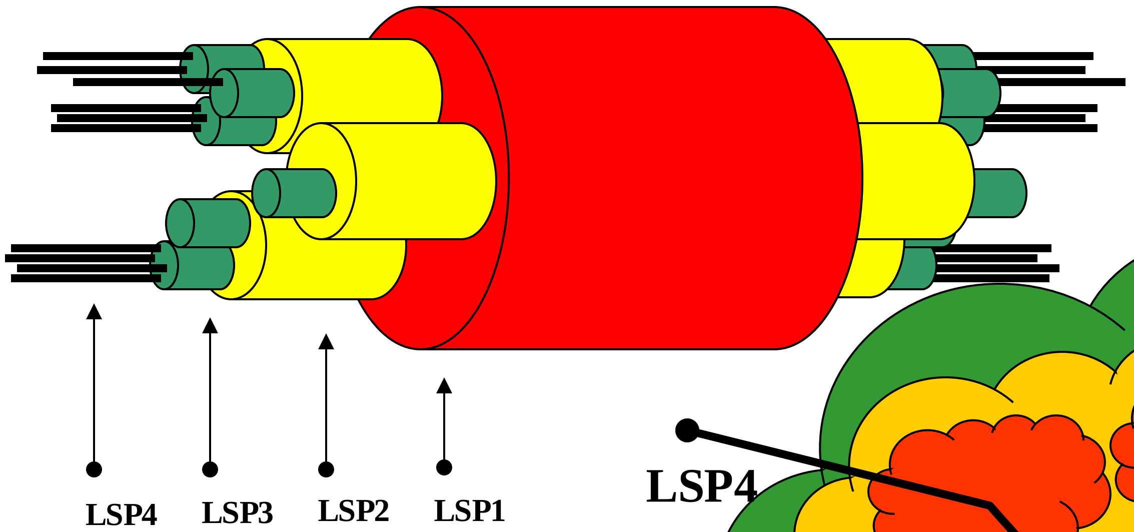


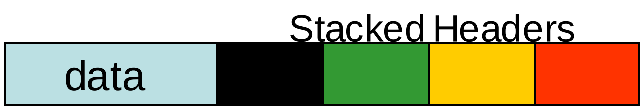
LER and LSR functions

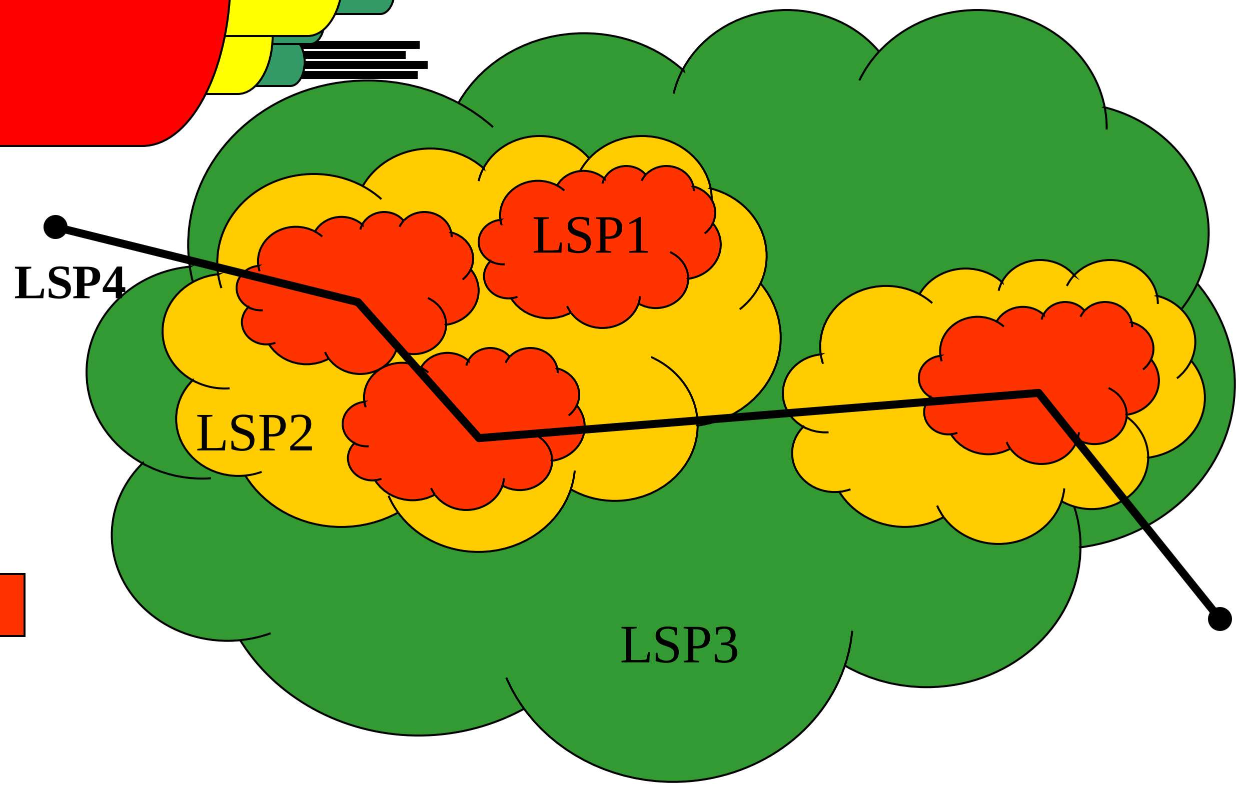
- LER
  - Routing over the MPLS network based on the IP address
  - Seting up the LSP by label distribution to other routers
  - Assigning the label and header at the ingress
  - Removing the label and header at the egress
- LSR
  - Receiving the label distribution signalling and updating the routing tables
  - Swapping the labels
  - Forwardsing the packets (frames)

Label “Stacking” or “Swapping”?

- Many layers via stacking!
- Hierarchical LSP encapsulation (embedding, nesting)
- Stripping – to be discussed later







MPLS header

- Header: 32 bit = 4 byte
- Label: 20 bits

```
 0 1 2 3 4 5 6 7
+-+-+-+-+-+-+-+-+
|    Label      | Entry Label:
+-+-+-+-+-+-+-+-+ Label Value, 20 bits
|    Label      | Exp: Experimental Use
+-+-+-+-+-+-+-+-+ 3 bits (CoS)
| Label | Exp |S| S: Bottom of Stack
+-+-+-+-+-+-+-+-+ 1 bit
|      TTL      | TTL: Time to Live
+-+-+-+-+-+-+-+-+ 8 bits
```

IP and MPLS Headers

- Routing and Forwarding

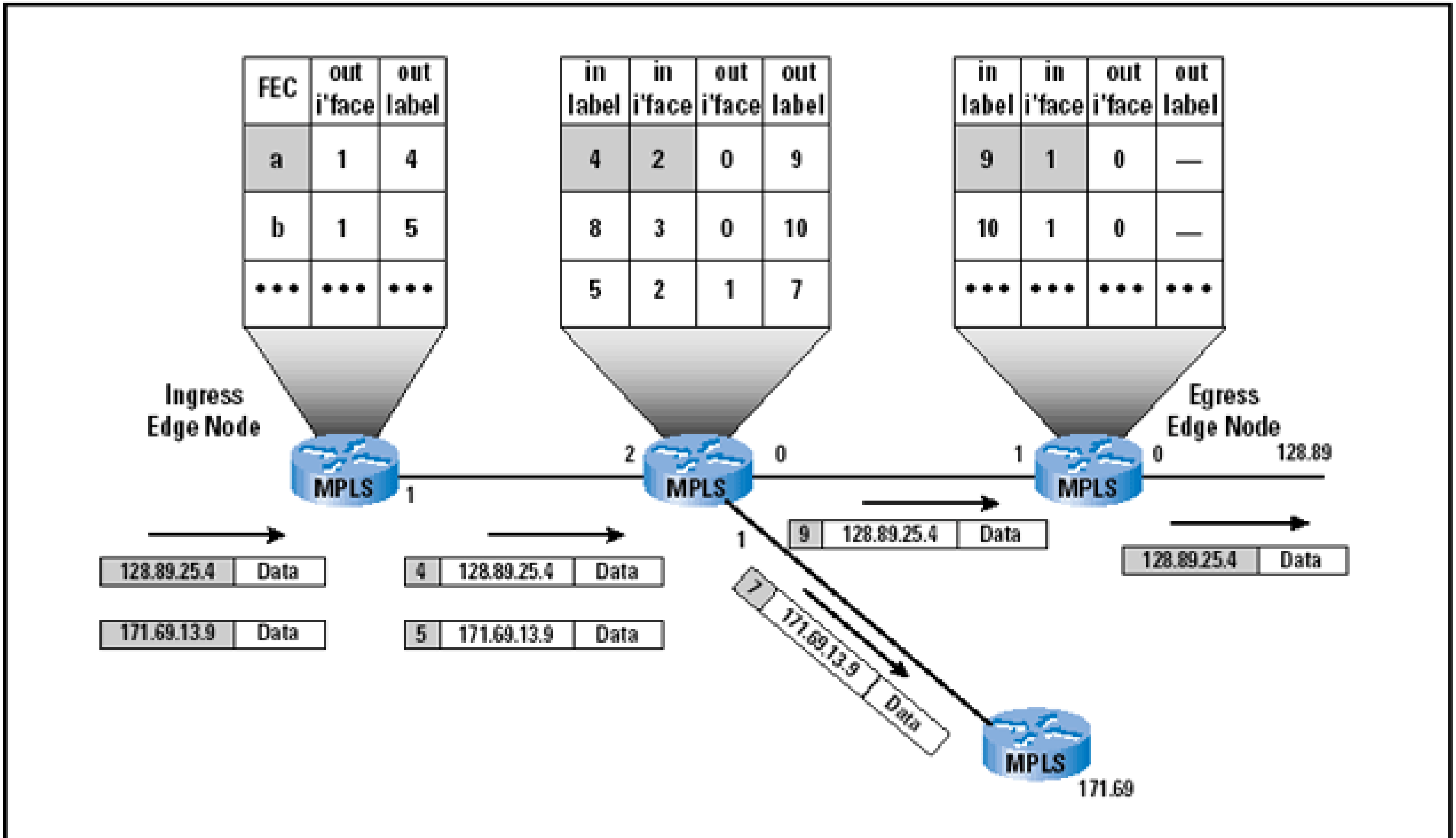
0	8	16	31
VERS	HLEN	Service Type	Total Length
Identification		Flags	Fragment Offset
TTL	Protocol	Header Checksum	
Source IP Address			
Destination IP Address			
Options			Padding
Data			
Data			
...			
Data			

0		7
Label		
Label		
Label	CoS	S
TTL		

MPLS forwarding

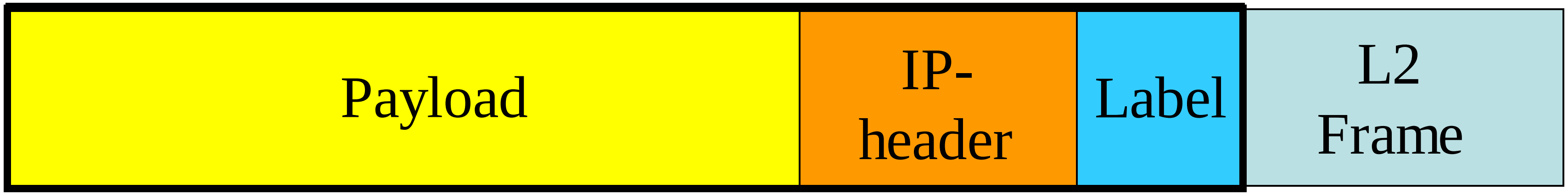
- http://www.cisco.com/c/en/us/about/press/internet-protocol-journal/back-issues/table-contents-10/mpls.html

Figure 2: MPLS Packet Forwarding



IP over MPLS over Ethernet?

- Labeled IP packet with e.g., Ethernet Frameing
- MPLS label between
  - the IP header and
  - the Ethernet header



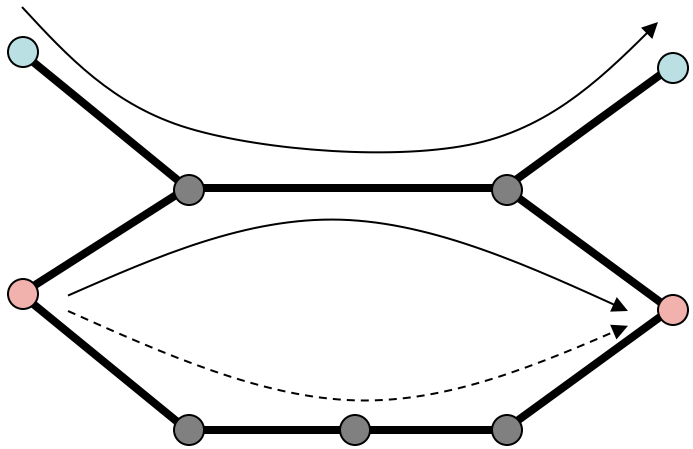
Label distribution mechanisms

- LSP setup
- LSR forwarding tables
- Different Label Distribution protocols:
  - **a Border Gateway Protocol (BGP)**
    - between different Internet AS-es
    - **MPLS extension**
  - **Resource reSerVation Protocol (RSVP)**
    - signalling where label distribution is assigned to RSVP flows
    - **RSVP-TE extension**
  - **Label Distribution Protocol (LDP),** defined by IETF for this purpose only
    - **CR-LDP**

MPLS TE

Traffic Engineering

- “put the traffic where enough resources are available”
- IP: shortest path = least-hop path
- MPLS: Arbitrary path can be chosen
  - Alternative paths – load sharing
  - Explicit Route or Hop-by-Hop Routing
    - Loose
    - Strict

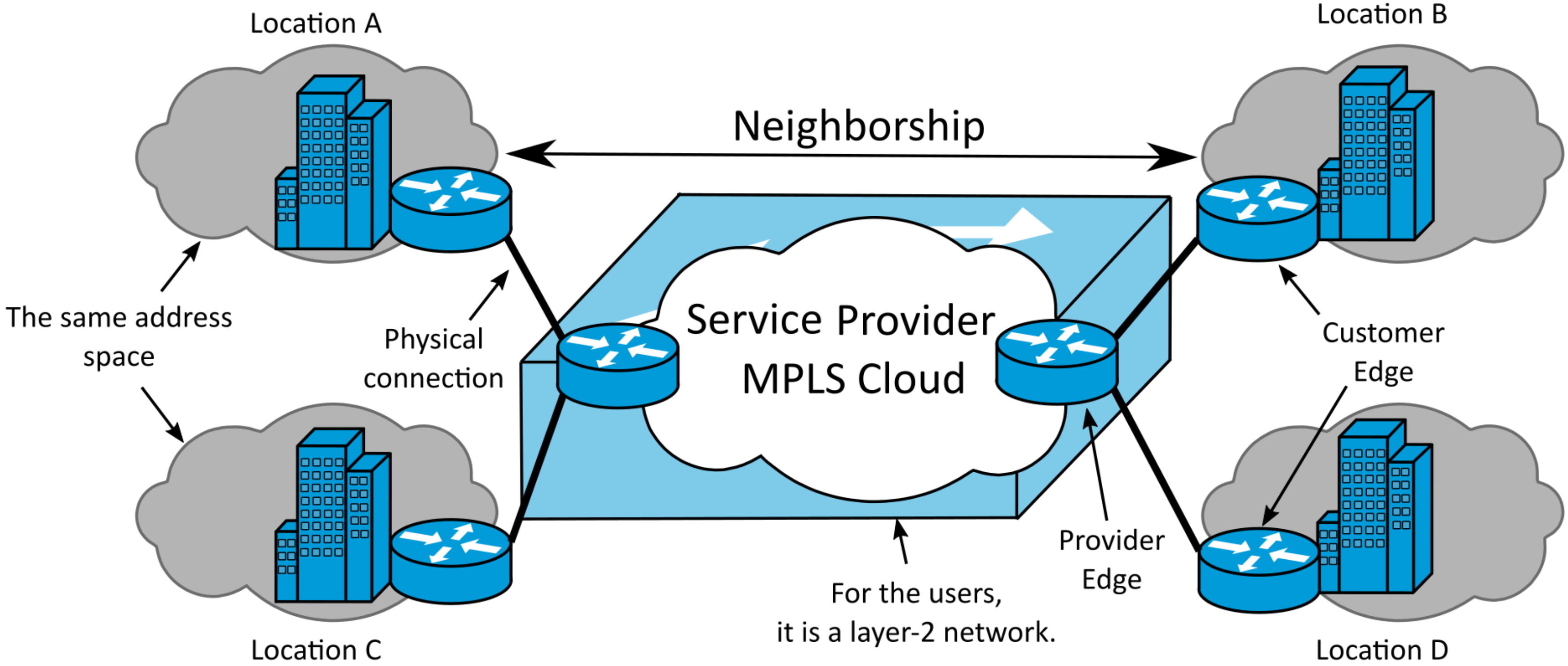


In case of failures:

- Protection / Restoration
- MPLS FRR
- (Fast Re-Route)

MPLS VPN

- Separate / distant locations in the same address space
- Separate traffic
- QoS (Quality of Service)



https://en.wikipedia.org/wiki/MPLS_VPN#/media/File:L2_MPLS_VPN_en.svg

MPLS QoS: CR-LDP Traffic Parameters slides 1-9 QoS in MPLS

U	F	Traf. Param. TLV		Length		
Flags			Frequency	Reserved	Weight	
Peak Data Rate (PDR)						
Peak Burst Size (PBS)						
Committed Data Rate (CDR)						
Committed Burst Size (CBS)						
Excess Burst Size (EBS)						

32 bit fields are short IEEE floating point numbers

Any parameter may be used or not used by selecting appropriate values

Flags control "negotiability" of parameters

Frequency constrains the variable delay that may be introduced

Weight of the CRLSP in the "relative share"

Peak rate (PDR+PBS) maximum rate at which traffic should be sent to the CRLSP

Committed rate (CDR+CBS) the rate that the MPLS domain commits to be available to the CRLSP

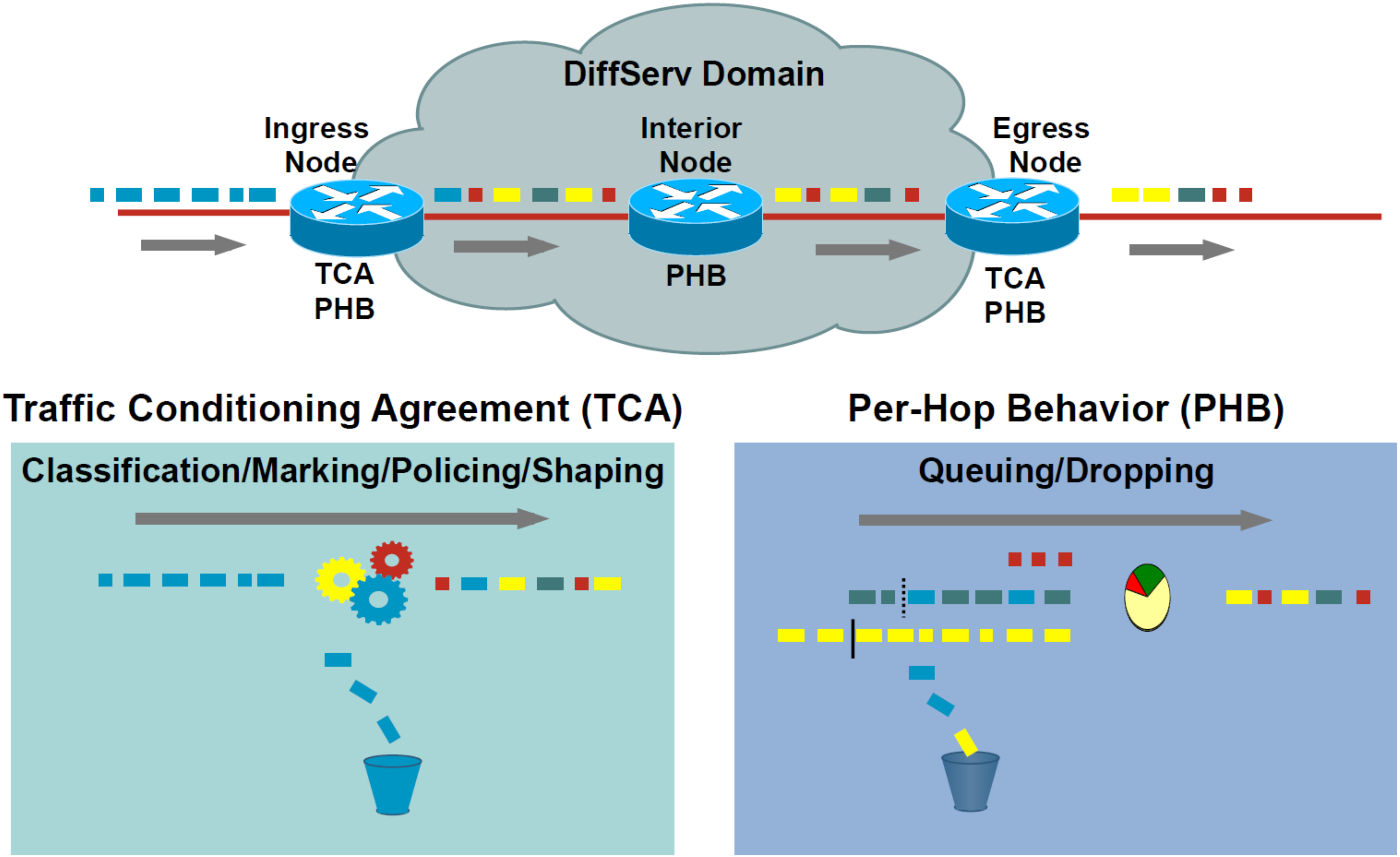
Excess Burst Size (EBS) to measure the extent by which the traffic sent on a CRLSP exceeds the committed rate

Forrás: Loa Andersson, Nortel: MPLS Tutorial, Infocom 2000

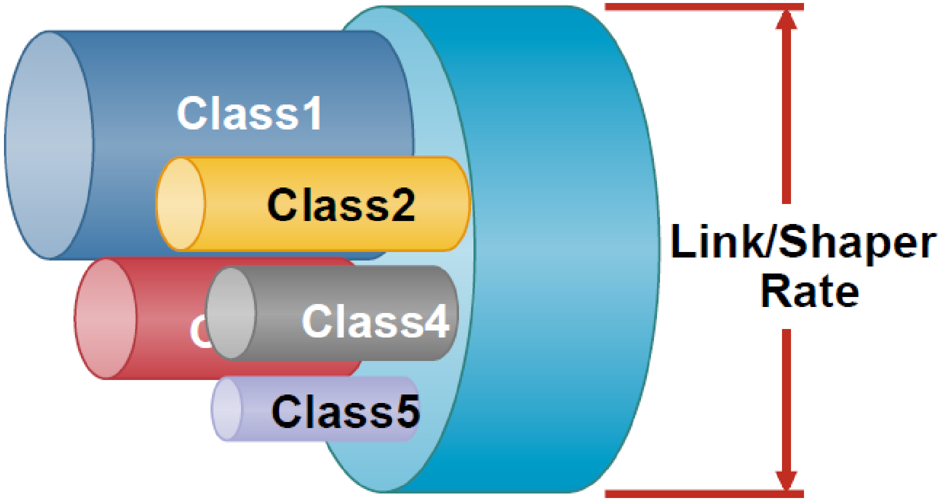
MPLS QoS Architecture

- MPLS does NOT define new QoS architectures
- MPLS QoS uses Differentiated Services (DiffServ) architecture defined for IP QoS
- DiffServ architecture defined in RFC2475
- MPLS support for DiffServ defined in RFC3270

MPLS QoS Architecture



SLA: Service Level Agreement



Class	Committed BW	Delay	Jitter	Loss
Real time	X	Low	Low	Low
Interactive	Y	Low	NA	Low
Business	Z	NA	NA	Low
Best Effort	NA	NA	NA	NA

- 3-5 classes typically
- Different traffic and quality requirements

MPLS Conclusion

MultiProtocol Label Switching:

- Unified IP/MPLS control
- Simpler than ATM - Not much new compared to ATM ☺
- Reduced label space rquirement via FEC (Forwarding Equivalence Class)
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- IPoMPLS: Peer Model !
  - RSVP-TE
  - CR-LDP
- MPLS-TP: MPLS Transport Profile
- GMPLS: Genelazied MPLS

Glossary

MPLS	Multi-Protocol Label Switching	Többprotokollos címkekapcsolás
VPN	Virtual Private Network	Virtuális magán hálózat
IP	Internet Protocol	Internet protokoll
ATM	Asynchronous Transfer Mode	Aszinkron átviteli mód
QoS	Quality of Service	Szolgáltatásminőség
LER	Label Edge Router	Címke behelyező (perem) útválasztó
LSR	Label Switching Router	Címke kapcsoló útválasztó
LSP	Label Switched Path	Címke kapcsolt útvonal
FEC	Forwarding Equivalence Class	Továbbítási ekvivalencia osztály
VPI/VCI	Virtual Path Identifier/Virtual Channel Identifier	Virtuális útvonal azonosító/virtuális csatorna azonosító
DLCI	Data Link Connection Identifier	Adat kapcsolat azonosító
CoS	Class of Service	Szolgáltatásosztály
TTL	Time to Live	Élettartam
LFIB	Label Forwarding Information Base	Címketovábbítási információs bázis
NHLFE	Next Hop Label Forwarding Entry	Következő ugrást leíró címketovábbítási elem
ILM	Incoming Label Map	Beérkező címkék térképe
FTN	FEC-to-NHLFE Map	FEC és NHLFE összerendelő táblázat
BGP	Border Gateway Protocol	Határkapu protokoll
RSVP	Resource reSerVation Protocol	Erőforrásfoglalási protokoll
LDP	Label Distribution Protocol	Címketerjesztő protokoll
OXC	Optical Cross Connect	Optikai rendező
GMPLS	Generalised Multi-Protocol Label Switching	Általánosított többprotokollos címkekapcsolás
MPλS	Multi-Protocol Lambda Switching	Többprotokollos hullámhosszkapcsolás
STM	Synchronous Transport Module	Szinkron átviteli modul

Optical Networks

3 Generations:

- 1. G: only transmission links are optical
- 2. G: whole transmission paths are optical
- 3. G: even the control is optical

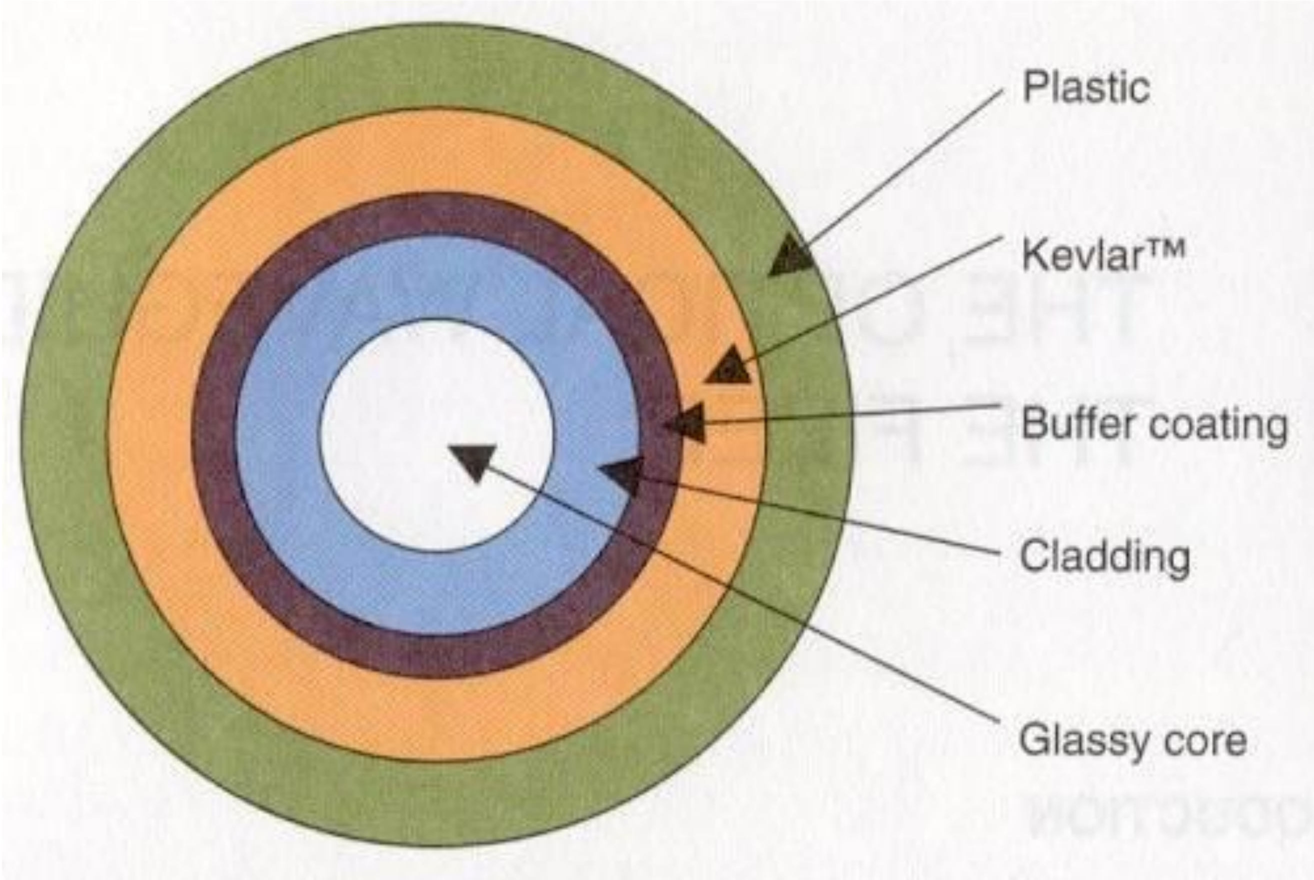
Multiplexing Solutions

- Space (OSDM)
  - Multifiber & Multicore
- Wavelength (WDM)
  - CWDM & DWDM
- Time (OTDM)
  - Packets & Pulses (ultrashort)
- Code (OCDM)
- OOFDM (Optical Orthogonal FDM)
- NDWDM (Nyquist WDM)

Optical Technologies

- Fibers (SMF, MMF, etc)
- AWG - Arrayed Waveguide Grating
- Transmission Impairments, transmitters, receivers, filters
- Optical Amplifiers (SOA, EDFA, RamanA)

Fiber Anatomy

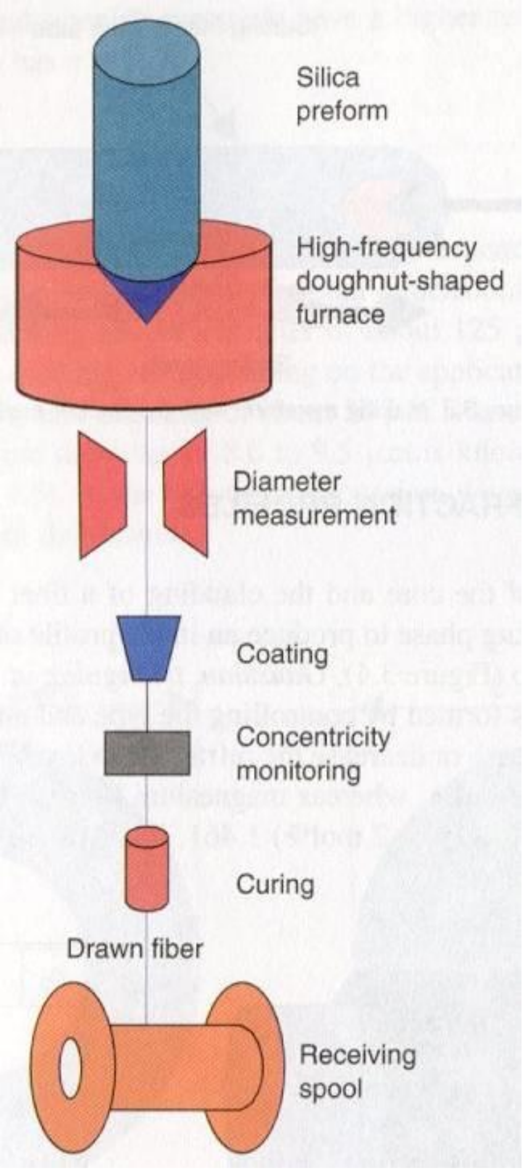


Cross section (not to scale)

Figure 3.1 Anatomy of a fiber

Source: Shivkumar Kalyanaraman

Fiber Manufacturing



- Dopping by rare earth elements
  - Graded index
  - (Step Index)

- Multiple cables per duct
- Up to 1000 fibers per cable
- Multi-core fibers?
- ~160 λ per fiber/core
- 10 Gbps or 100 Gbps per λ

Bit-rate / N.o.channels / Reach

	Bit-Rate [Gbit/s]	Distance (Reach) L [km]	Optical Band [GHz]	Max. No. of Channels
a	100	4200	50	96
b	200	800	50	96
c	300	1100	75	64
d	400	500	75	64
e	500	600	100	48

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Tibor Cinkler (**3.**) Apri 6, 202

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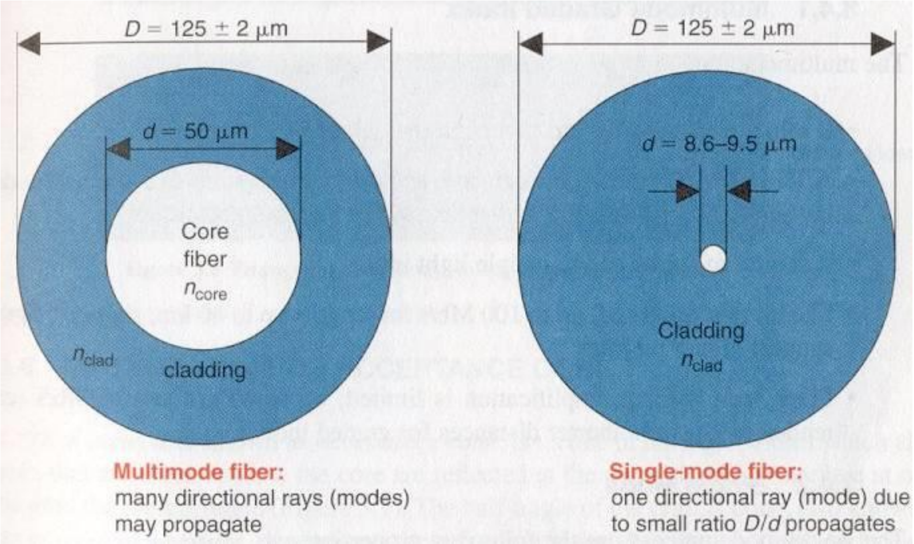
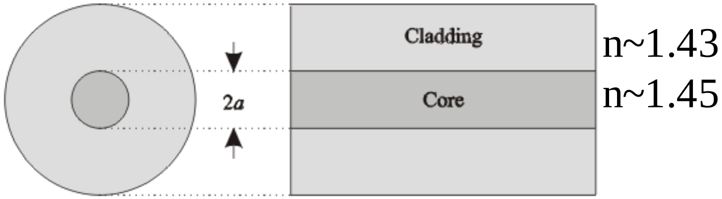
Single and MultiMode Fiber

- Single-Mode Fiber (SMF) (8 to 10 μm mag)
- Multimode Fiber (MMF) (50 to 85 μm mag)
- SiO_2 (or plastic)
- 3 low attenuation bands (windows): 0.8, 1.3 , 1.55 μm



Refraction Index (RI):



Source:
Shivkumar Kalyanaraman

<u>Absorption and Attenuation:</u> Absorption Spectrum

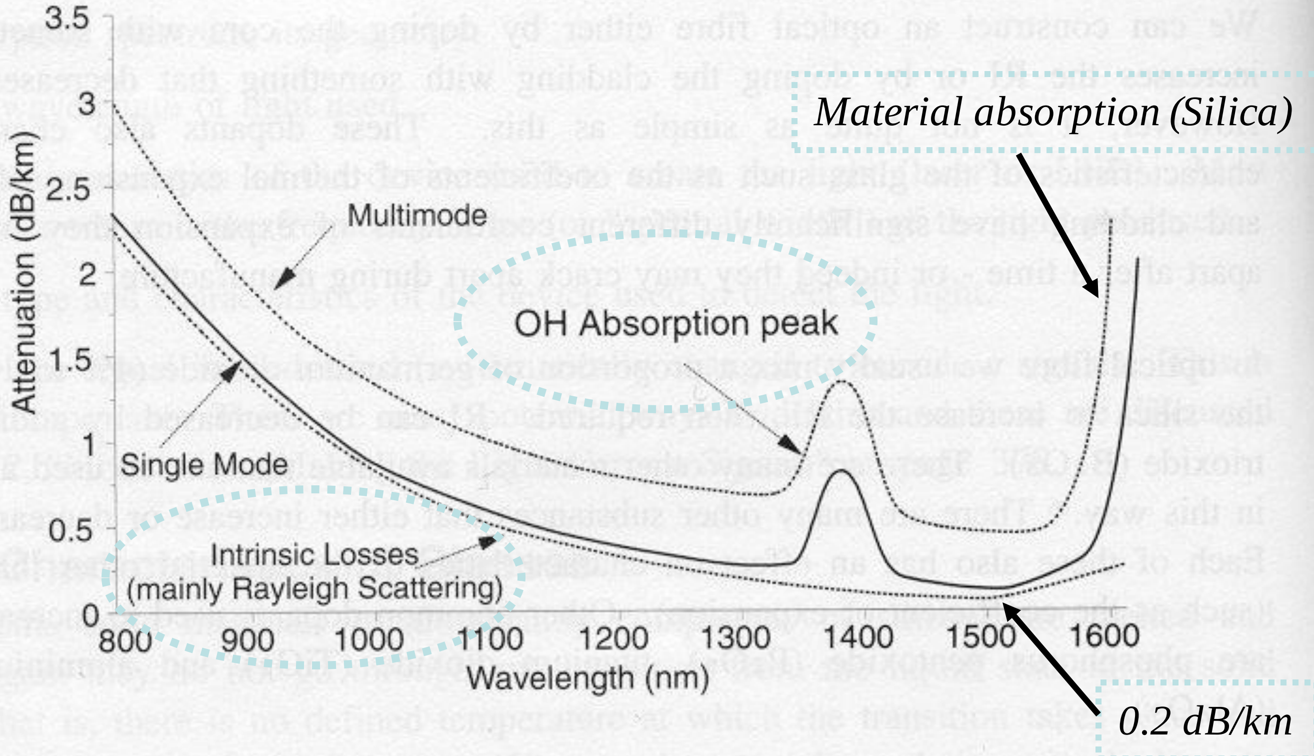


***Figure 13.** Typical Fibre Infrared Absorption Spectrum. The lower curve shows the characteristics of a single-mode fibre made from a glass containing about 4% of germanium dioxide (GeO_2) dopant in the core. The upper curve is for modern graded index multimode fibre. Attenuation in multimode fibre is higher than in single-mode because higher levels of dopant are used. The peak at around 1400 nm is due to the effects of traces of water in the glass.*

Forrás: Shivkumar Kalyanaraman

Fiber: Transmission Windows

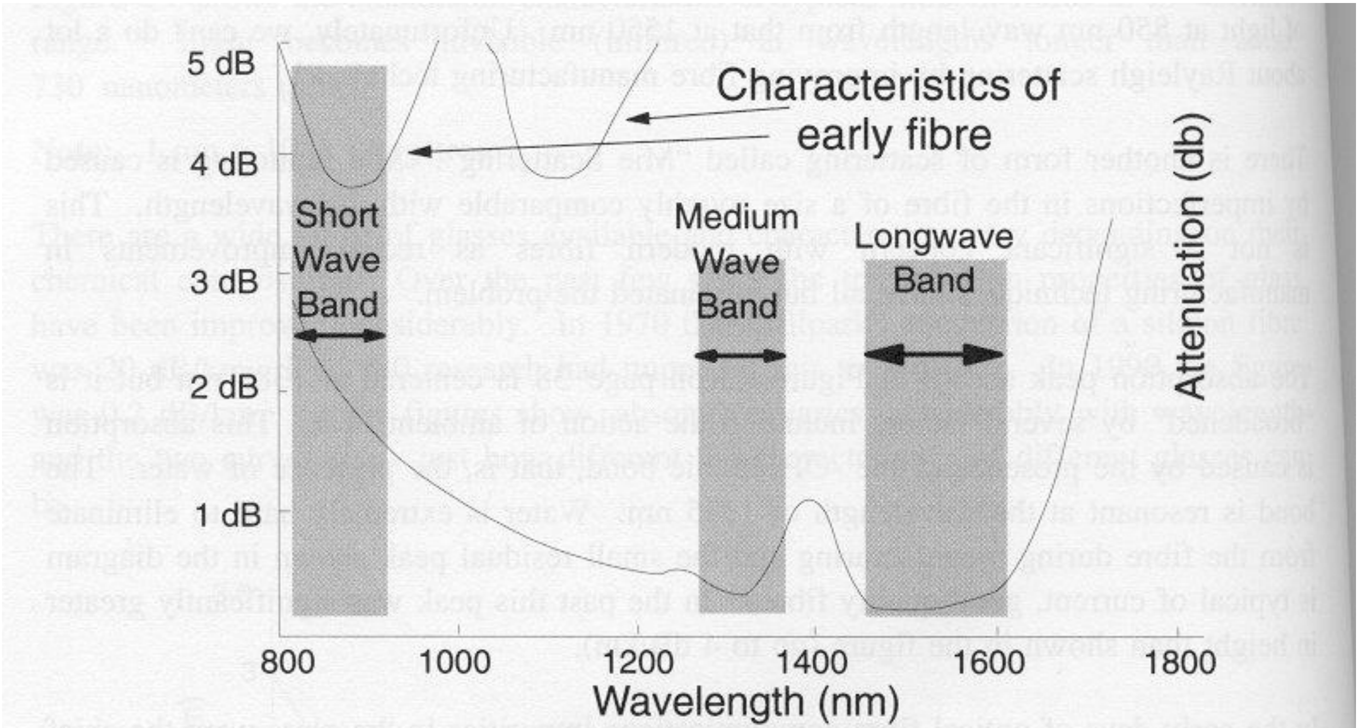


Figure 14. *Transmission Windows. The upper curve shows the absorption characteristics of fibre in the 1970s. The lower one is for modern fibre.*

Lucent's new AllWave Fiber (1998) eliminates absorption peaks due to watervapor in the 1400nm area!

Forrás: Shivkumar Kalyanaraman

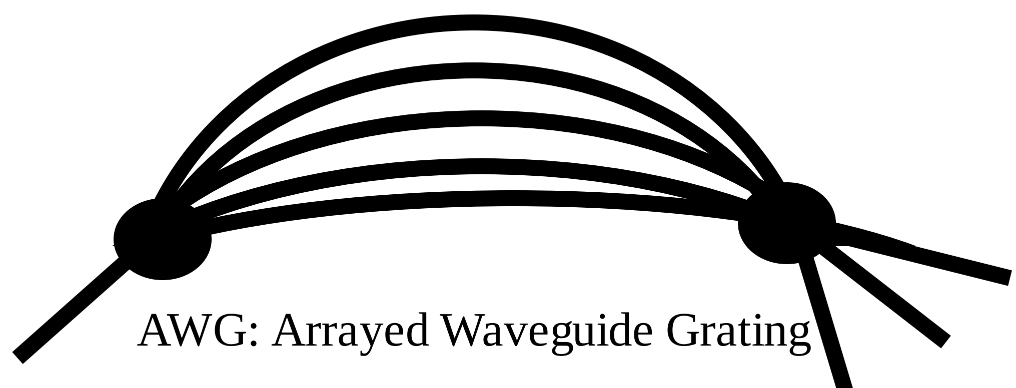
Fiber Bands:

O-band: (Original) 1260-1360nm
E-band: (Extended) 1360-1460nm
S-band: (Short) 1460-1530nm
C-band: (Conventional): 1530-1565nm
L-band: (Long) 1565-1625nm
U-band: (Ultra-long): 1625-1675nm

Wavelength MUX/DEMUX

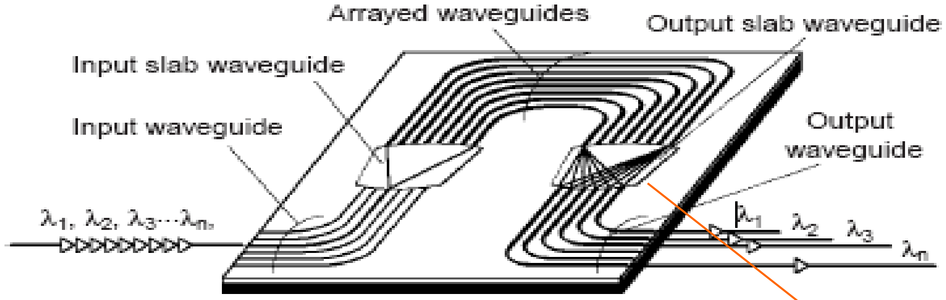
Point-to-point WDM link ...

- DWDM (Denser – Wider – Denser)
- CWDM (Coarse)
- (WDM: Wavelength Division Multiplexing)



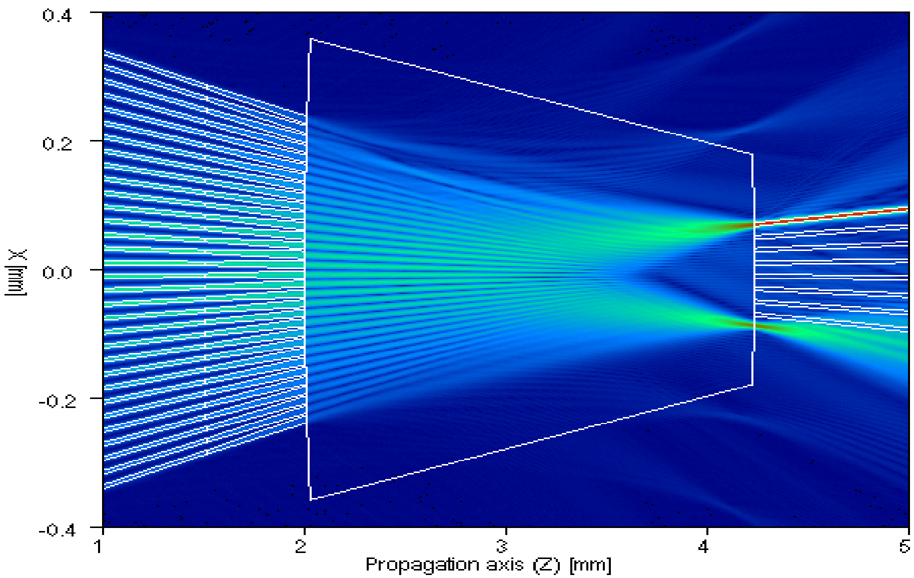
AWG: Arrayed Waveguide Grating

Arrayed waveguide grating



- **AWG**

- Great scalability
- Low losses
- Non reconfigurable
  - It requires wavelength conversion

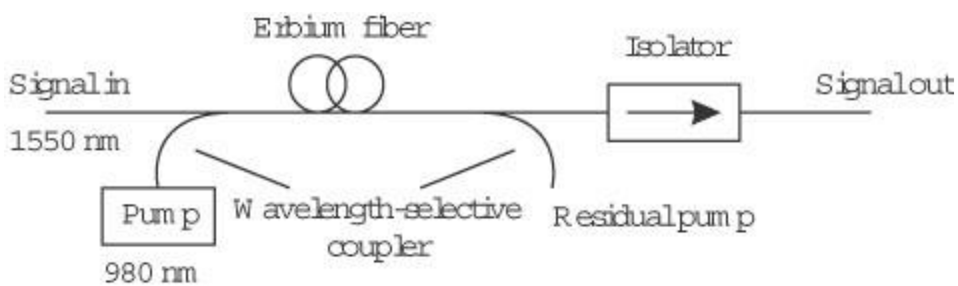


Source: Robotiker, Andrea Bianco Redondo Networks 2008, Budapest

C2V animation

All-Optical 3R?

- 3R: Re-Amplification, Re-Shaping, Re-Timing
  - all optically?
- SOA: Semiconductor Optical Amplifier
- EDFA: Erbium Dopped Fiber Amplifier (Er^{3+} or smilar elements)
- Ramman Amplifier



OTN: G.872 + G. 709 + etc.

- Optical Transport Network - Digtal Wrapper
- Defines:
  - Simultaneous wavelength **AND** Time Division Multiplexing
    - „Overlay” – „Peer” – „Augmented” Models
  - Optical layer parameters
  - Frameing structures and byte definitions
  - Intra- and Inter-Domain Interfaces: IaDI, IrDI
  - FEC (Forward Error Correction)
  - Applications

OTN vs OTNT: strict and loose (general) sense

Strict: Optical Transport Network (OTN)

„…Optical Network Elements connected by optical fibre links, able to provide functionality of transport, multiplexing, routing, management, supervision and survivability of optical channels carrying client signals…"

„… provision of transport for any digital signal independent of client-specific aspects..."

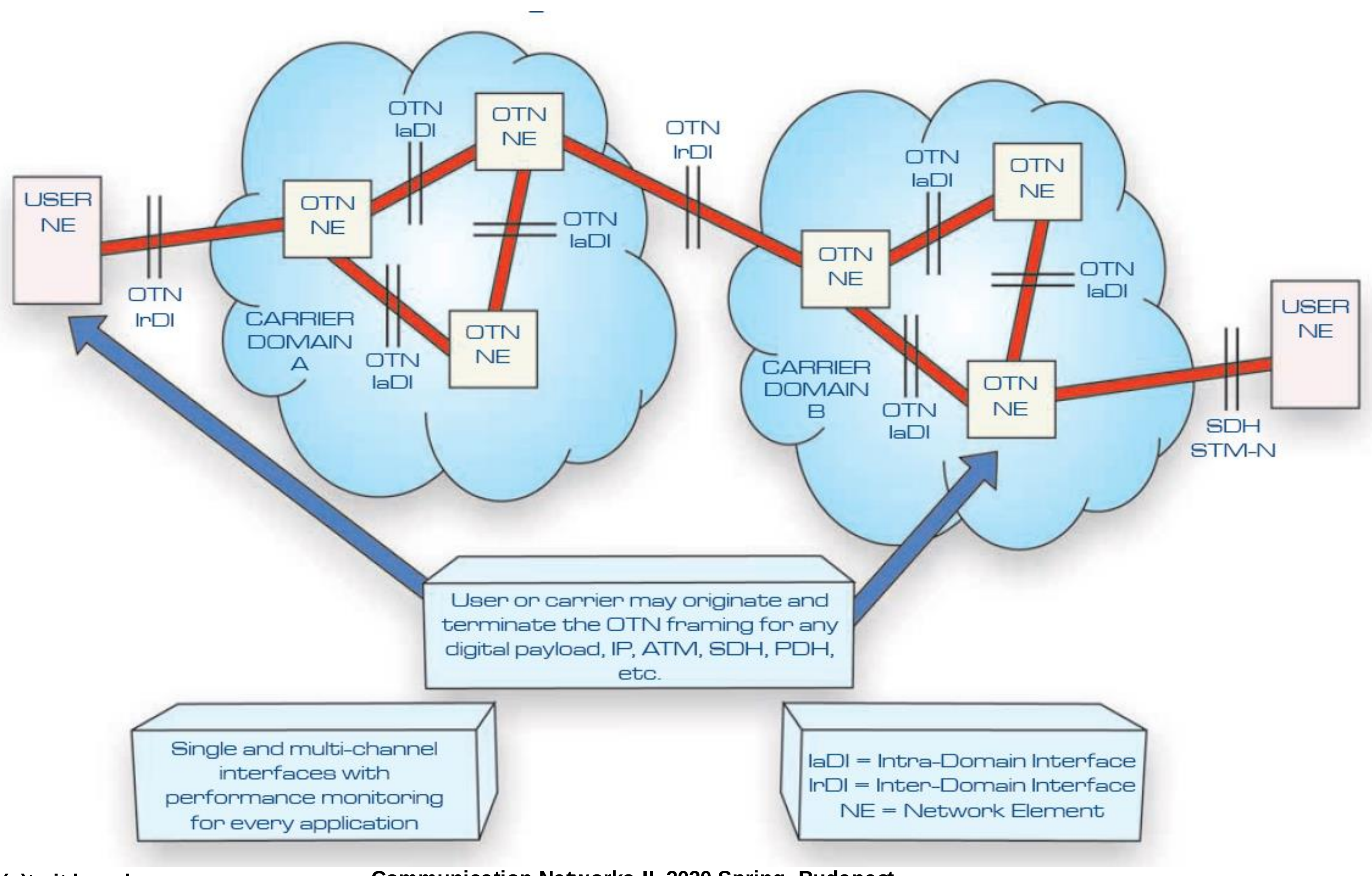
- **ITU-T G.709** (01/03) Interfaces for the **OTN**
- **ITU-T G.798** (5/02) Characteristics of **OTN** Hierarchy Equipment Functional Blocks
- **ITU-T G.872** (10/01) Architecture for the **OTN**
- **ITU-T G.8251** (10/01) The Control of Jitter and Wander within the **OTN**

General: Optical Transport Networks & Technologies (OTNT)

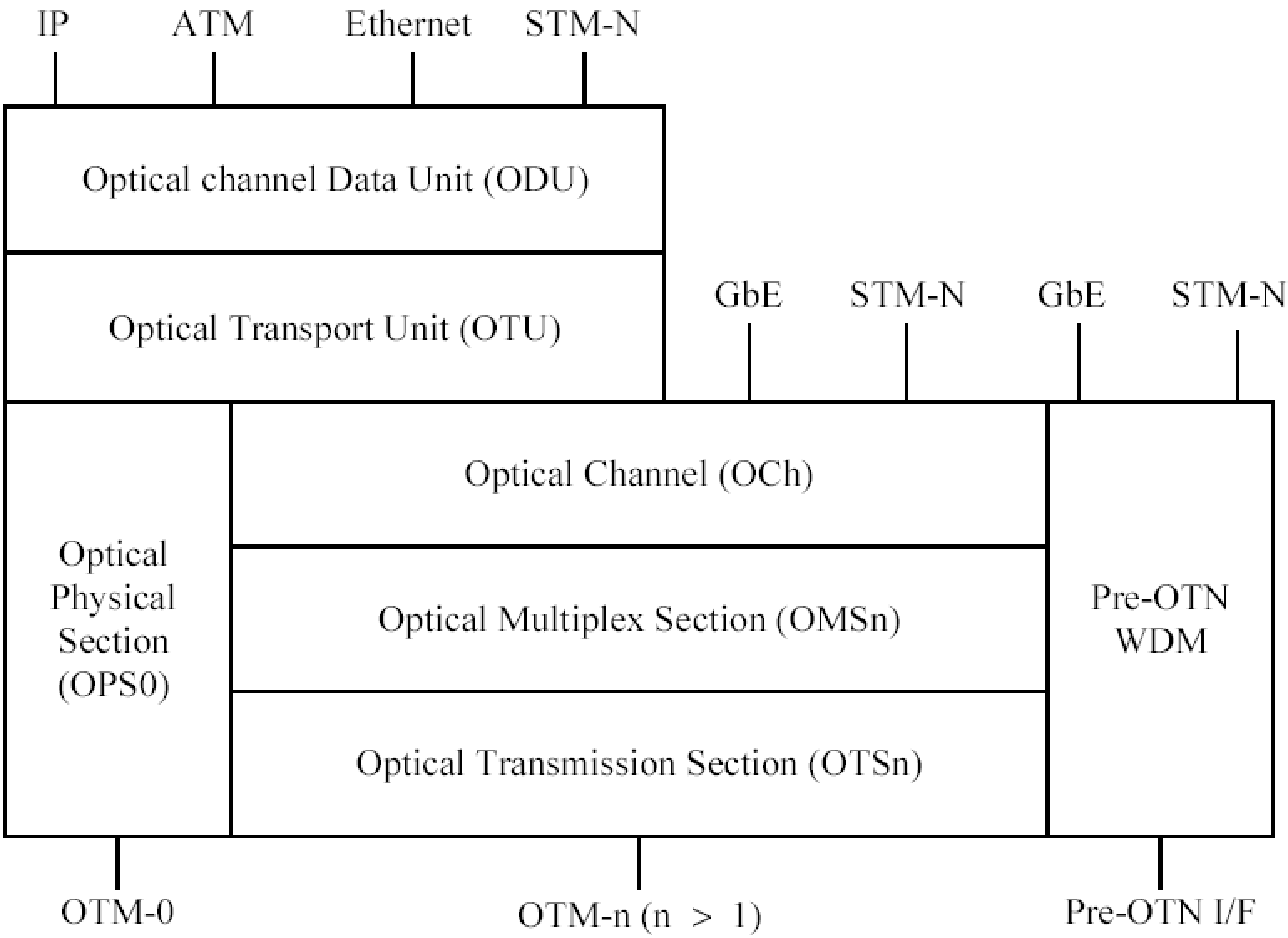
- All network functionality and related technologies that are based on optical transport
- E.g., SDH also falls into this category

Global Optical Transport Network

http://www.itu.int/dms_pub/itu-t/oth/0B/04/T0B040000150001PDFE.pdf



OTN and WDM

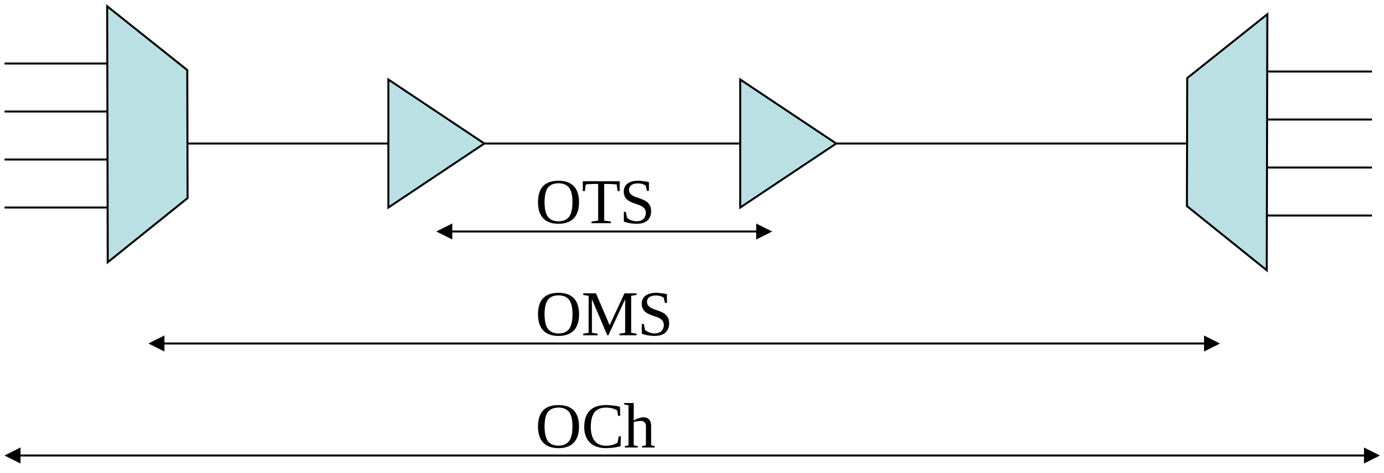


Source: ITU-T G.872: Relationship between OTN and WDM

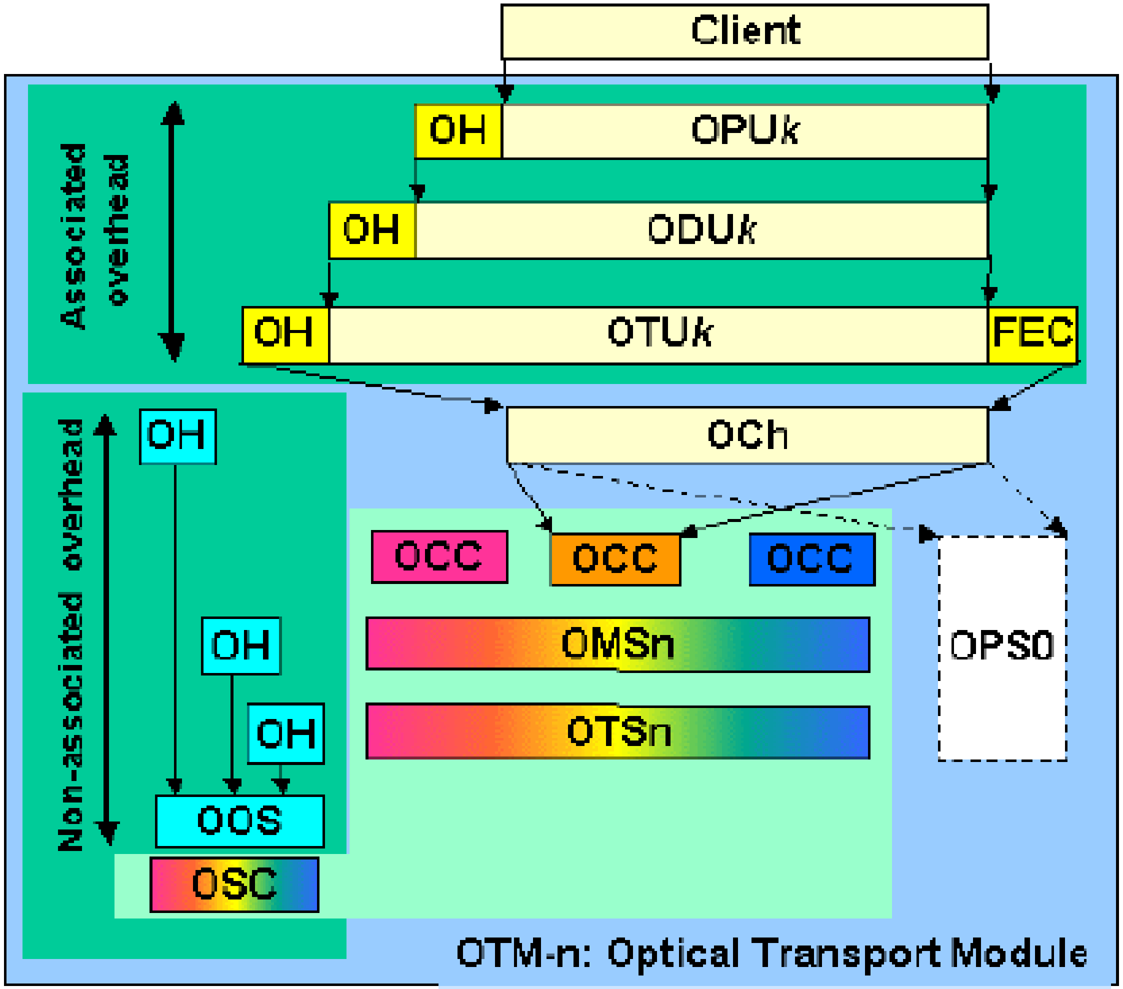
G.709 OTN

Optical Transport Network:

- OTS: Optical Transmission Section
- OMS: Optical Multiplex Section
- Och: Optical (Lambda) Channel



ITU-T G.709 framing structure



OPU: OCh Payload Unit

ODU: OCh Data Unit

OTU: OCh Transport Unit

Optical Channel

Optical Channel Carrier

Optical Multiplex Section

Optical Transmission Section

OTM Overhead Signal

Optical Supervisory Channel

Optical Physical Section

Source: Alcatel

OCh frame

OTU: Optical Channel Transport Unit

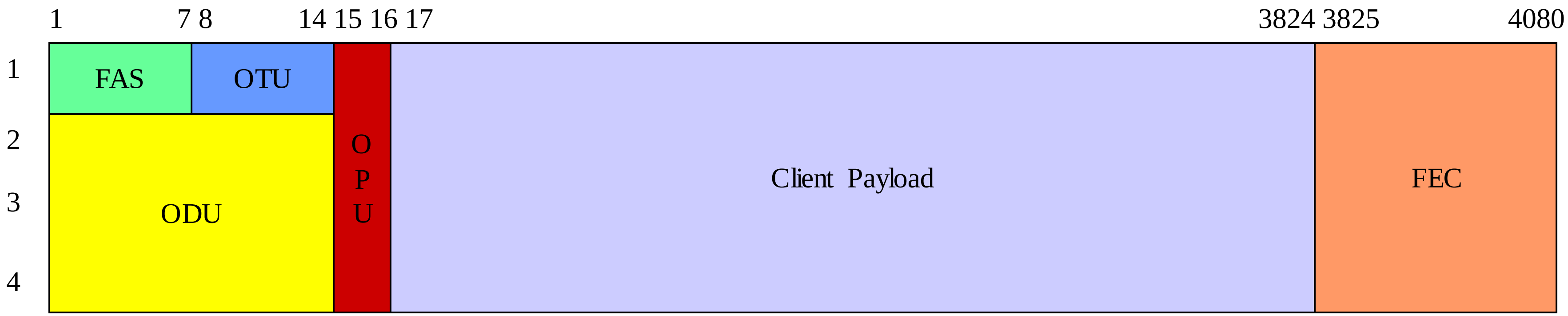
- FAS: Frame Alignment Signal (+MFAS)
- OTU-OH: Supervison: 16 bit GCCO (General Communication Channel)
- FEC: Forward Error Correction (OTU FEC)

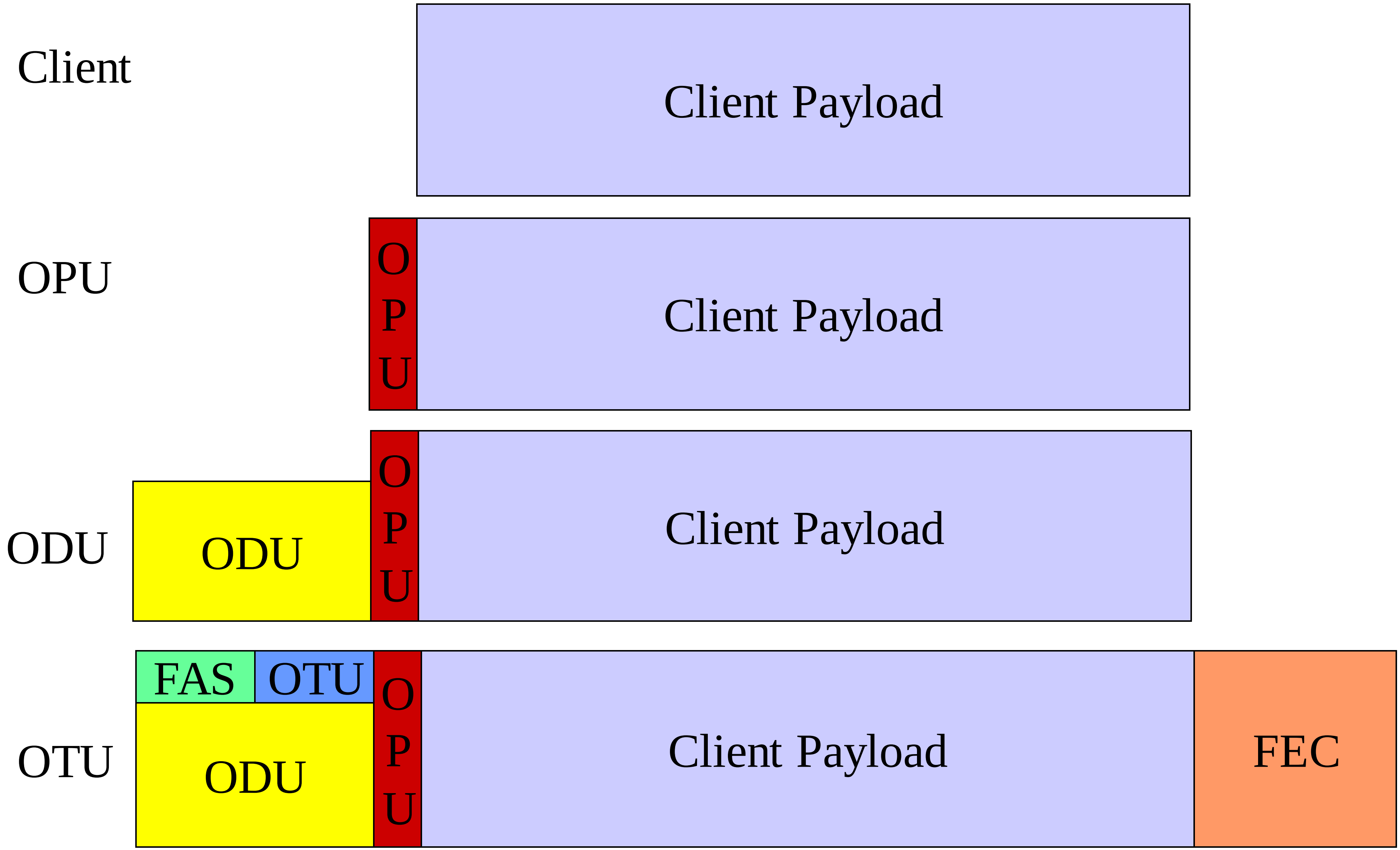
ODU: Optical Channel Data Unit OH

- Protection
- End-to-end path supervison (at ODU level) (GCC1, GCC2)
- Tandem connection monitoring

OPU: Optical Channel Payload Unit OH

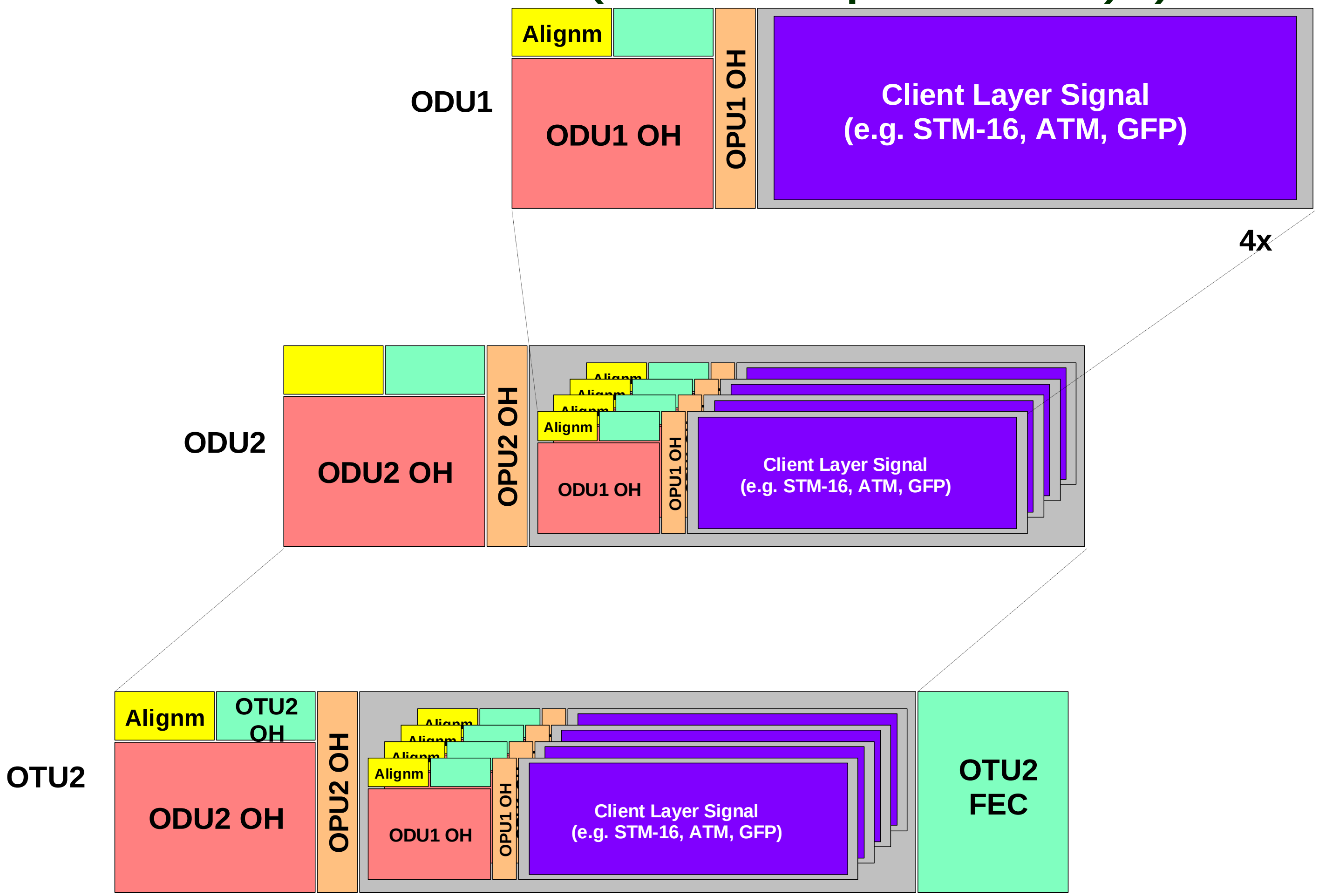
- PT: Payload Type, e.g.: SDH, ATM, GFP
- vcPT: virtual concatenation PT




Client
Client Payload
OPU
O
P
U
Client Payload
ODU
ODU
O
P
U
Client Payload
FAS
OTU
OTU
ODU
O
P
U
Client Payload
FEC

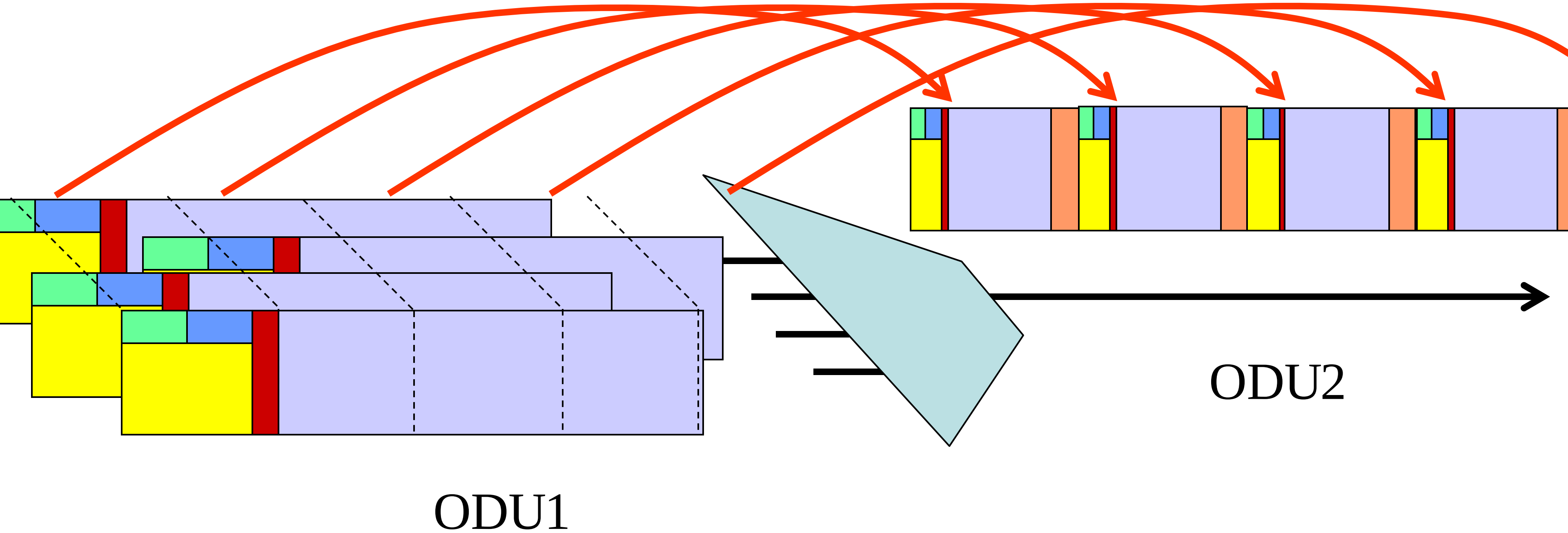
4*ODU1 → ODU2 mux

(ITU-T G.709/Y.1331 – Example of multiplexing 4 ODU1 signals into an ODU2 (artist impression))



NOTE - The ODU1 floats in ¼ of the OPU2 Payload area. An ODU1 frame will cross multiple ODU2 frame boundaries.
A complete ODU1 frame (15296 bytes) requires the bandwidth of (15296/3808 =) 4.017 ODU2 frames. This is not illustrated.

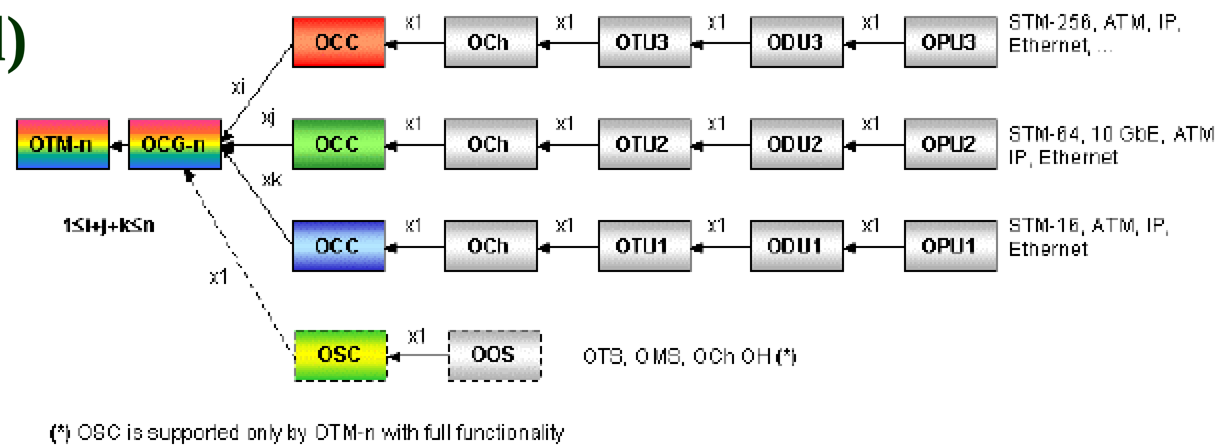
Multiplexing 4 ODU1 signals into an ODU2 (~~artist~~ engineer impression)

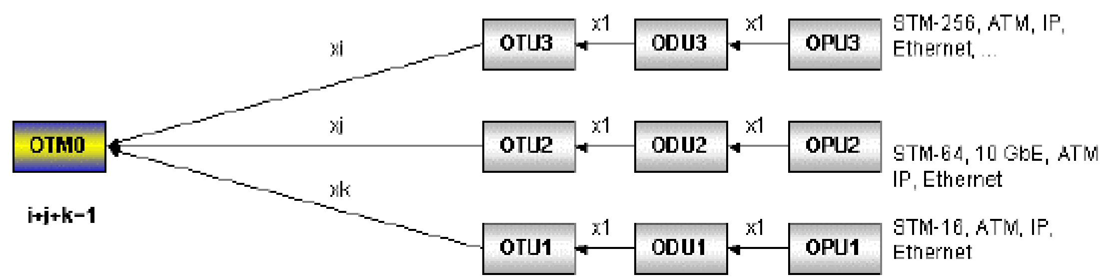


Multiplexing Structure

OTH: Optical Transport Hierarchy
OTM: Optical Transport Module
OTM-n.m:
n: number of λ channels
m: Bit-rate of channels: (1) 2.5 Gbit/s; (2) 10 Gbit/s; (3) 40 Gbit/s; or any combination
+ OH (non-associated)

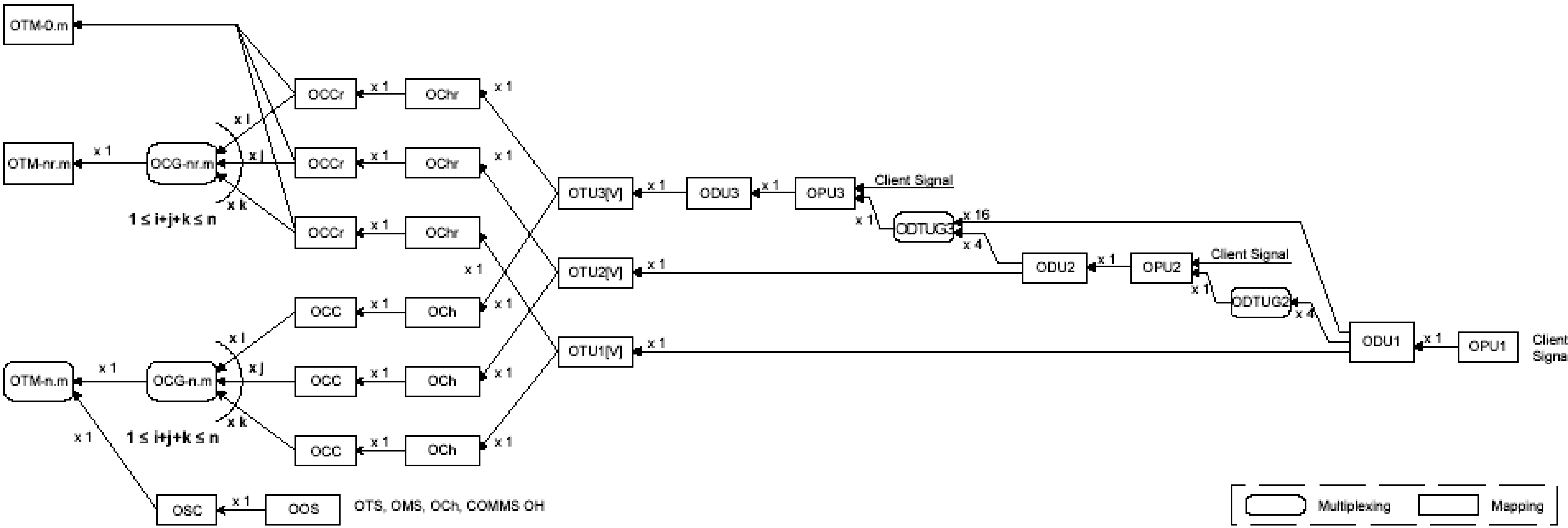
OTM-5.12:
5λ, 2.5 or 10 Gbit/s





OTM multiplexing structures

OTM-0.m, OTM-nr.m, OTM-n.m



Forrás: ITU-T G.709/Y.1331 - OTM multiplexing and mapping structures

Examples

- 1 STM-16 frame → 2.55 OTU-1 frames
  16x270x9 bytes brutto / 3809x4 bytes netto = 2.55
- 1 STM-64 frames → 10.2 OTU-2 frames
  64x270x9 bytes brutto / 3809x4 byte netto = 10.2

(Virtual Concatenation: e.g.: one ODU2-4v can transfer one STM-256)

G.709 Interface	Line Rate	Corresponding SONET/SDH Rate	Line Rate
OTU-1	2.666 Gbps	OC-48/STM-16	2.488 Gbps
OTU-2	10.709 Gbps	OC-192/STM-64	9.953 Gbps
OTU-3	43.018 Gbps	OC-768/STM-256	39.813 Gbps

+7%

Source: Guylain Barlow, Innocor Ltd.: **A G.709 Optical Transport Network Tutorial**

Bit-rates and frame "duration"

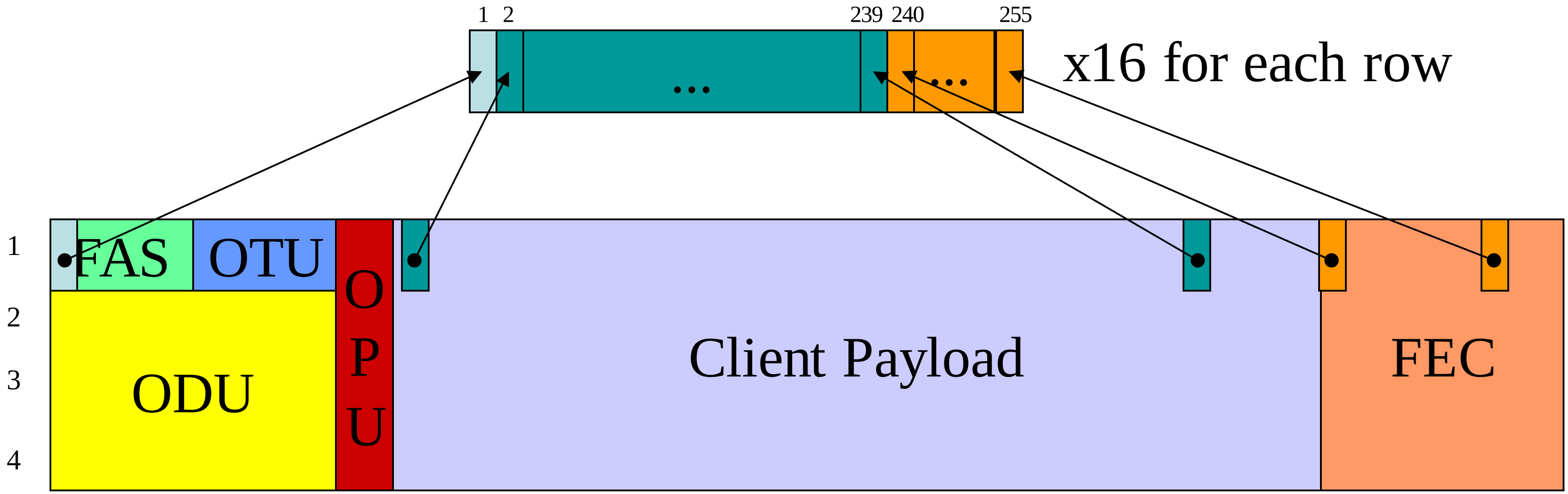
Framing hierarchy	OPU [Gbit/s]	ODU [Gbit/s]	OTU [Gbit/s]	Time [μs]
1	2.488320	239/238 * 2.488320	255/238 * 2.488320	48.971
2	238/237 * 9.953280	239/237 * 9.953280	255/237 * 9.953280	12.191
3	238/236 * 39.813120	239/236 * 39.813120	255/236 * 39.813120	3.035

Tolerance in all cases: ±20ppm

FEC

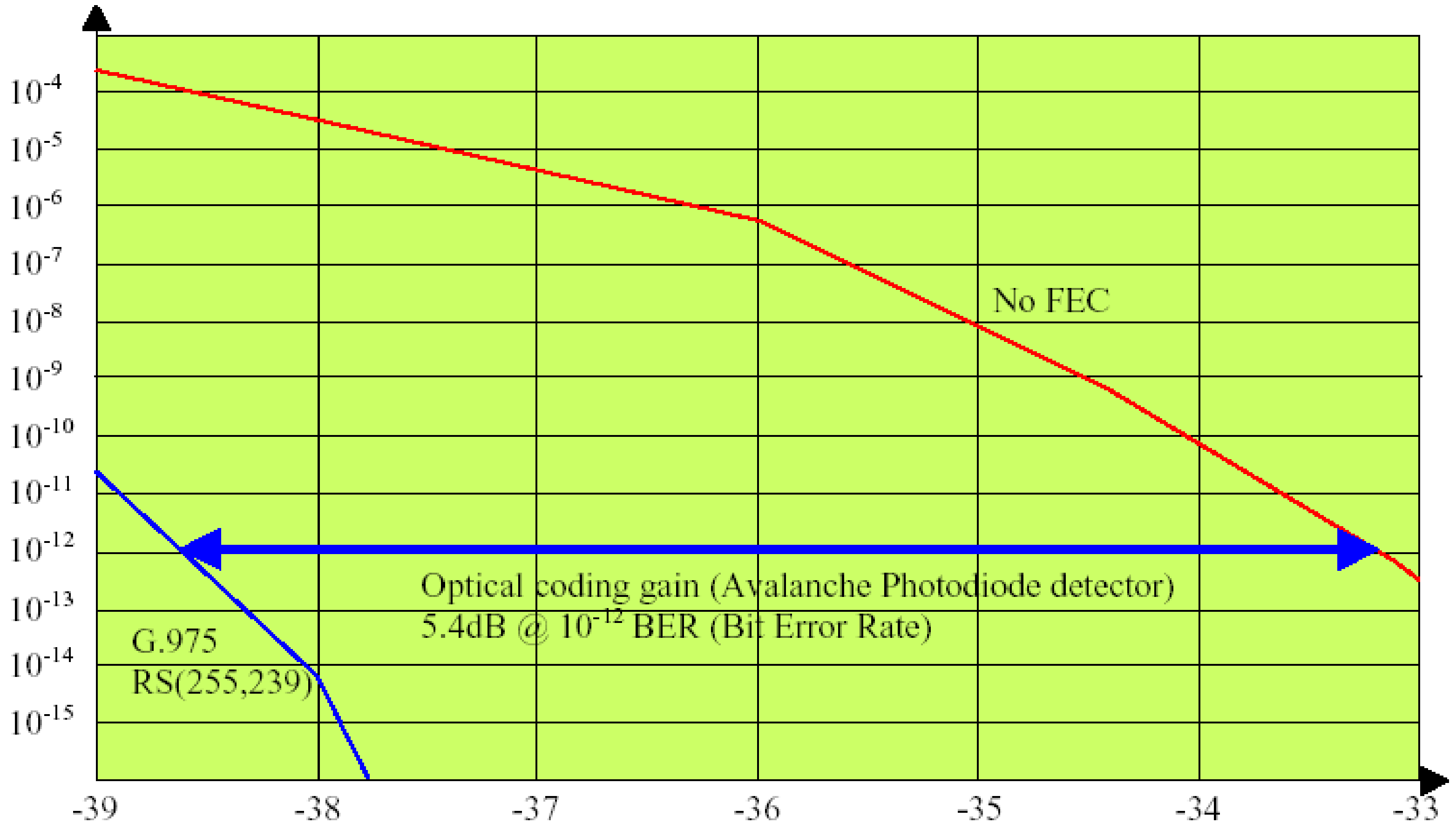
RS (255,239) Reed Solomon code
- Simple
- Significant bit-error correction capability
- Suitable for Block-failures (max 8 bytes)

16 blocks ← interleaving
- Lower per-block bit-rate than line-rate
- Lower sensitivity to block-failures (works even for 16x8=128 consequent bytes)



Gain of FEC (1)

BER vs. power level with and without FEC



Source: Guylain Barlow, Innocor Ltd.: **A G.709 Optical Transport Network Tutorial**