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

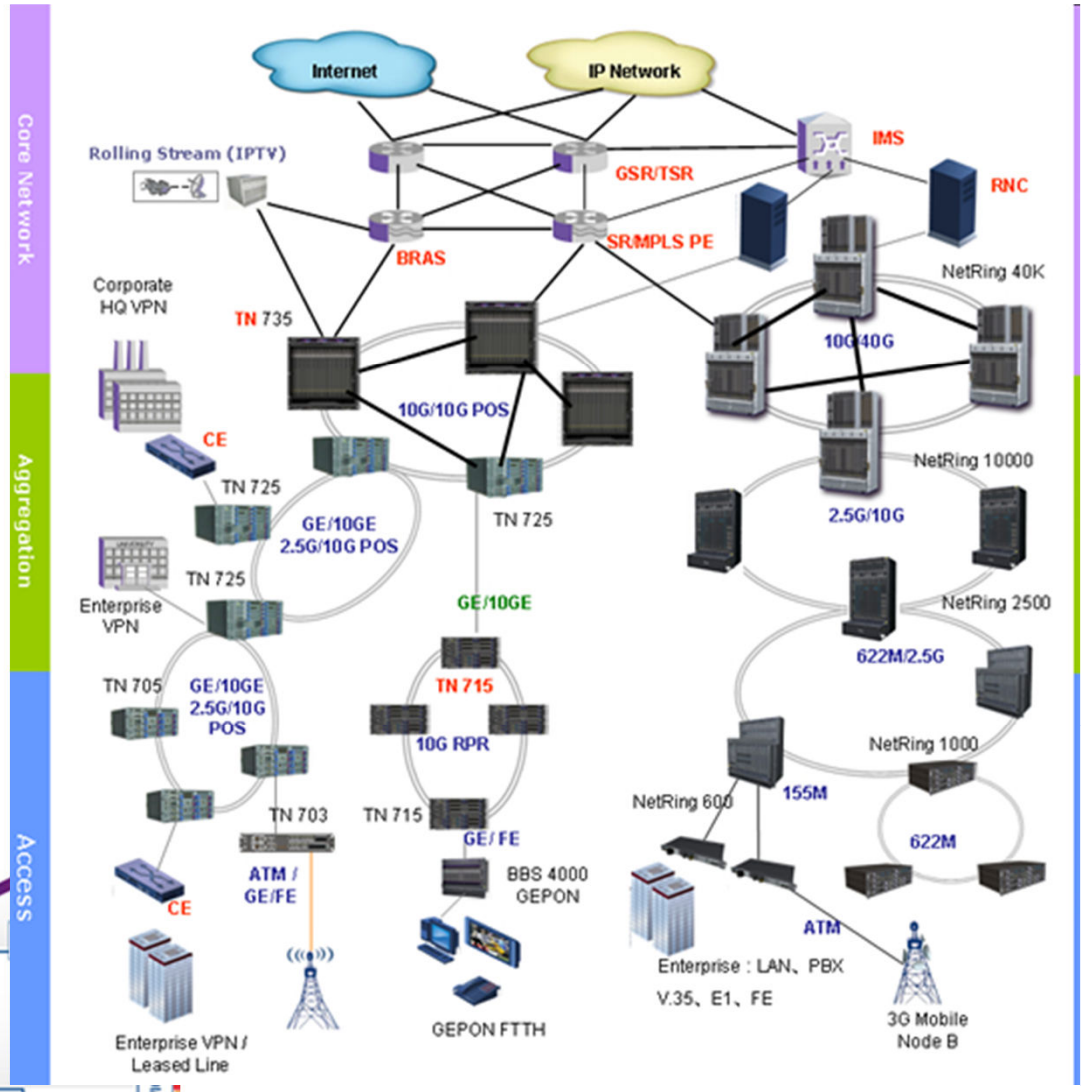
- Evolution of transmission techniques
  - 1915 New York - San Francisco telephony - copper/analog
  - 1936 coaxial cabel PSTN NY - Philadelphia
  - 1947 microwave links
  - 1962 telecom. satelite
  - 1980 fiber
  - 1988 SONET (ANSI) and SDH (CCITT → ITU) standard

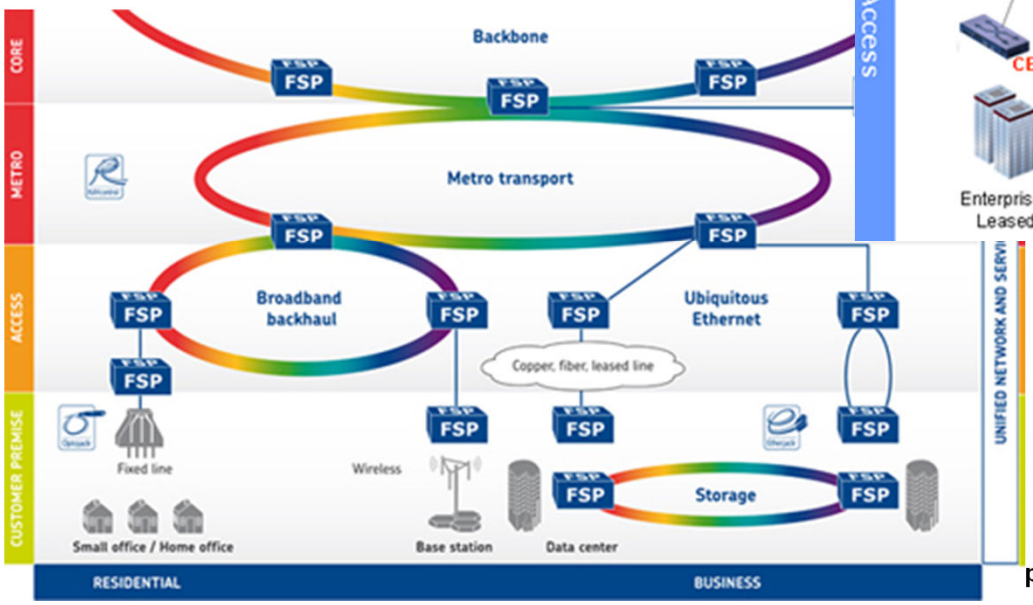
Analog -> Digital

PDH -> SDH

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

Access
Metro
Core





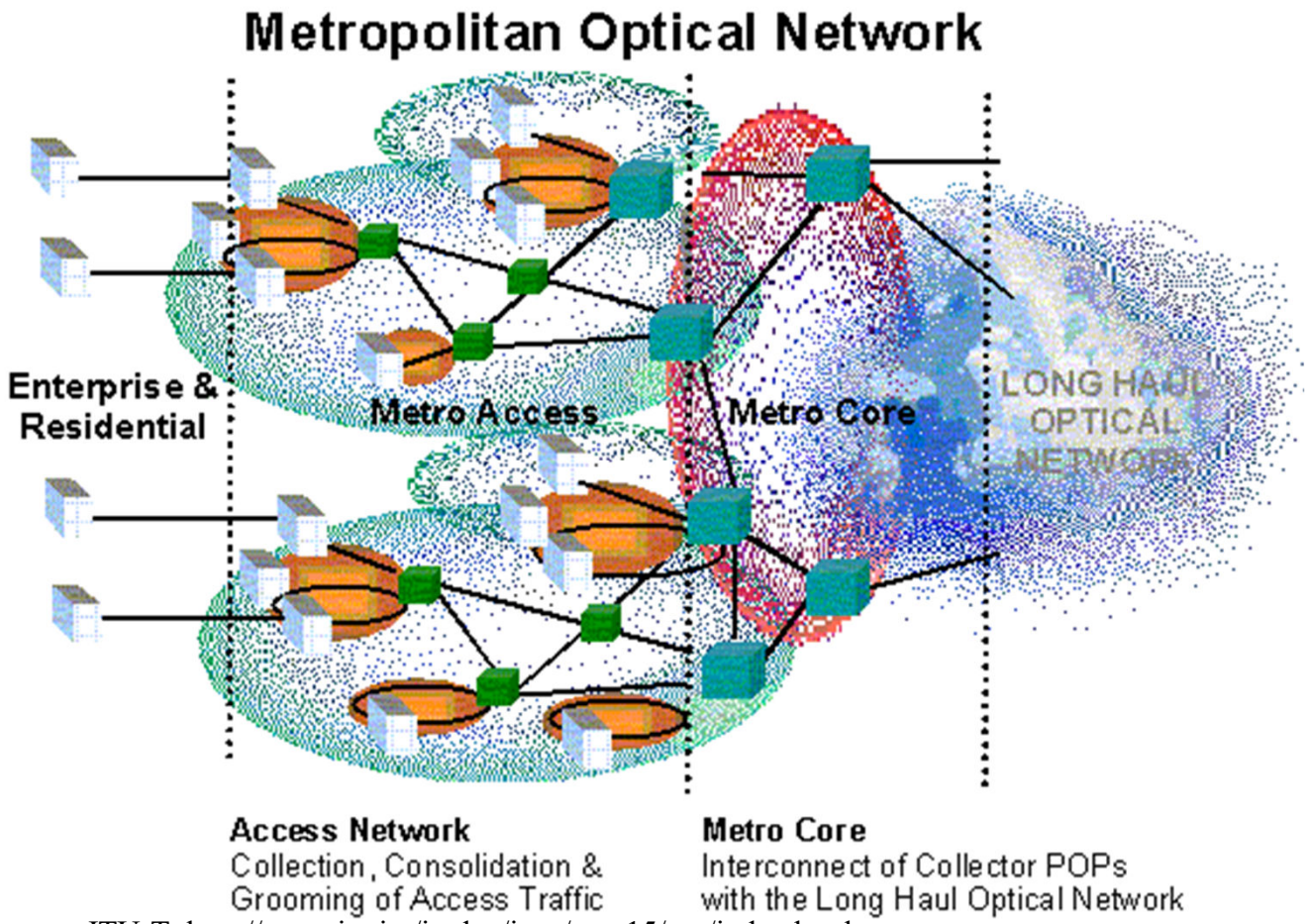
MON-LHON — Positioning

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

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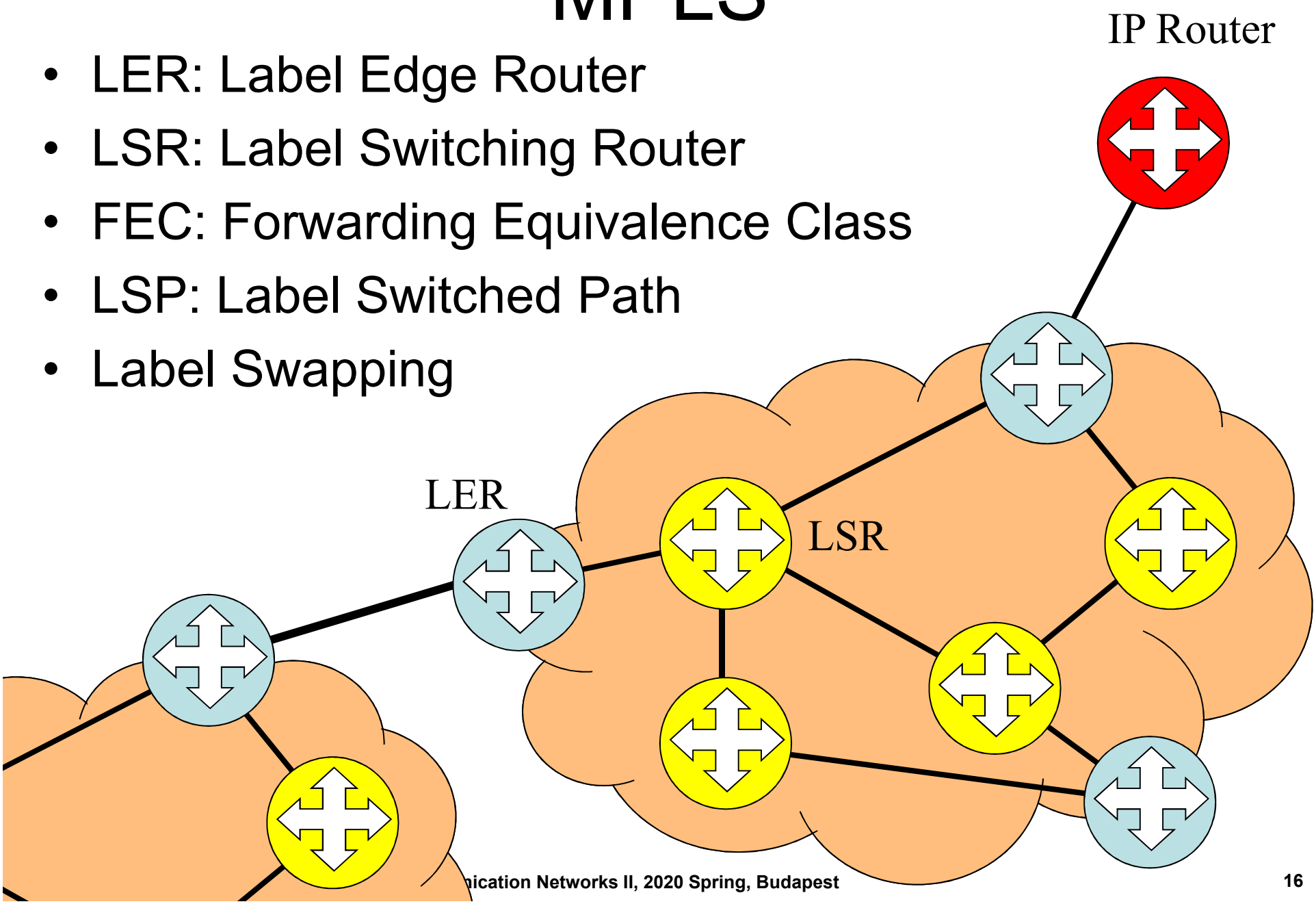
MPLS

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

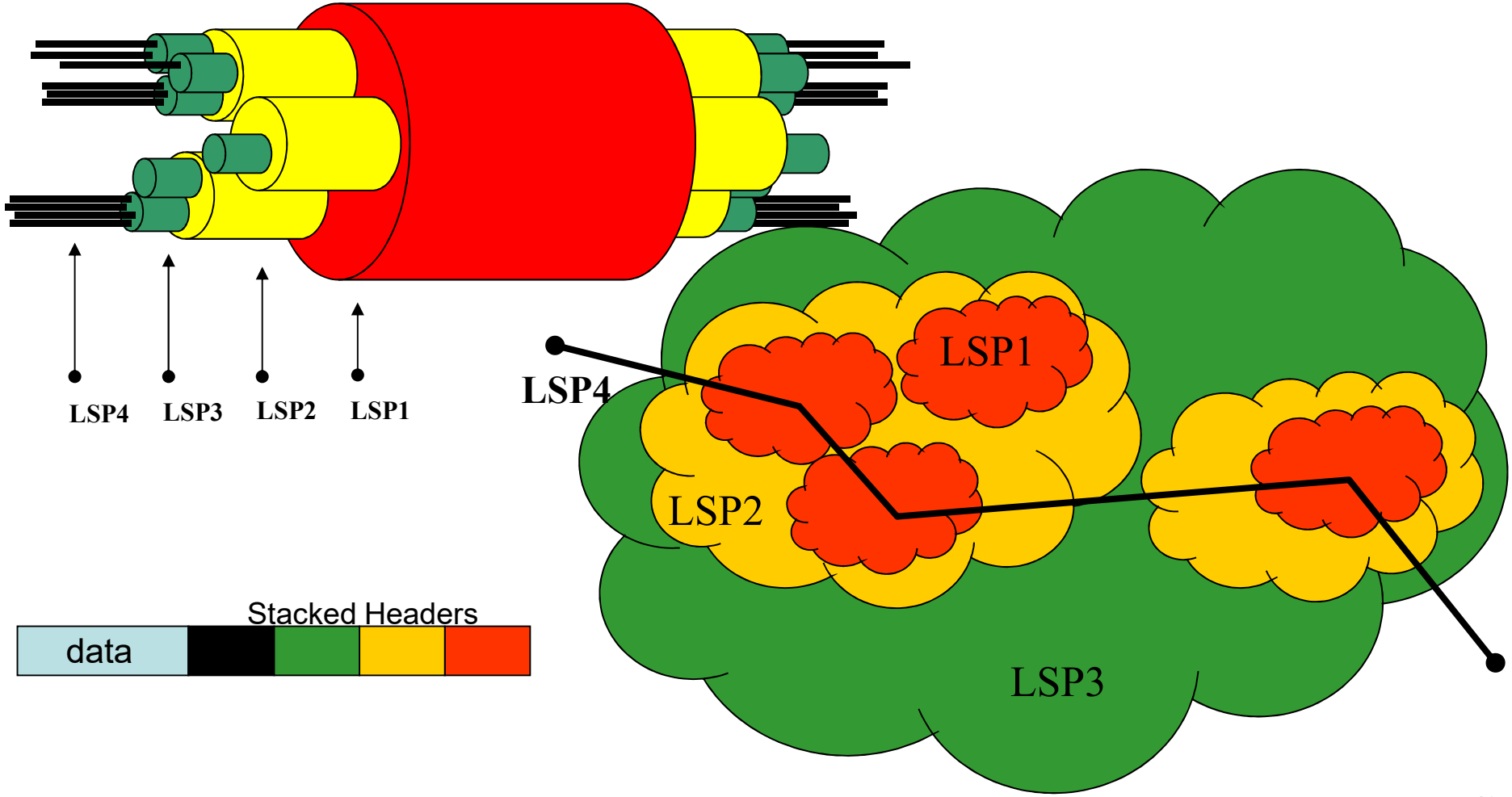


LER and LSR functions

- 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



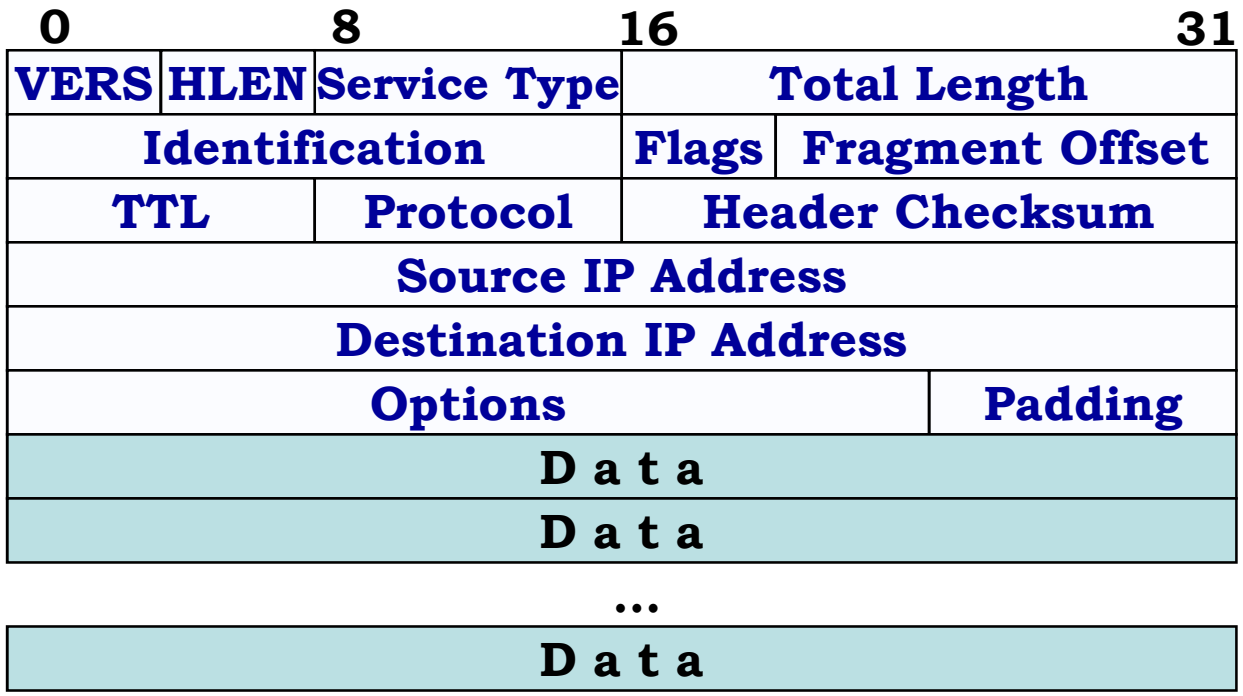
MPLS header

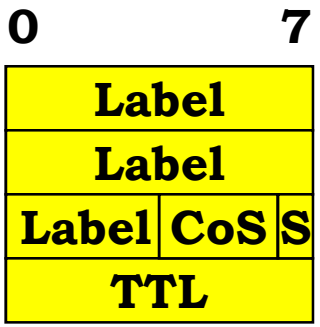
- Header: 32 bit = 4 byte
- Label: 20 bits

```
 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

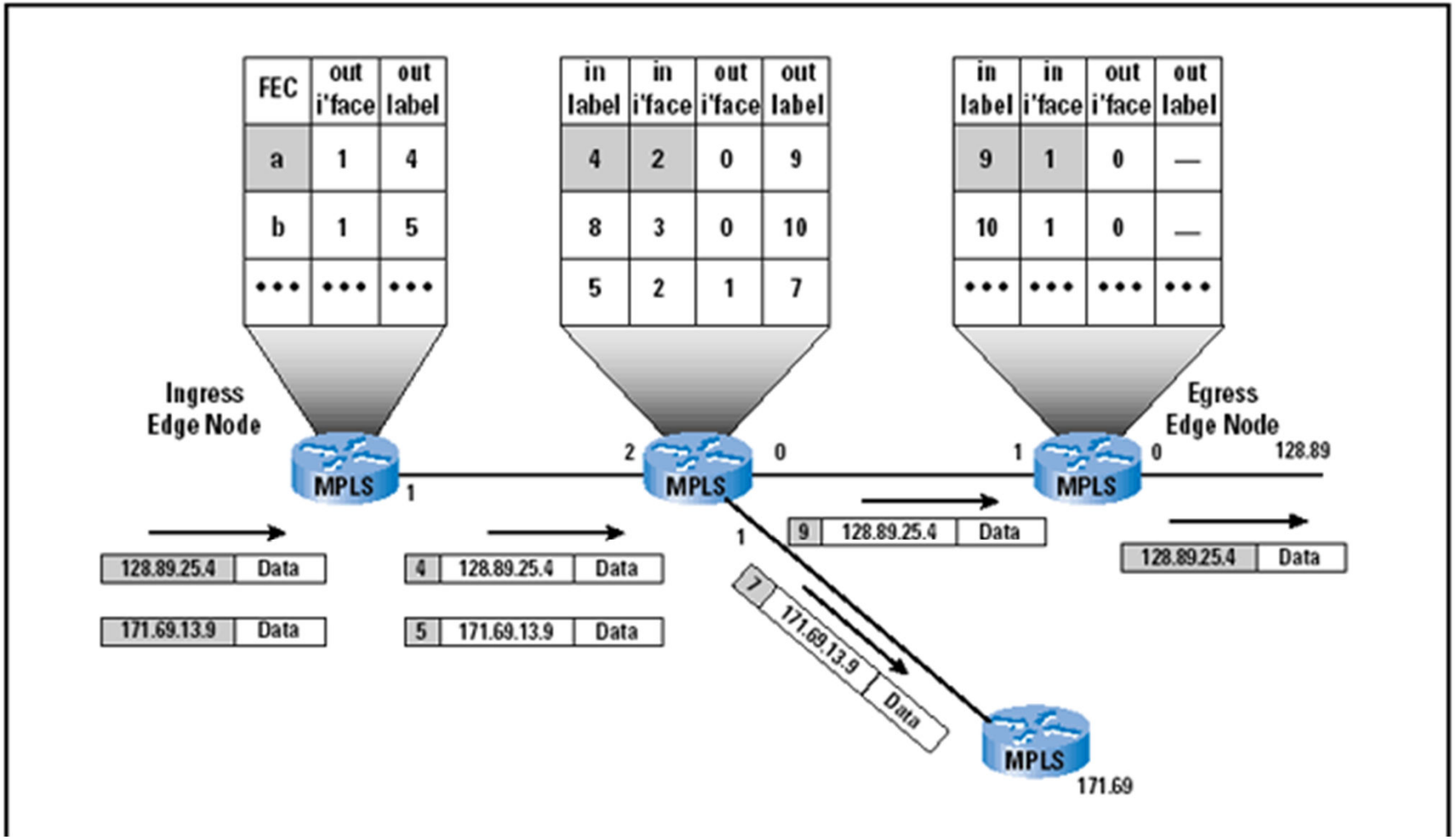




MPLS forwarding

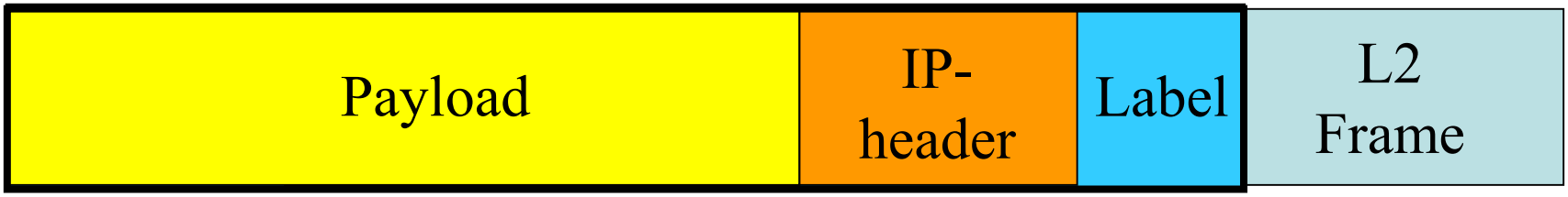
- http://www.cisco.com/c/en/us/about/press/internet-protocol-journal/back-issues/table-contents-10/mpls.html

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



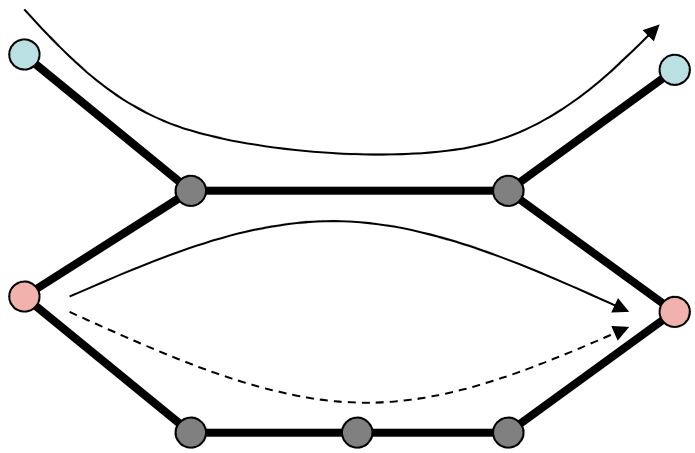
Label distribution mechanisms

- 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

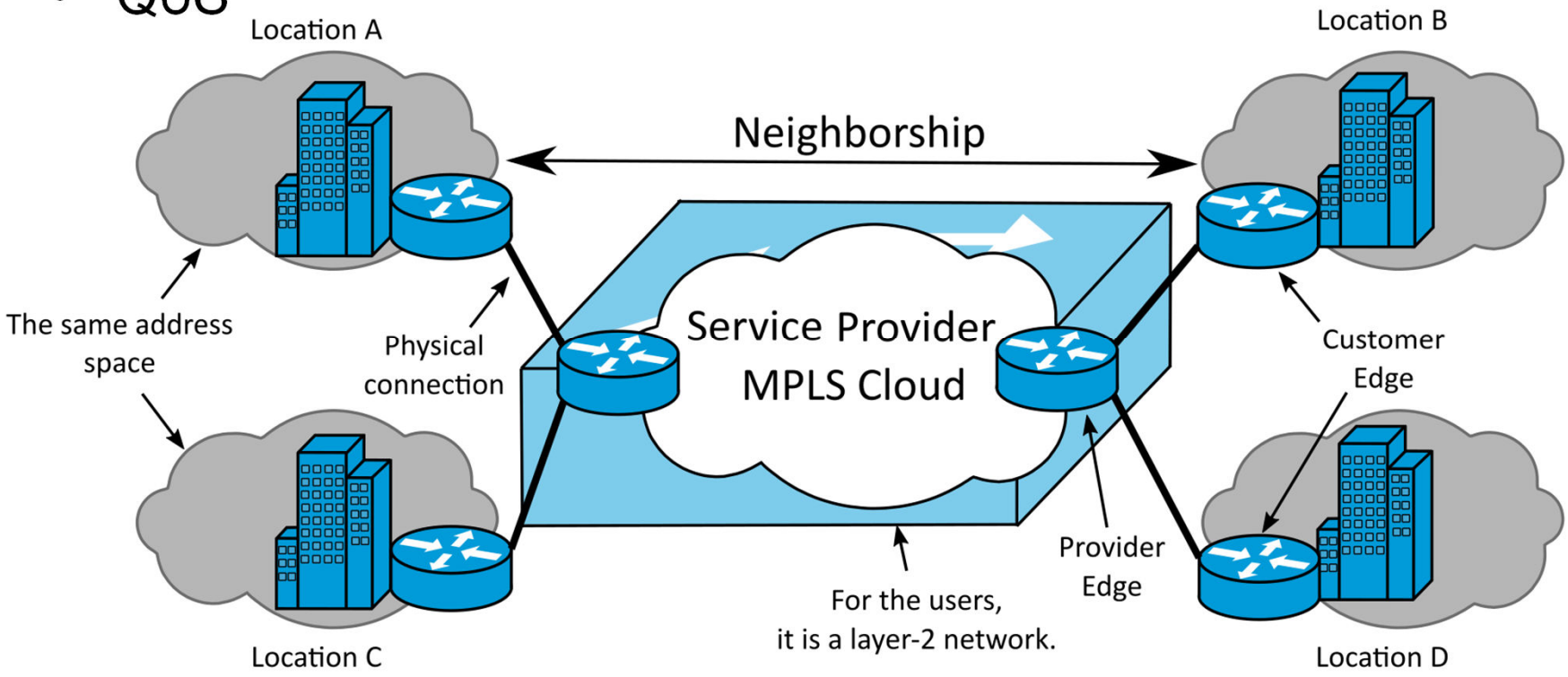


In case of failures:

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

MPLS VPN

- Separate / distant locations in the same address space
- Separate treaffic
- QoS



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

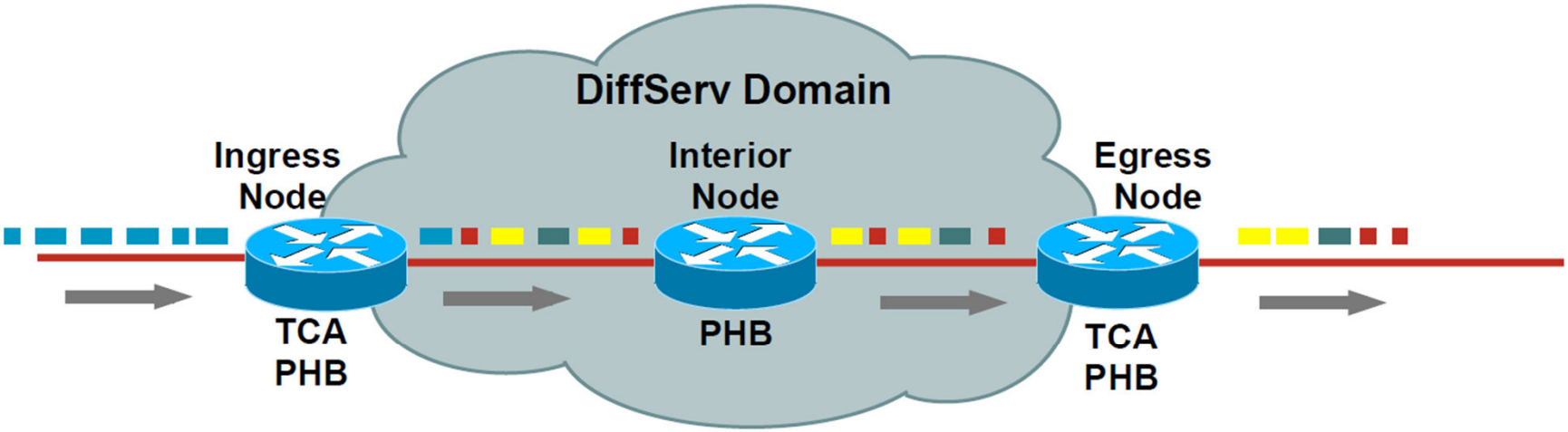
Excess Burst Size (EBS) to measure the extent by which the traffic sent on a CRLSP exceeds the committed rate

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

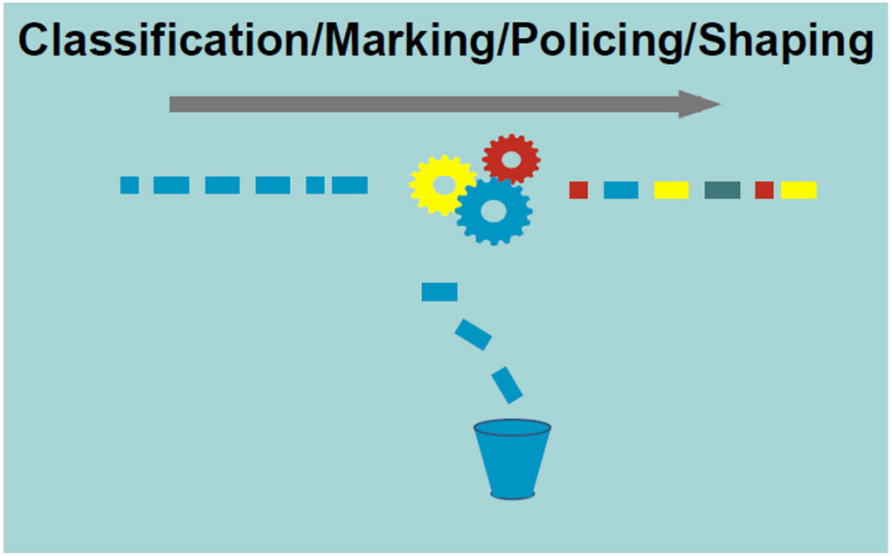
MPLS QoS Architecture

- 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

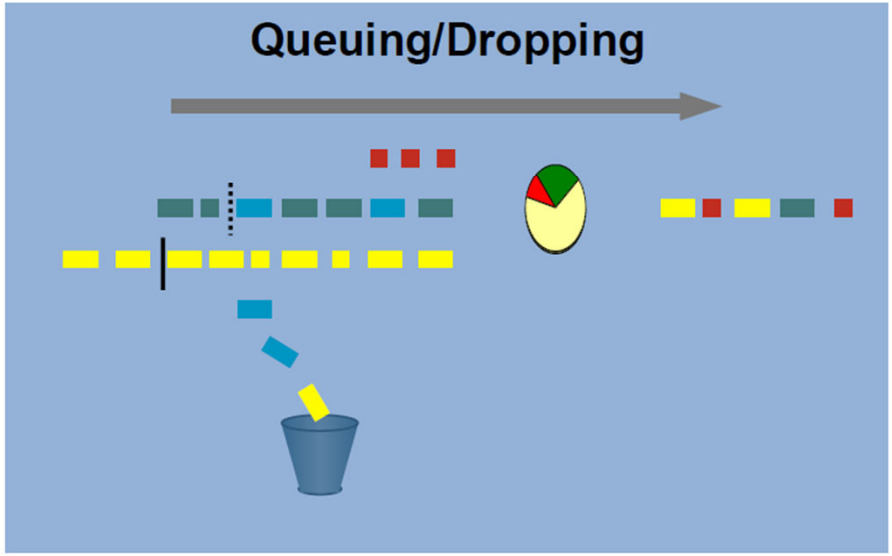
MPLS QoS Architecture



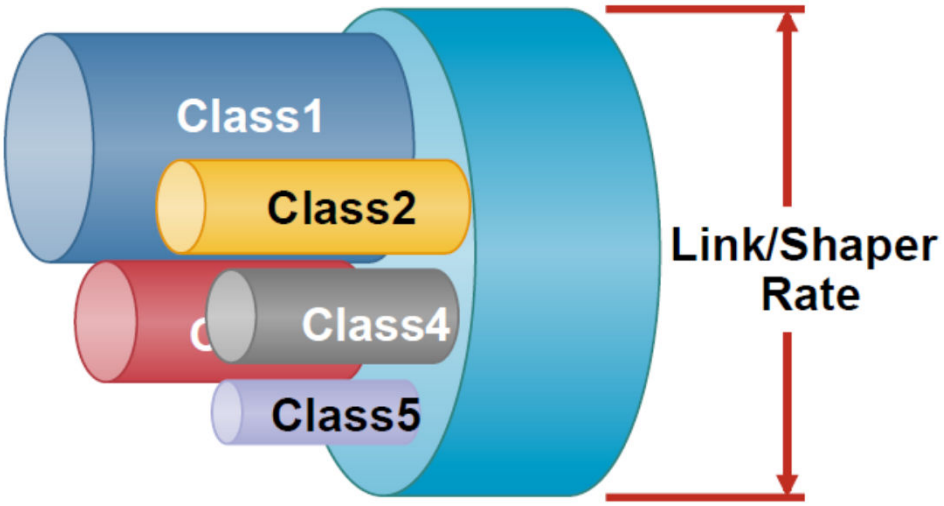
Traffic Conditioning Agement (TCA)



Per-Hop Behavior (PHB)



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)
- Label Swapping and Stacking
- 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-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
MPλ S	Multi-Protocol Lambda Switching	Többprotokollos hullámhosszkapcsolás
STM	Synchronous Transport Module	Szinkron átviteli modul

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Tibor Cinkler (**3.**) April 6, 2020

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

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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

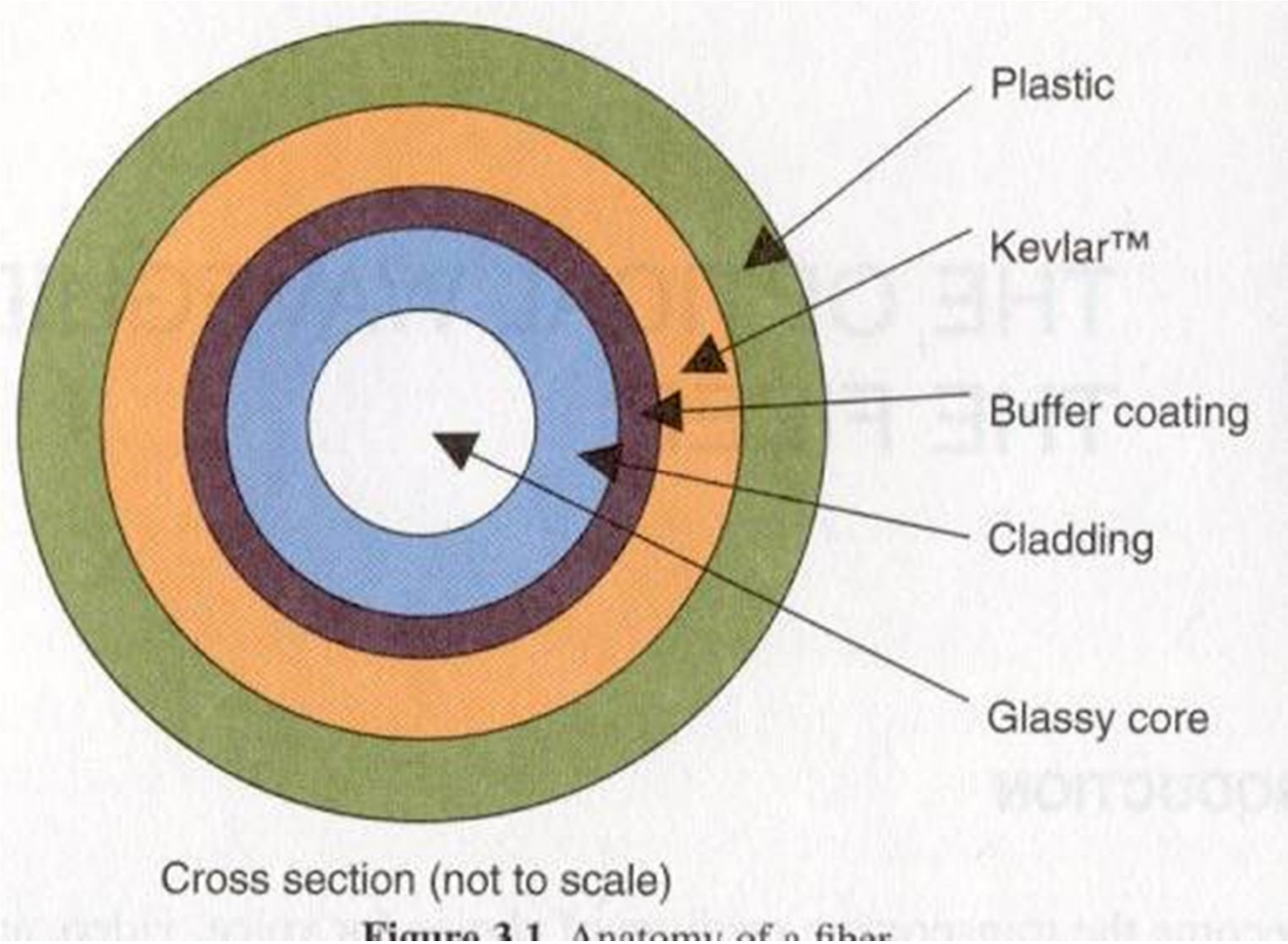
Multiplexing Solutions

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

Optical Technologies

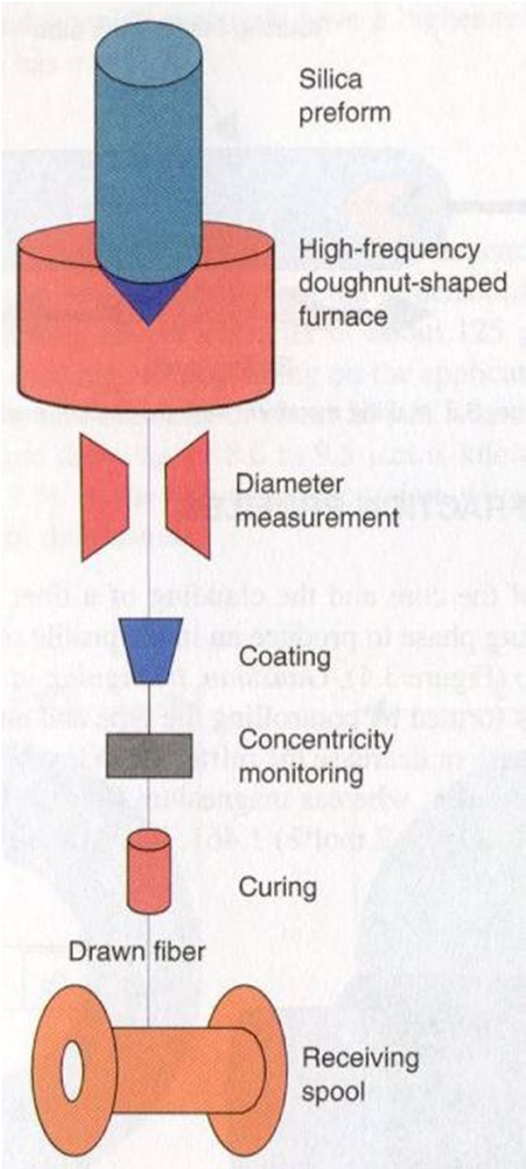
- Fibers (SMF, MMF, etc)
- AWG - Arrayed Waveguide Grating
- Transmission Impairments, transmitters, receivers, filters
- Optical Amplifiers (SOA, EDFA, RamanA)

Fiber Anatomy



Source: Shivkumar Kalyanaraman

Fiber Manufacturing



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

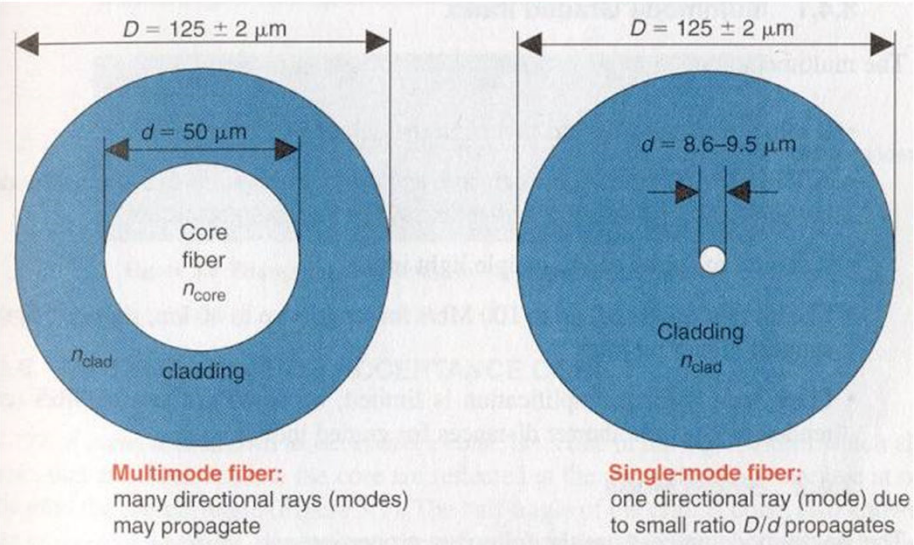
- Multiple cables per duct
- Up to 1000 fibers per cable
- Multi-core fibers?
- ~160 λ per fiber/core
- 10 Gbps or 100 Gbps per λ

Bit-rate / N.o.channels / Reach

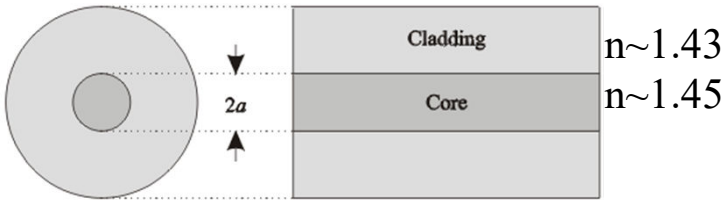
	Bit-Rate [Gbit/s]	Distance (Reach) L [km]	Optical Band [GHz]	Max. No. of Channels
a	100	4200	50	96
b	200	800	50	96
c	300	1100	75	64
d	400	500	75	64
e	500	600	100	48

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

Absorption and Attenuation: Absorption Spectrum

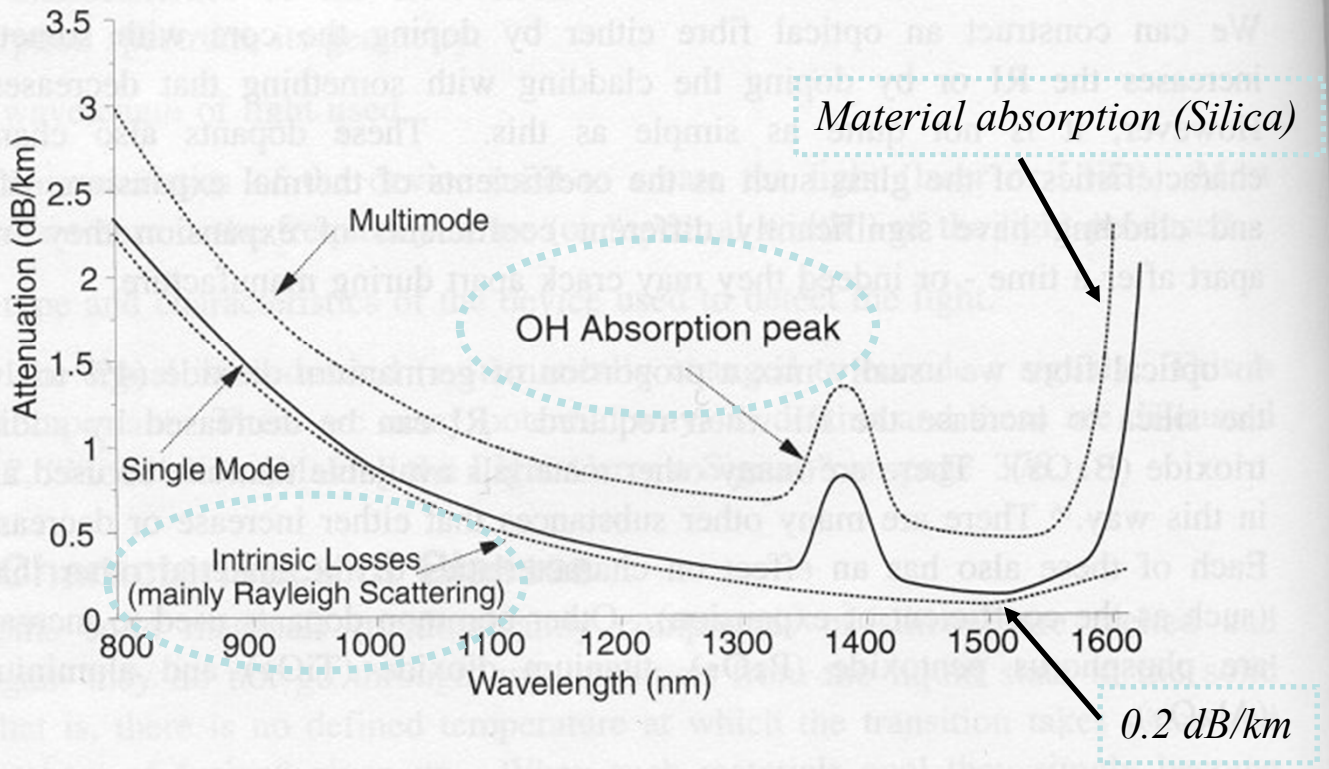


Figure 13. *Typical Fibre Infrared Absorption Spectrum. The lower curve shows the characteristics of a single-mode fibre made from a glass containing about 4% of germanium dioxide (GeO_2) dopant in the core. The upper curve is for modern graded index multimode fibre. Attenuation in multimode fibre is 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

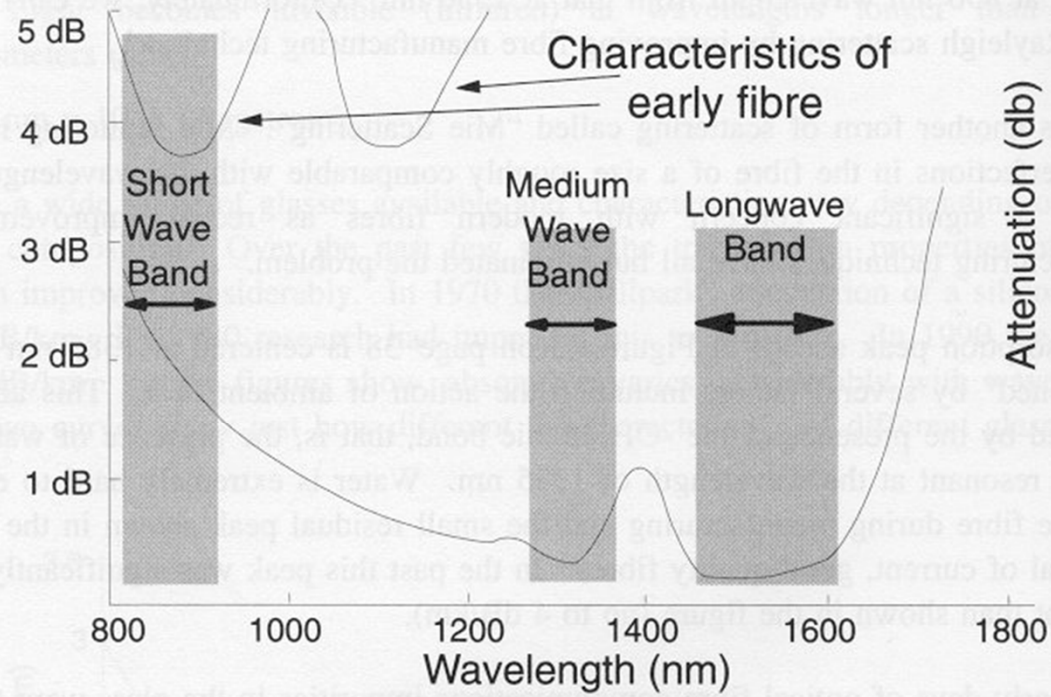


Figure 14. *Transmission Windows. The upper curve shows the absorption characteristics of fibre in the 1970s. The lower one is for modern fibre.*

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

Forrás: Shivkumar Kalyanaraman

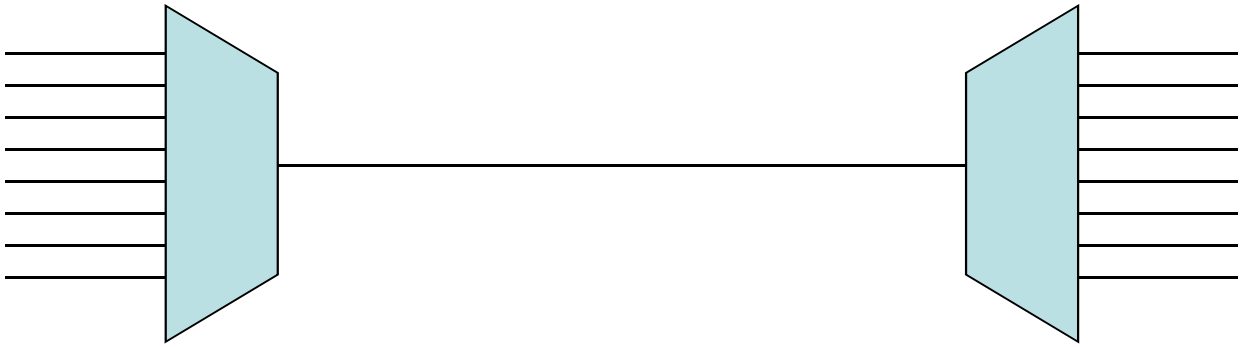
<u>Fiber Bands:</u>

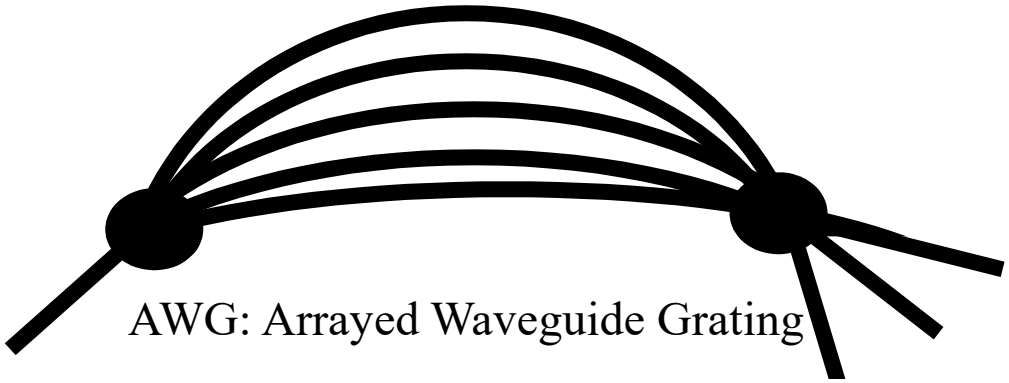
O-band: (Original) 1260-1360nm
E-band: (Extended) 1360-1460nm
S-band: (Short) 1460-1530nm
C-band: (Conventional): 1530-1565nm
L-band: (Long) 1565-1625nm
U-band: (Ultra-long): 1625-1675nm

Wavelength MUX/DEMUX

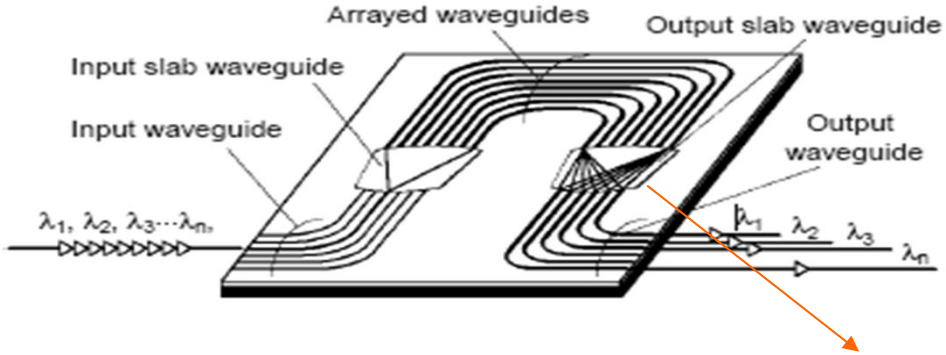
Point-to-point WDM link ...

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

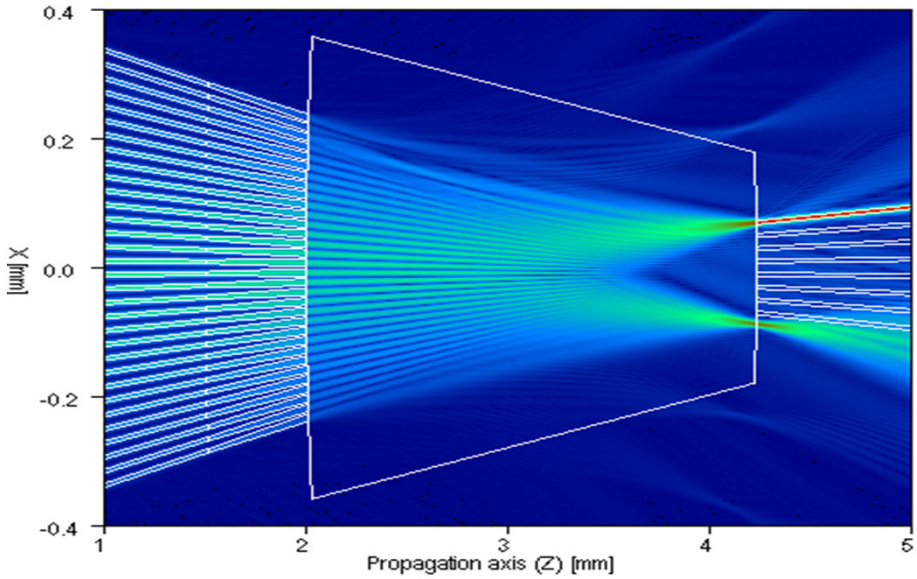




Arrayed waveguide grating



- **AWG**



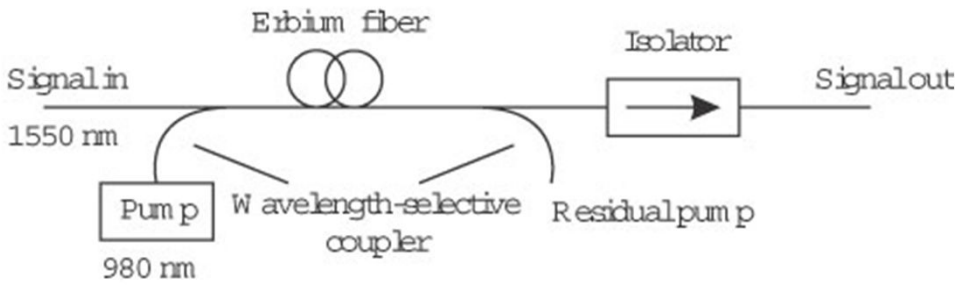
- Great scalability
- Low losses
- Non reconfigurable
  - It requires wavelength conversion

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...”

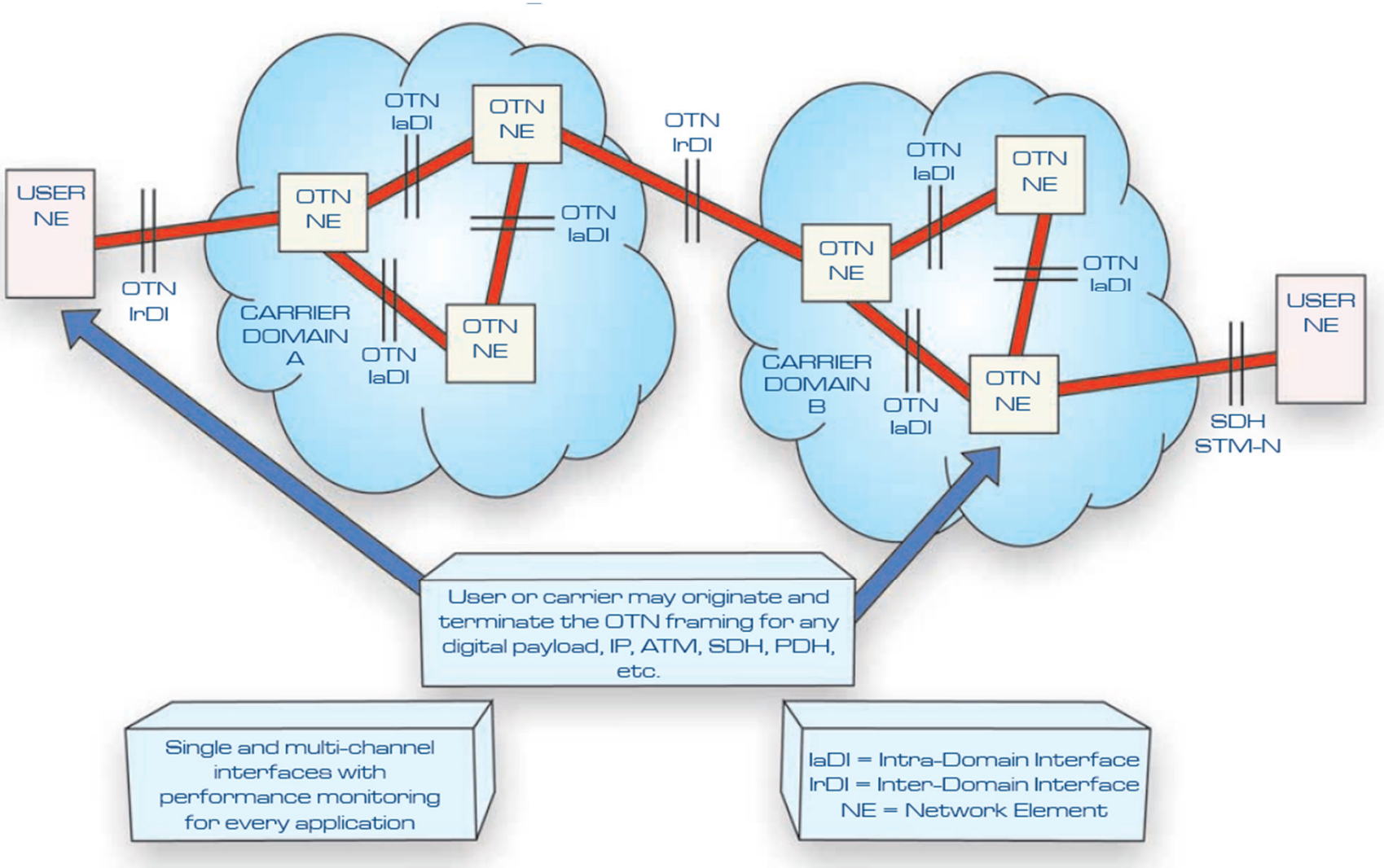
- **ITU-T G.709** (01/03) Interfaces for the **OTN**
- **ITU-T G.798** (5/02) Characteristics of **OTN** Hierarchy Equipment Functional Blocks
- **ITU-T G.872** (10/01) Architecture for the **OTN**
- **ITU-T G.8251** (10/01) The Control of Jitter and Wander within the **OTN**

General: Optical Transport Networks & Technologies (OTNT)

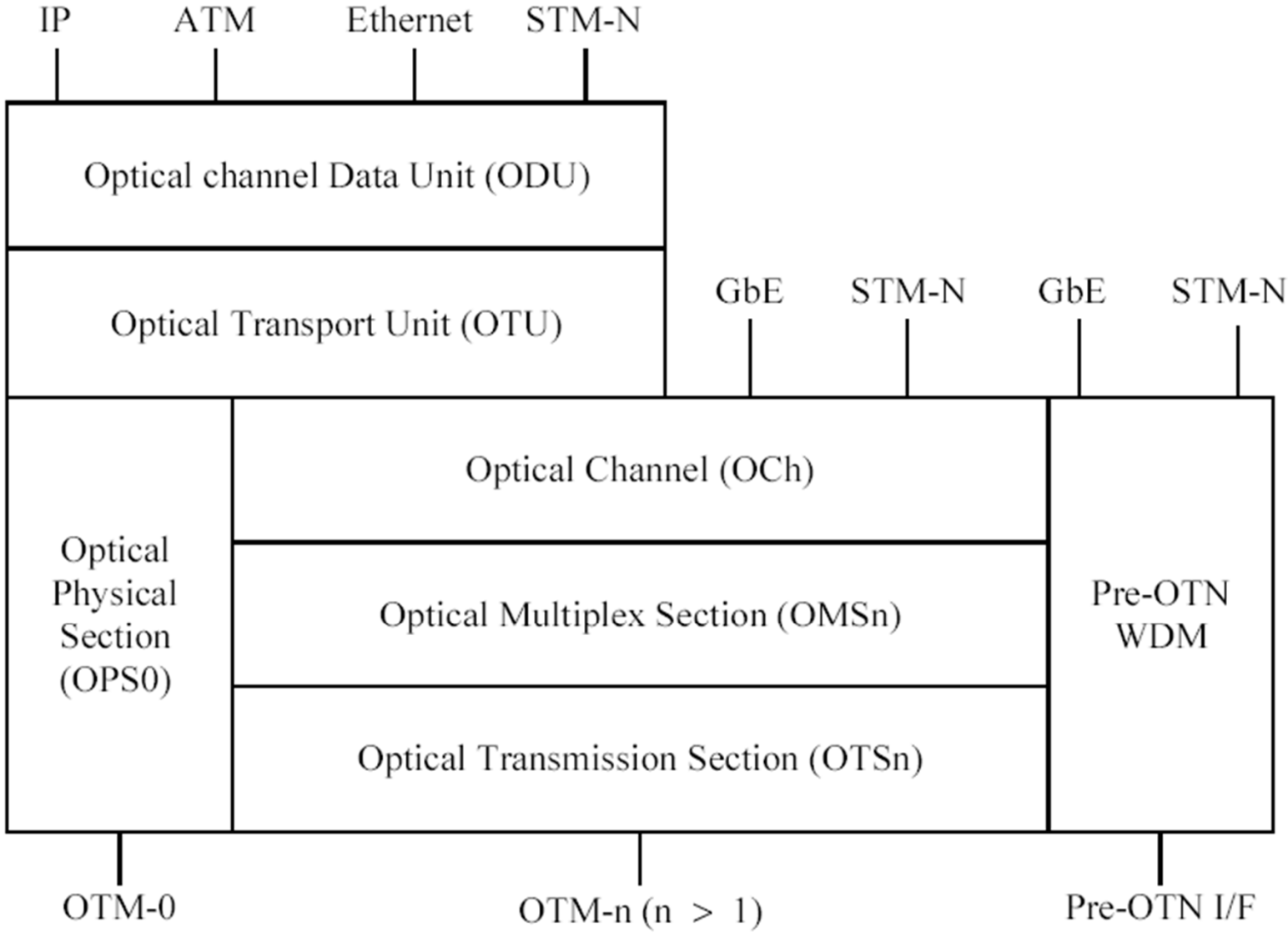
- All network functionality and related technologies that are based on optical transport
- E.g., SDH also falls into this category

Global Optical Transport Network

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



OTN and WDM

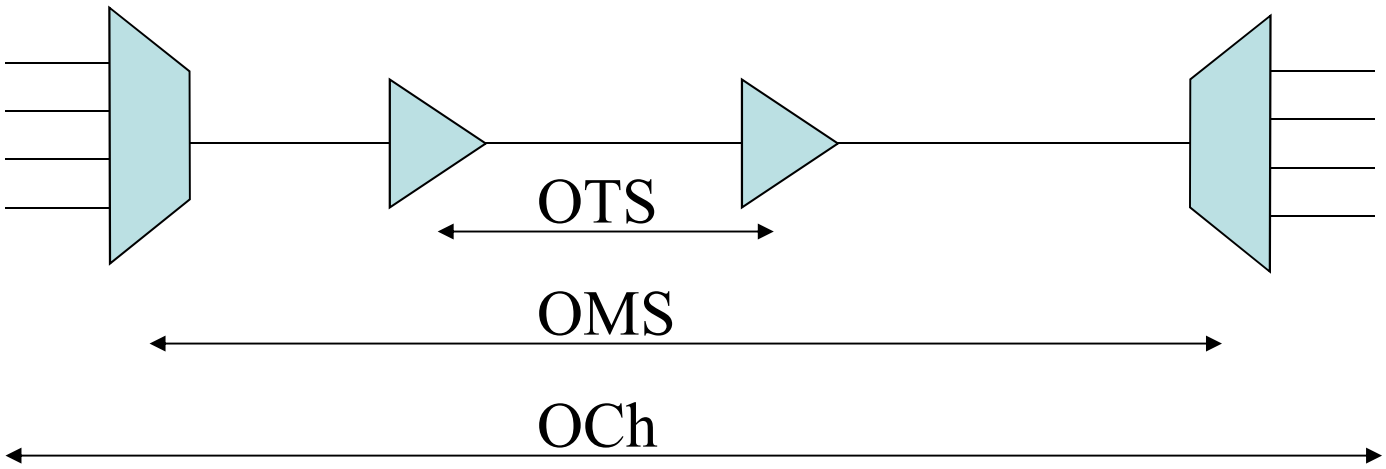


Source: ITU-T G.872: Relationship between OTN and WDM

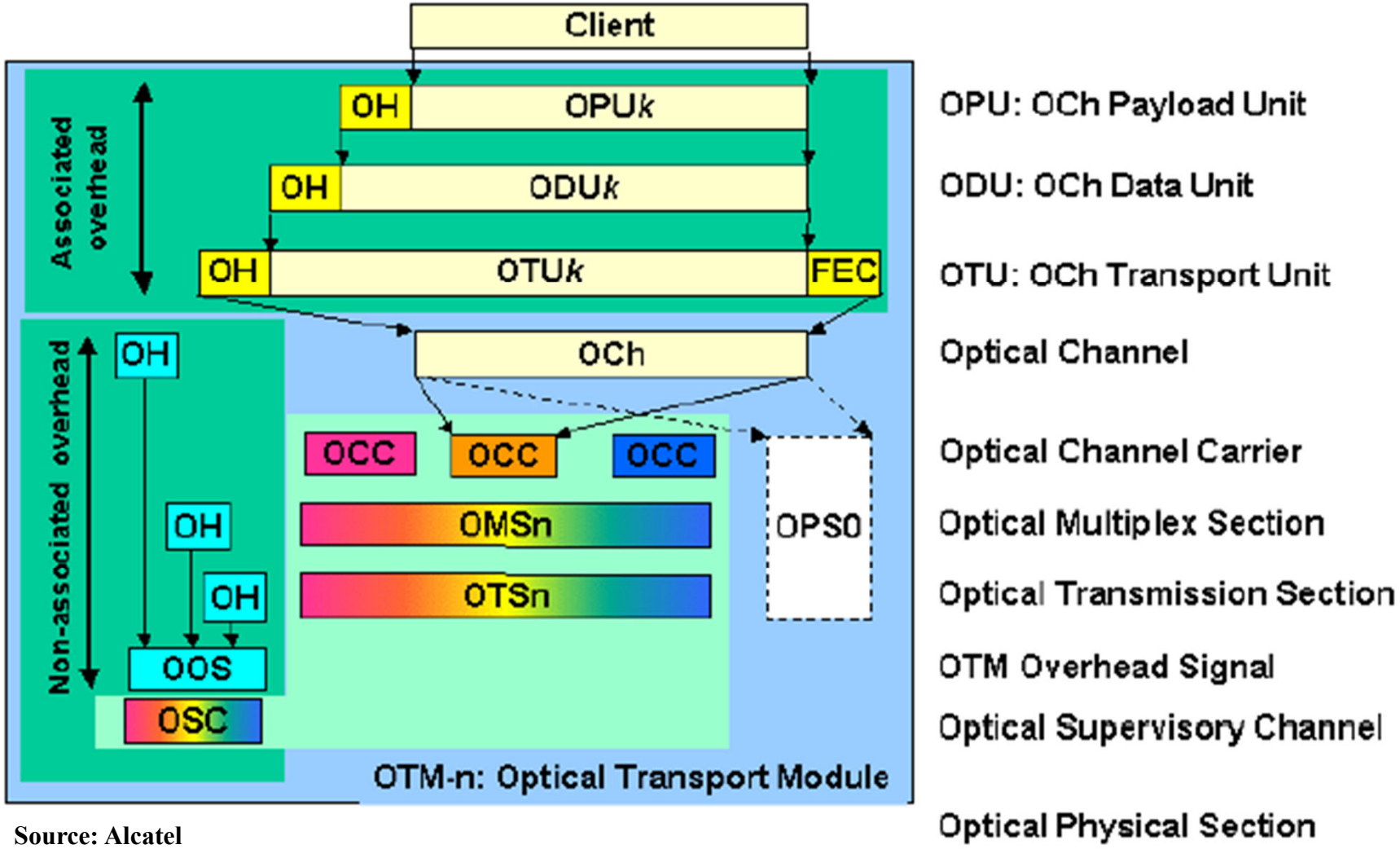
G.709 OTN

Optical Transport Network:

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



ITU-T G.709 framing structure



Source: Alcatel

OCh frame

OTU: Optical Channel Transport Unit

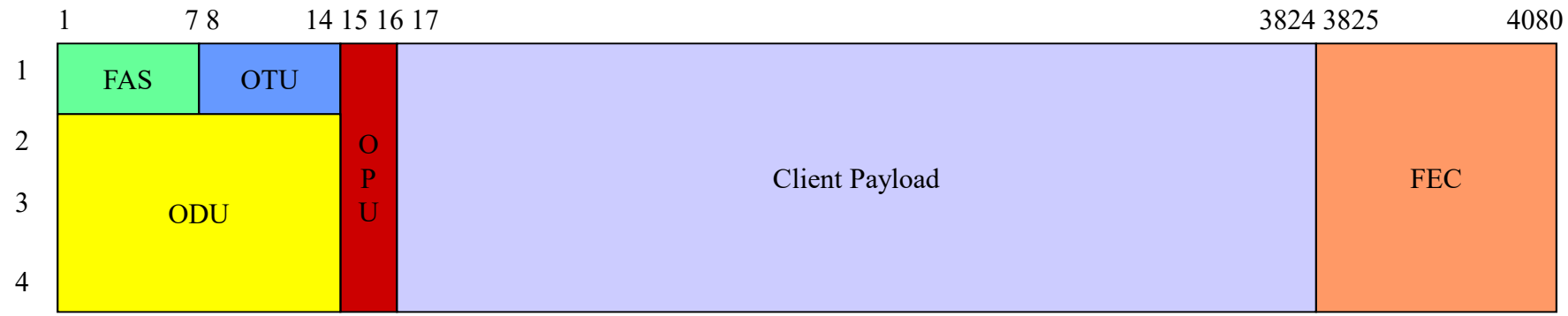
- FAS: Frame Alignment Signal (+MFAS)
- OTU-OH: Supervison: 16 bit GCCO (General Communication Channel)
- FEC: Forward Error Correction (OTU FEC)

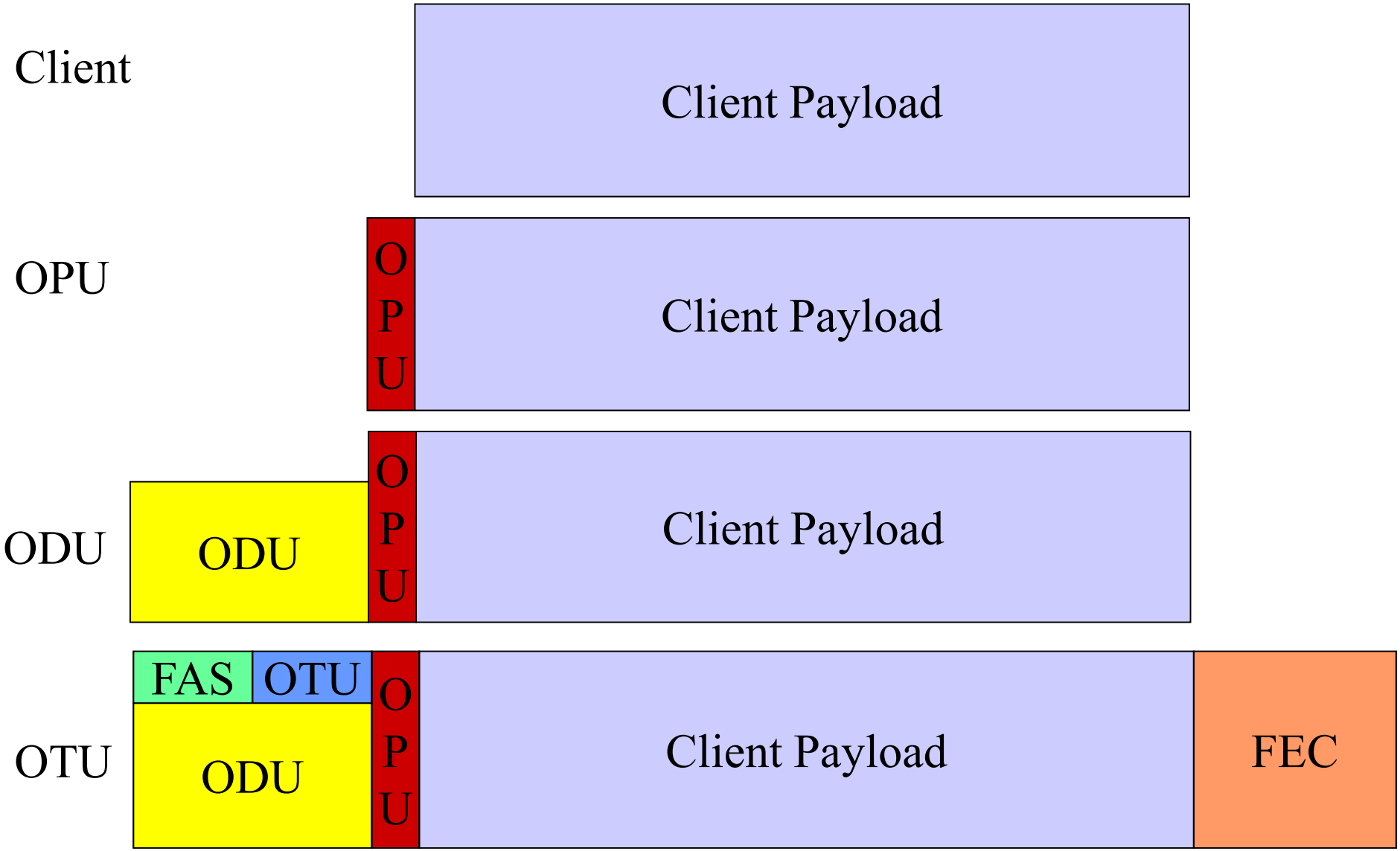
ODU: Optical Channel Data Unit OH

- 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
OTU
FAS
OTU
ODU
O
P
U
Client Payload
FEC

Communication Networks II

BMEVITMA310 in English

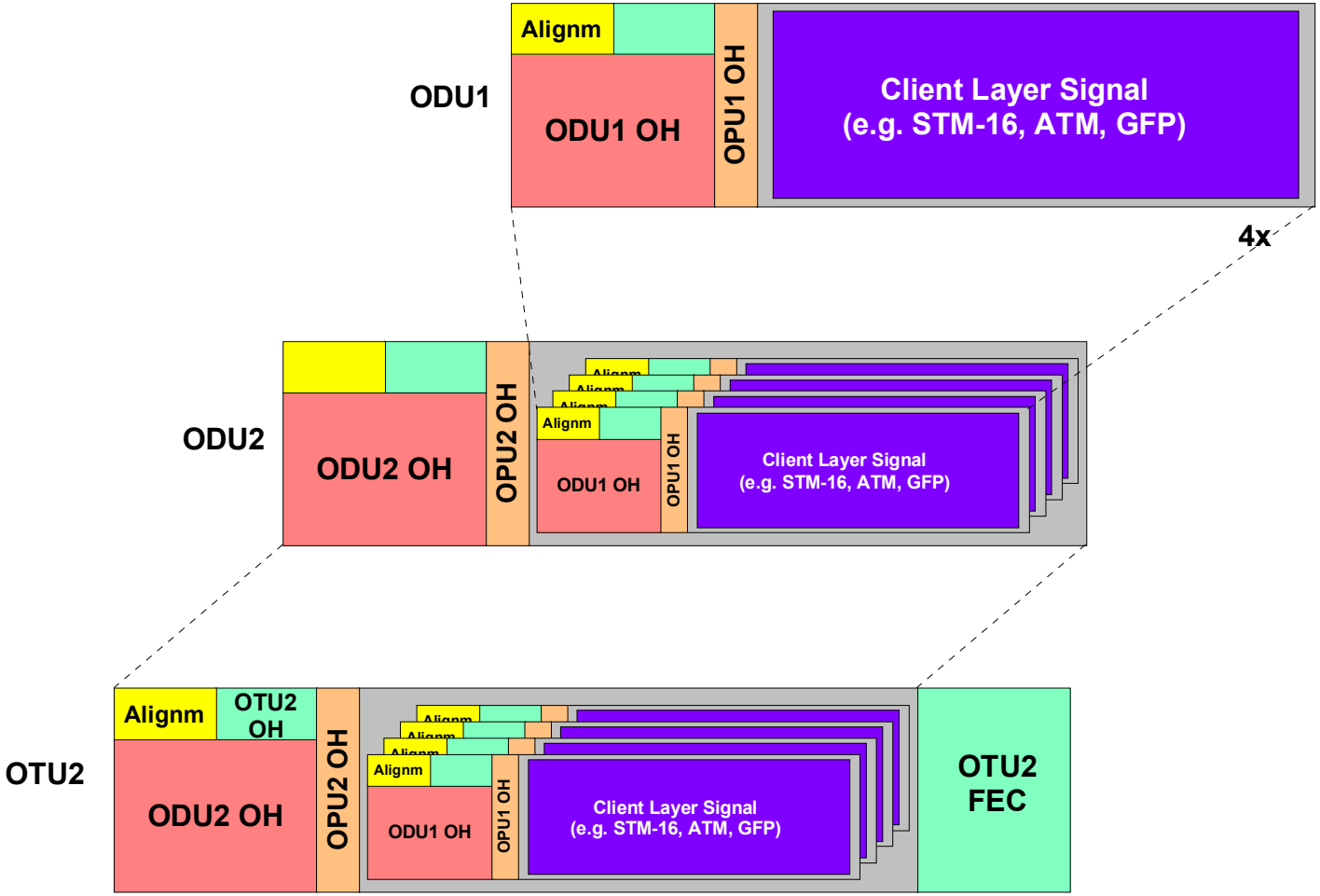
Tibor Cinkler (**4.**) April 27, 2020

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

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

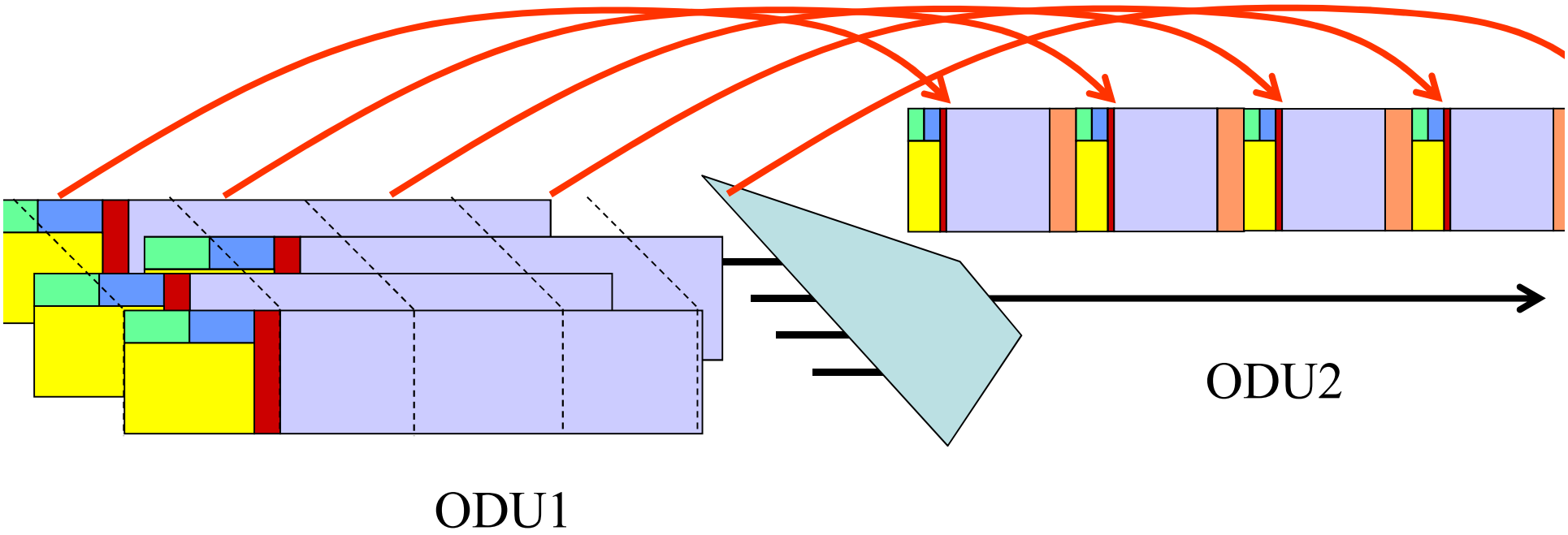
4*ODU1 → ODU2 mux

(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.

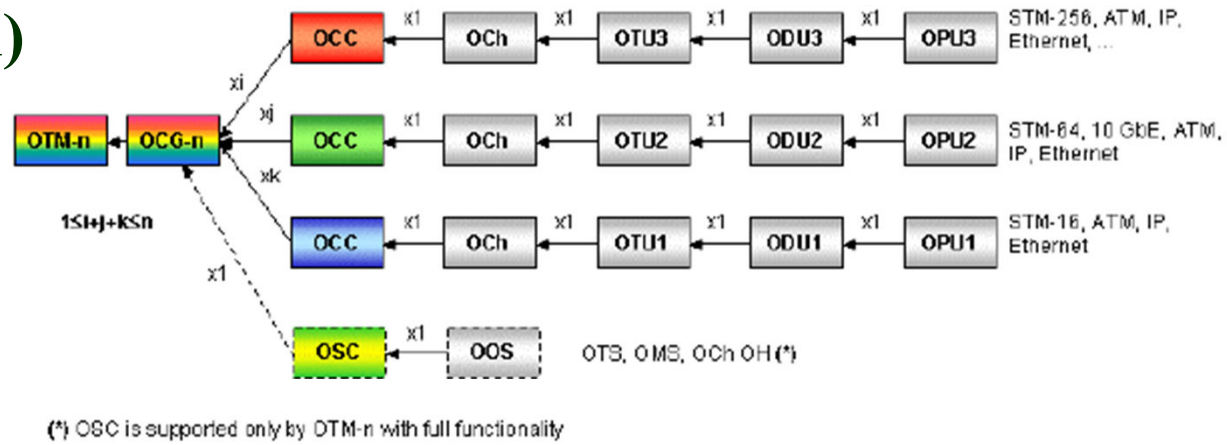
Multiplexing 4 ODU1 signals into an ODU2 (~~engineer~~ impression)

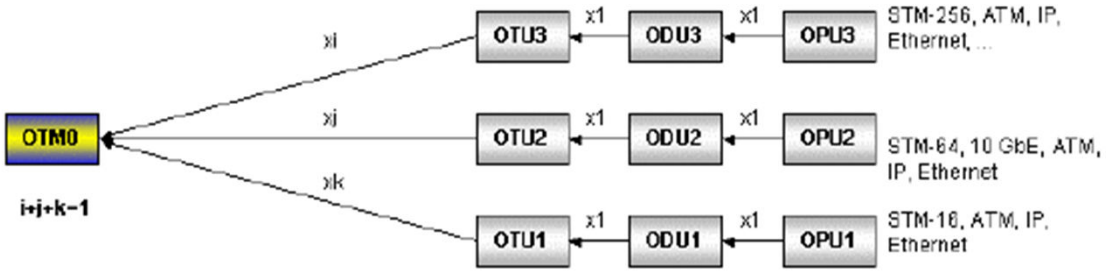


Multiplexing Structure

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)

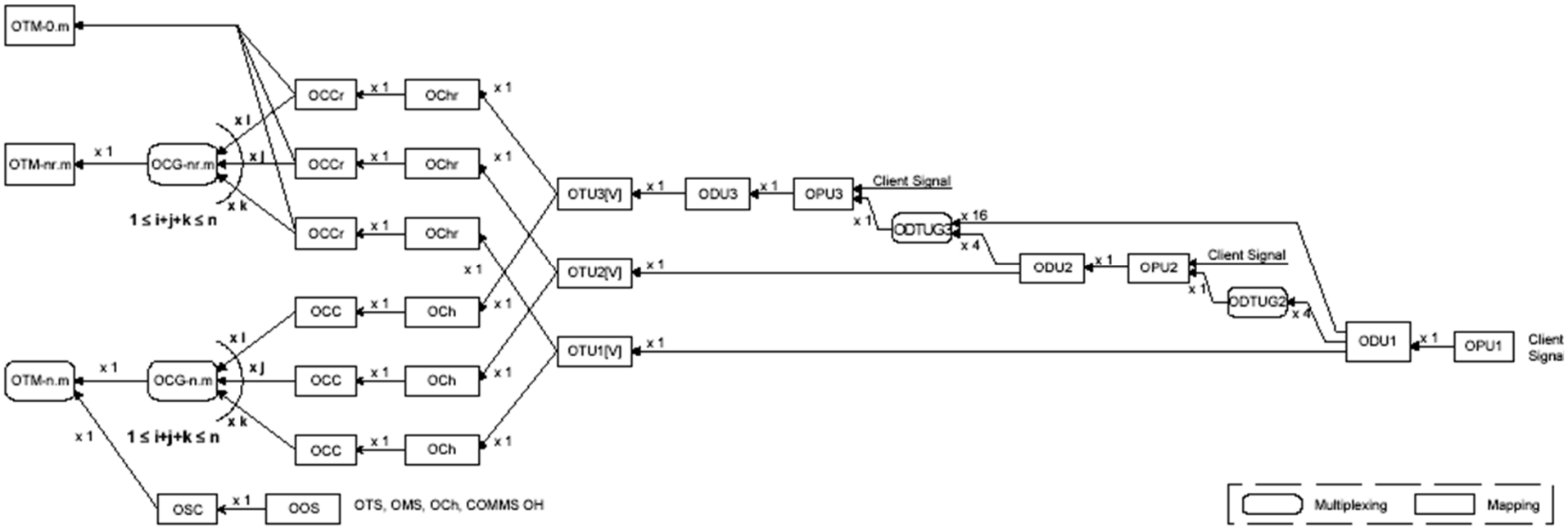
OTM-5.12:
5λ, 2.5 or 10 Gbit/s





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”

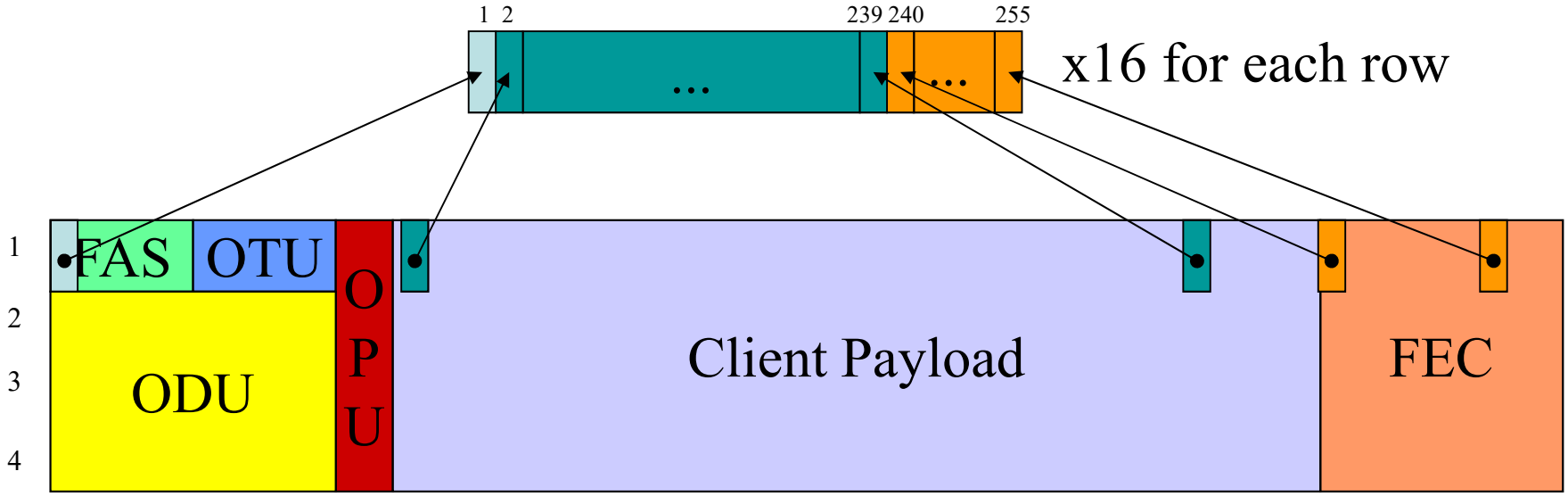
Framing hierarchy	OPU [Gbit/s]	ODU [Gbit/s]	OTU [Gbit/s]	Time [μs]
1	2.488320	239/238 * 2.488320	255/238 * 2.488320	48.971
2	238/237 * 9.953280	239/237 * 9.953280	255/237 * 9.953280	12.191
3	238/236 * 39.813120	239/236 * 39.813120	255/236 * 39.813120	3.035

Tolerance in all cases: ±20ppm

FEC

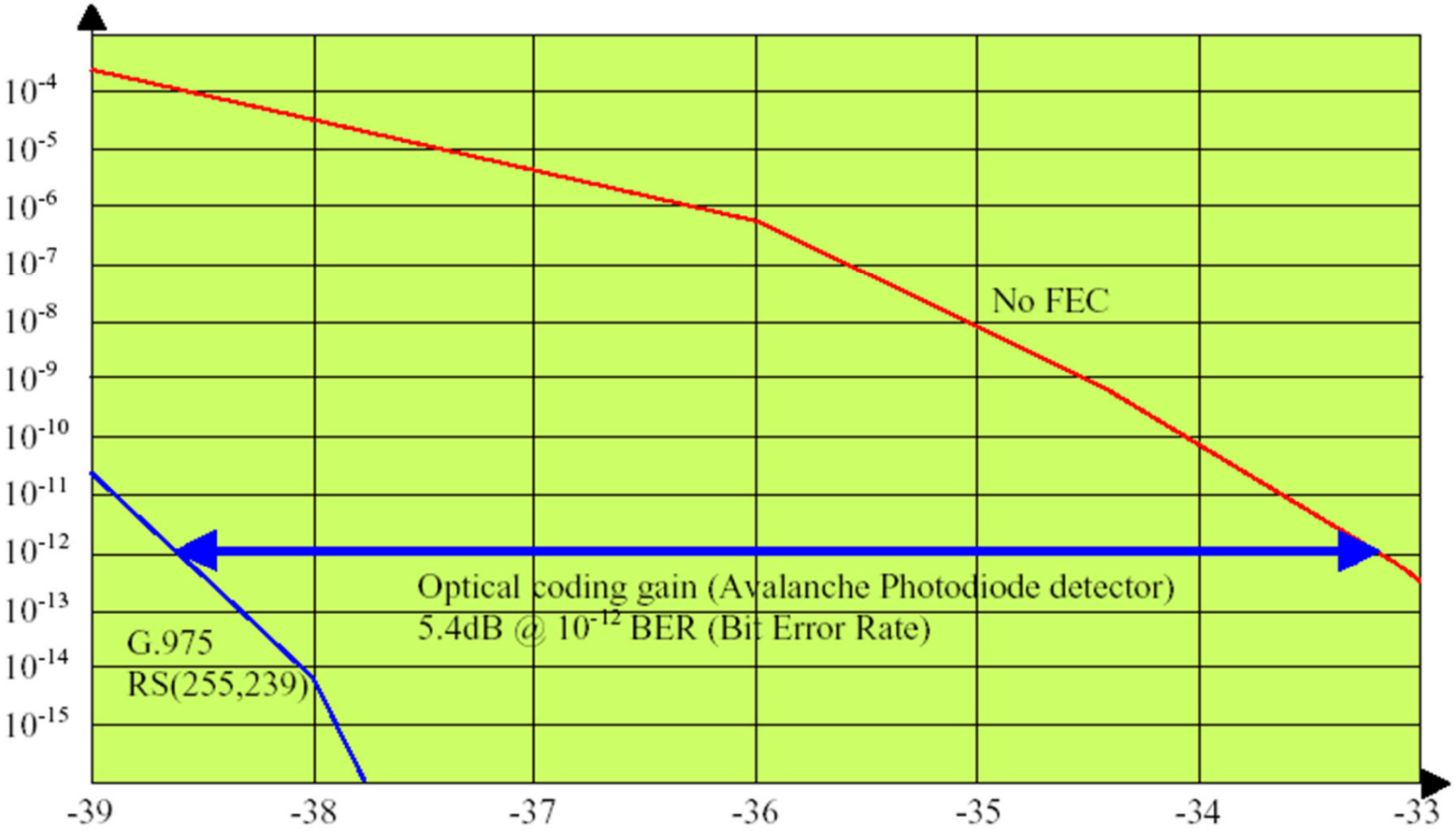
RS (255,239) Reed Solomon code
- Simple
- Significant bit-error correction capability
- Suitable for Block-failures (max 8 bytes)

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**

Why to use FEC? (DW, OTN, G.709)

Power level gain: 7% FEC → 5dB or:

- 20 km longer regenerator sessions
- 10^{-14} BER instead of 10^{-4} BER
- 2.5 Gbit/s-os link can be used at 10 Gbit/s
- Early detection of signal quality deterioration
- Better SNR
- Each 4th regenerator can be left out
- FEC can be switched off → all ‘0’

Conclusion

SDH not enough!

SDH +GFP+VirCat+LCAS → ngSDH

- (TDM+FEC) + (WDM+Mngmnt) → OTN

  OTN + GFP+VirCat+LCAS + Ctrl → ☺

Glossary (OTN)

- 3R Reamplification, Reshaping and Retiming
- AIS Alarm Indication Signal
- APS Automatic Protection Switching
- BIP Bit Interleaved Parity
- CBR Constant Bit Rate
- CRC Cyclic Redundancy Check
- FAS Frame Alignment Signal
- FEC Forward Error Correction
- GCC General Communication Channel
- IaDI Intra-Domain Interface
- IrDI Inter-Domain Interface
- LCAS Link Capacity Adjustment Scheme
- MFAS MultiFrame Alignment Signal
- MFI Multiframe Indicator
- MSI Multiplex Structure Identifier
- naOH non-associated overhead
- NNI Network Node Interface
- OCC Optical Channel Carrier
- OCCo Optical Channel Carrier – overhead
- OCCp Optical Channel Carrier – payload
- OCCr Optical Channel Carrier with reduced functionality
- OCG Optical Carrier Group
- OCGr Optical Carrier Group with reduced functionality
- OCh Optical channel with full functionality
- OChr Optical channel with reduced functionality
- ODU Optical Channel Data Unit
- ODUk Optical Channel Data Unit-k
- ODTUjk Optical channel Data Tributary Unit j into k
- ODTUG Optical channel Data Tributary Unit Group
- ODUk-Xv X virtually concatenated ODUk's
- OH Overhead
- OMS Optical Multiplex Section
- OMS-OH Optical Multiplex Section Overhead
- OMU Optical Multiplex Unit
- ONNI Optical Network Node Interface
- OOS OTM Overhead Signal
- OPS Optical Physical Section
- OPU Optical Channel Payload Unit
- OPUk Optical Channel Payload Unit-k
- OPUk-Xv X virtually concatenated OPUk's
- OSC Optical Supervisory Channel
- OTH Optical Transport Hierarchy
- OTM Optical Transport Module
- OTN Optical Transport Network
- OTS Optical Transmission Section
- OTS-OH Optical Transmission Section Overhead
- OTU Optical Channel Transport Unit
- OTUk completely standardized Optical Channel Transport Unit-k
- OTUkV functionally standardized Optical Channel Transport Unit-k
- PCC Protection Communication Channel
- PLD Payload
- PM Path Monitoring
- PMI Payload Missing Indication
- PMOH Path Monitoring OverHead
- ppm parts per million
- PT Payload Type
- RS Reed-Solomon
- SM Section Monitoring
- SMOH Section Monitoring OverHead
- TC Tandem Connection
- TCM Tandem Connection Monitoring
- TCMOH Tandem Connection Monitoring OverHead
- UNI User-to-Network Interface
- VCG Virtual Concatenation Group
- VCOH Virtual Concatenation Overhead
- vcPT virtual concatenated Payload Type

Optical networks

- Motivation
- 3 generations
- Multiplexing solutions
- Heterogeneous data plane
- Homogeneous control and management planes
- Evolution:

SDH→ATM→MPLS→ngSDH→OTN→ASON/MPλS→ASTN/GMPLS→OBS → OPS

Why are Optical Networks needed at all?

- Not optical transmission links but networks!
- Bandwidth
- Speed (Response time)
- Denser virtual topology (via WDM or fibers)
  - Decreasing the load of IP switches and DXCs ☺
  - More ports ☹
  - Decreasing the delay ☺
  - For IP and Voice

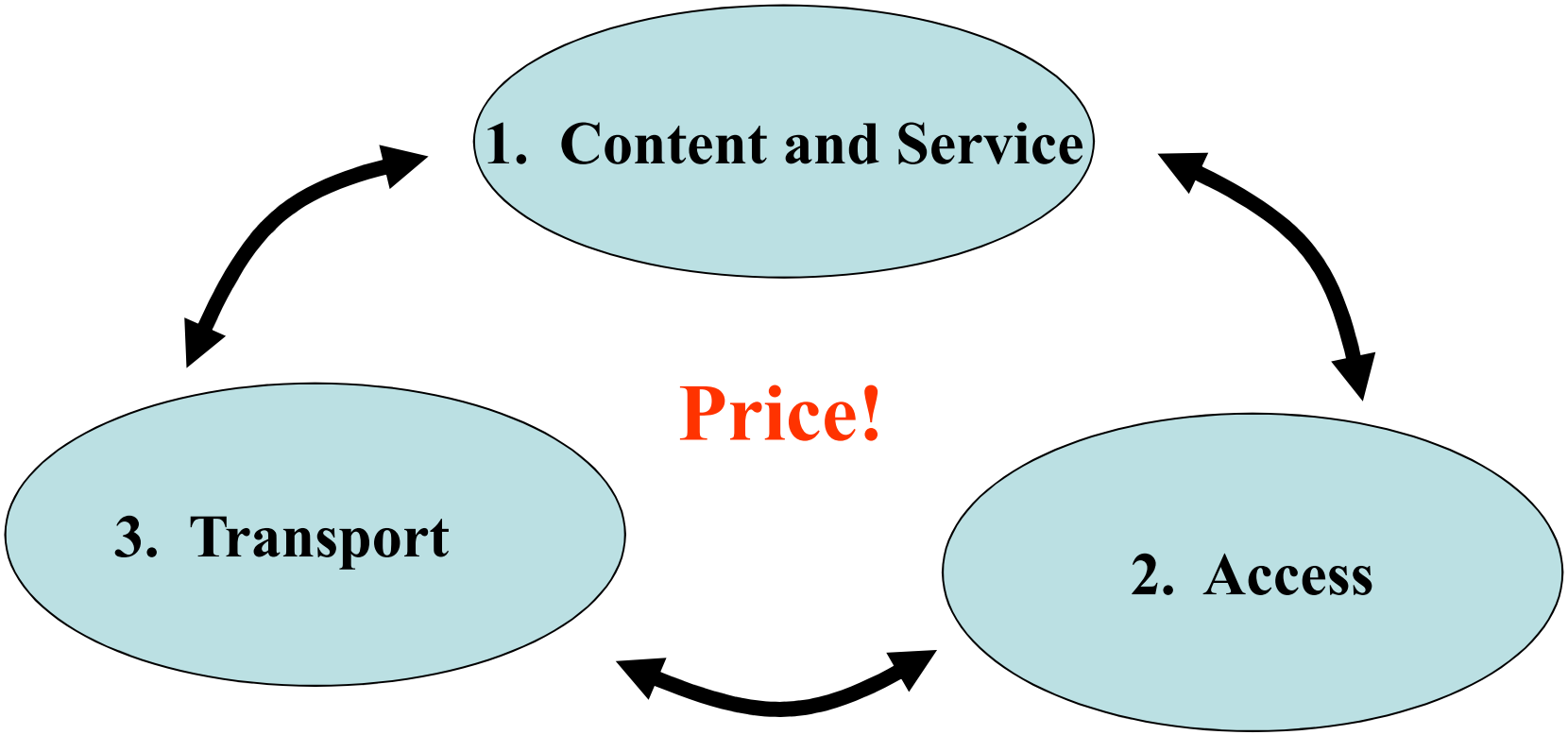
Motivation

- Advantages of the Optical Transmission:
  - Huge Bandwidth
  - Minor attenuation
  - Distorsions can be compensated
  - Resistent to EM, crosstalk, tempereture,...
  - Cheap (Cu $\rightarrow SiO_2$)
  - Metal free, does not conduct
  - Light
  - Thin

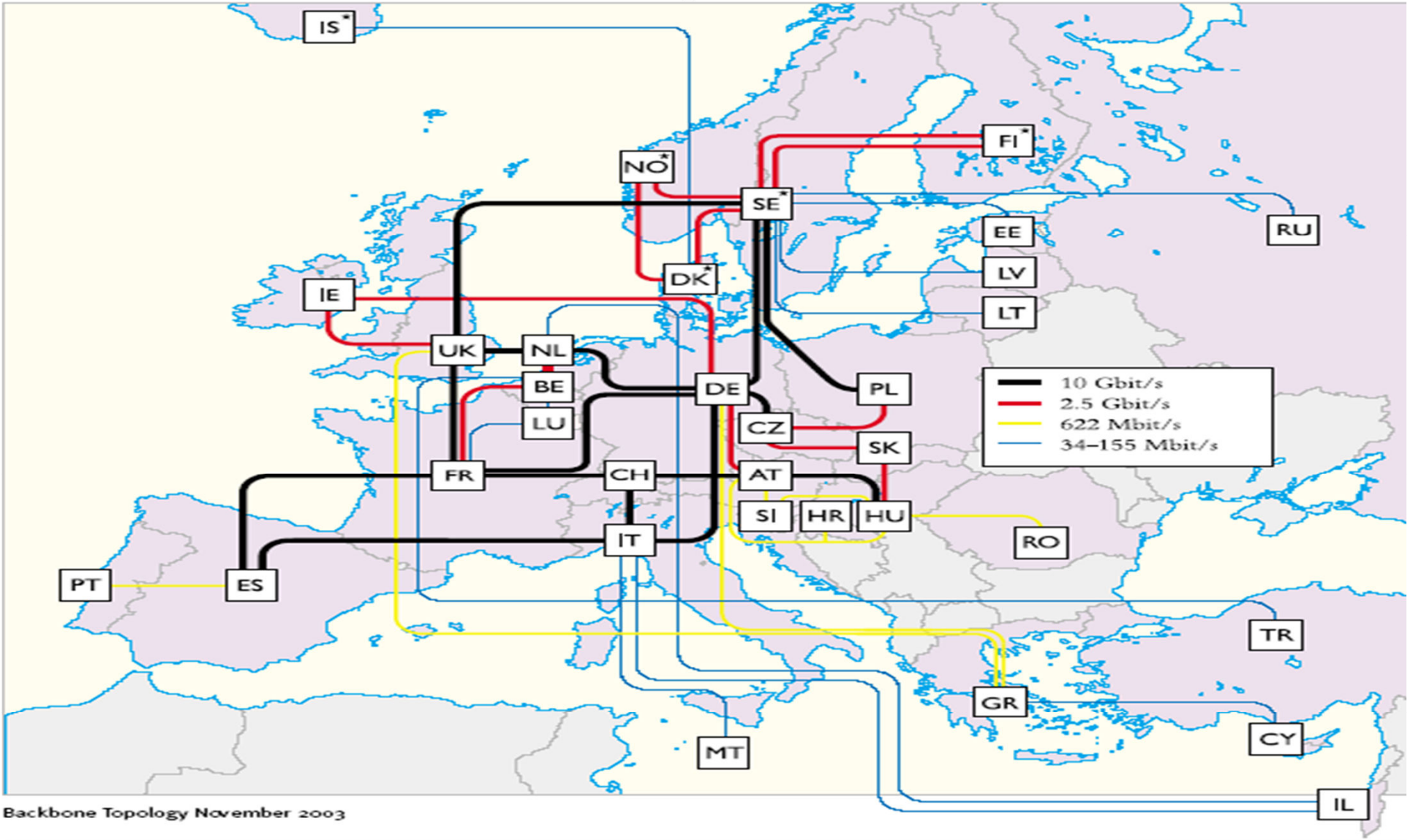
Bandwidth-hungry Applications

- **Peer-to-Peer**
- **GRIDs**
- **SAN, oSAN**
- **Audio and Video Broadcast, IPTV**
- **VoD (video) 4k, 3D,…**
- **VoIP (voice)**
- **Telemedicine**
- **Distant Learning**
- **Video Conferencing**
- **IP-Radio, IP-TV**
- **VoD, YouTube**
- **Peer-Casting (Peer-to-Peer Multi-Casting)**
- **Distributed Video Coding (DVC) (transcoding)**

“Circus viciosus”



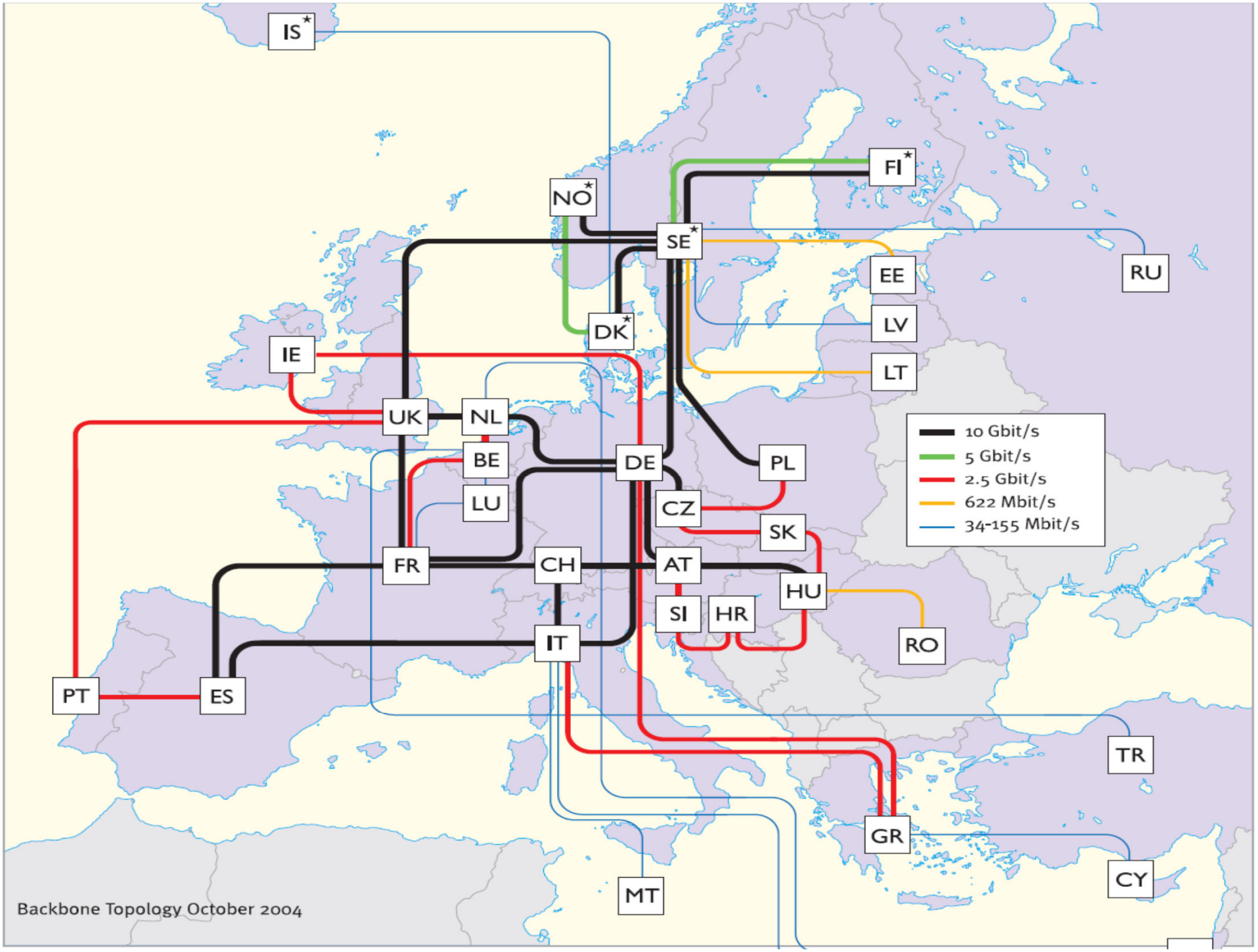
Geant Europan network



Backbone Topology November 2003

AT Austria	CZ Czech Republic	ES Spain	HR Croatia	IS Iceland*	LV Latvia	PL Poland	SE Sweden*
BE Belgium	DE Germany	FI Finland*	HU Hungary	IT Italy	MT Malta	PT Portugal	SI Slovenia
CH Switzerland	DK Denmark*	FR France	IE Ireland	LT Lithuania	NL Netherlands	RO Romania	SK Slovakia
CY Cyprus	EE Estonia	GR Greece	IL Israel	LU Luxembourg	NO Norway*	RU Russia	TR Turkey
							UK United Kingdom

*Connections between these countries are part of NORDUnet (the Nordic regional network)


IS
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SI
HR
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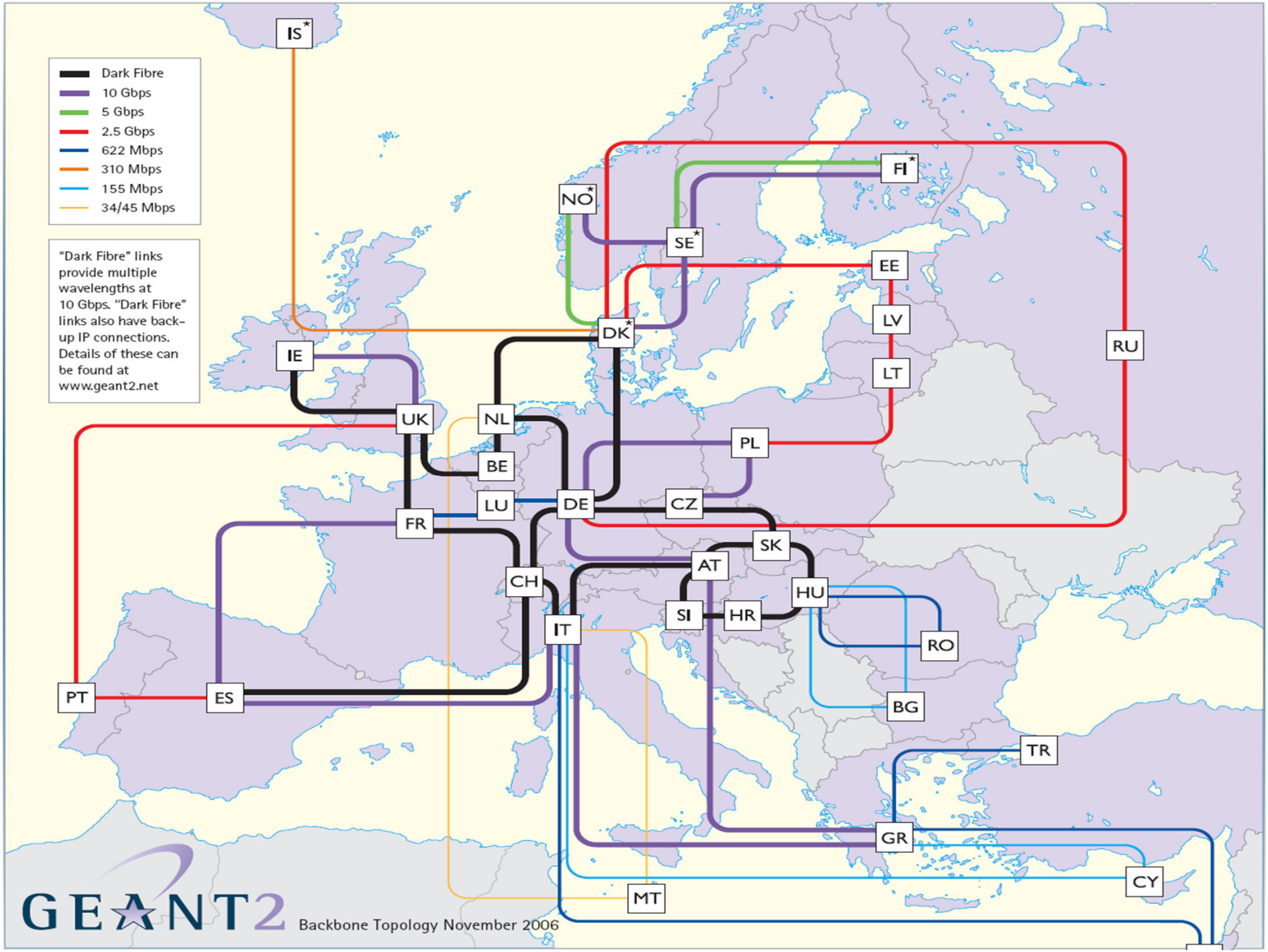
IT
PT
ES
TR
GR
CY
MT
10 Gbit/s
5 Gbit/s
2.5 Gbit/s
622 Mbit/s
34-155 Mbit/s
Backbone Topology October 2004


Dark Fibre
10 Gbps
5 Gbps
2.5 Gbps
622 Mbps
310 Mbps
155 Mbps
34/45 Mbps
"Dark Fibre" links provide multiple wavelengths at 10 Gbps. "Dark Fibre" links also have back-up IP connections. Details of these can be found at www.geant2.net
IS*
NO*
SE*
FI*
EE
LV
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RU
DK*
IE
UK
NL
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CH
HU
SI
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IT
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BG
PT
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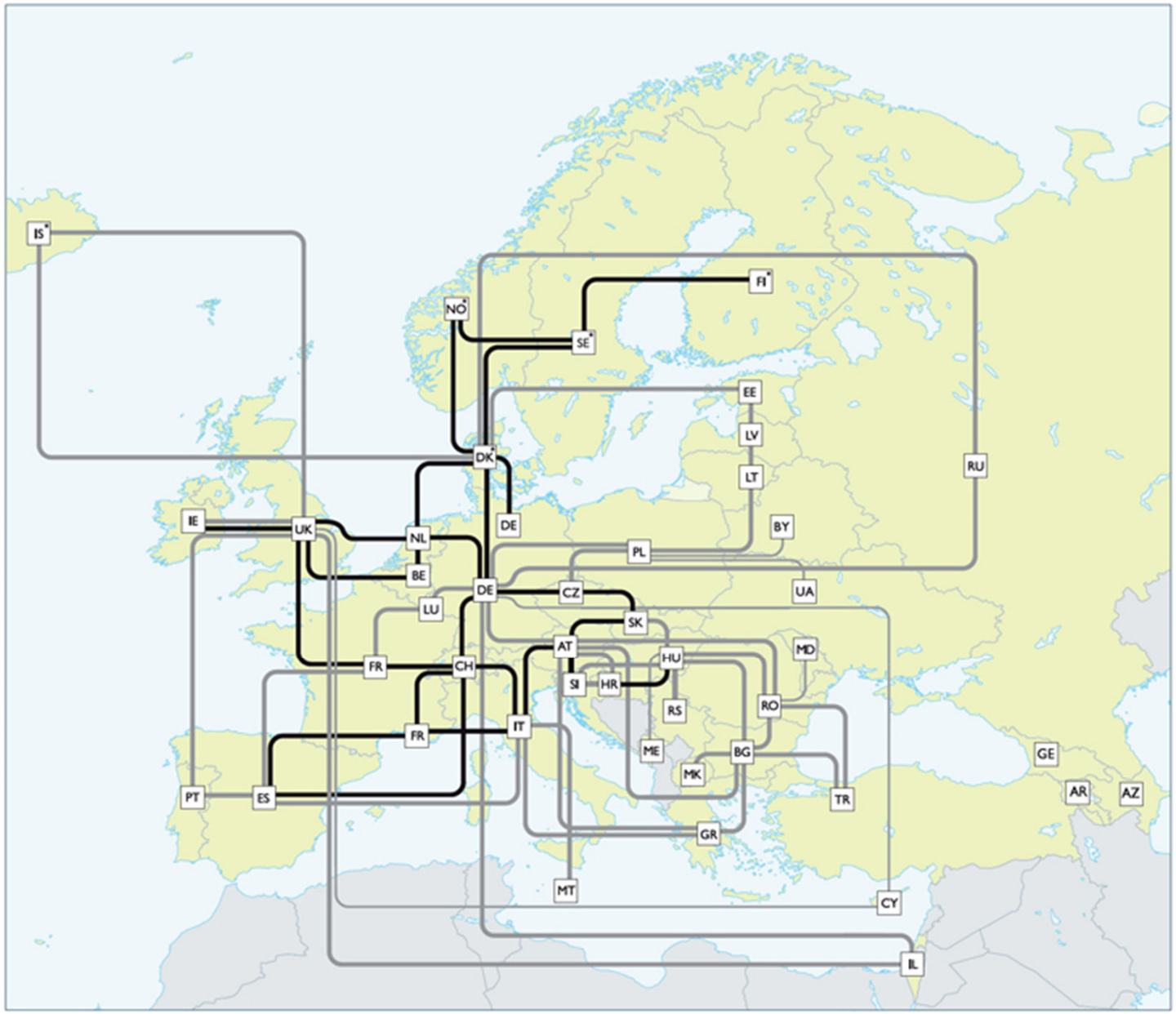
CY
MT
GEANT2
Backbone Topology November 2006

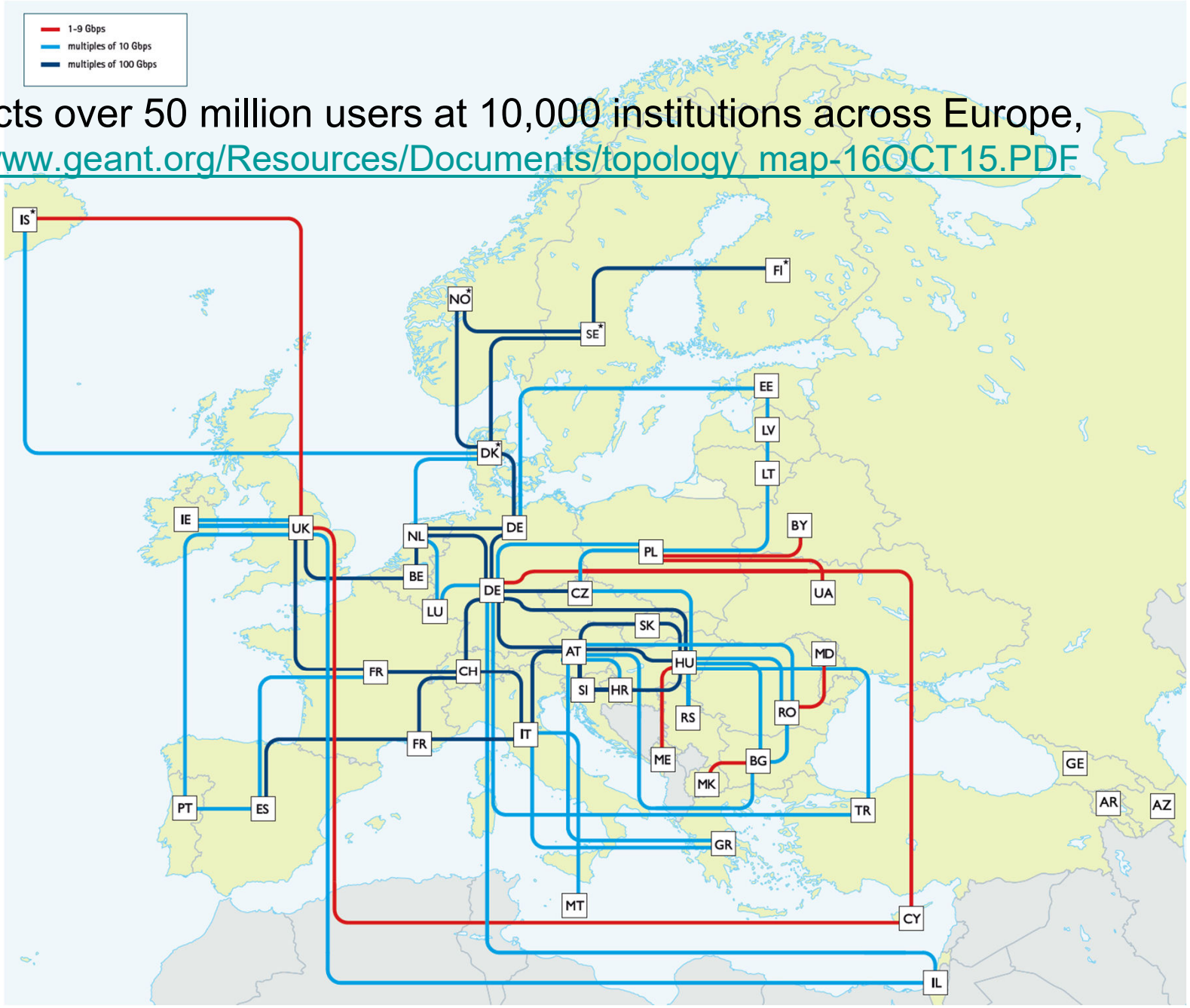
The Pan-European Research and Education Network

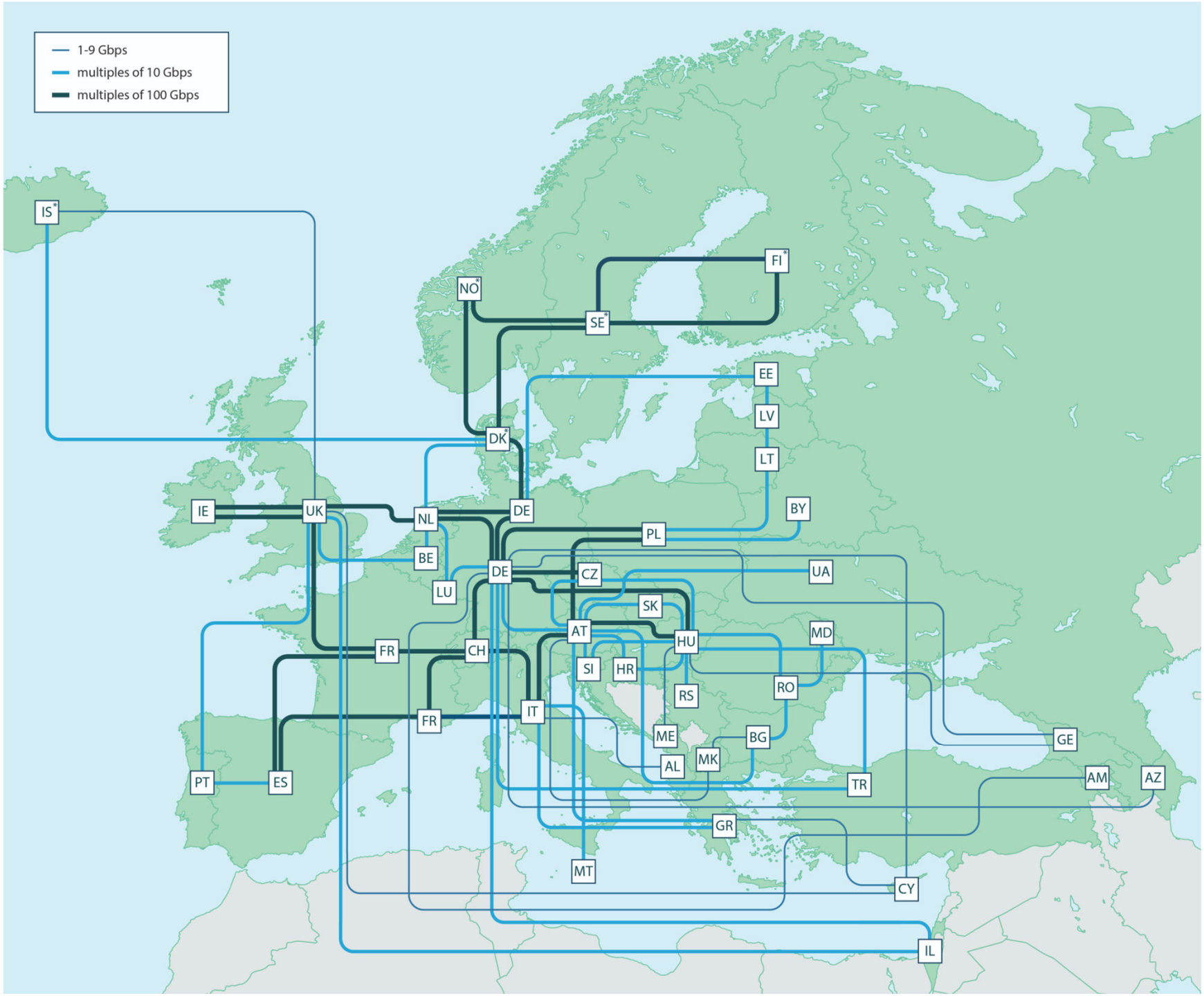
GÉANT interconnects Europe's National Research and Education Networks (NRENs). Together we connect over 50 million users at 10,000 institutions across Europe.



GÉANT connectivity as at September 2013. GÉANT is operated by DANTE on behalf of Europe's NRENs. Black lines indicate dark fibre.

connects over 50 million users at 10,000 institutions across Europe,
http://www.geant.org/Resources/Documents/topology_map-16OCT15.PDF




1-9 Gbps
multiples of 10 Gbps
multiples of 100 Gbps
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SE*
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EE
LV
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MD
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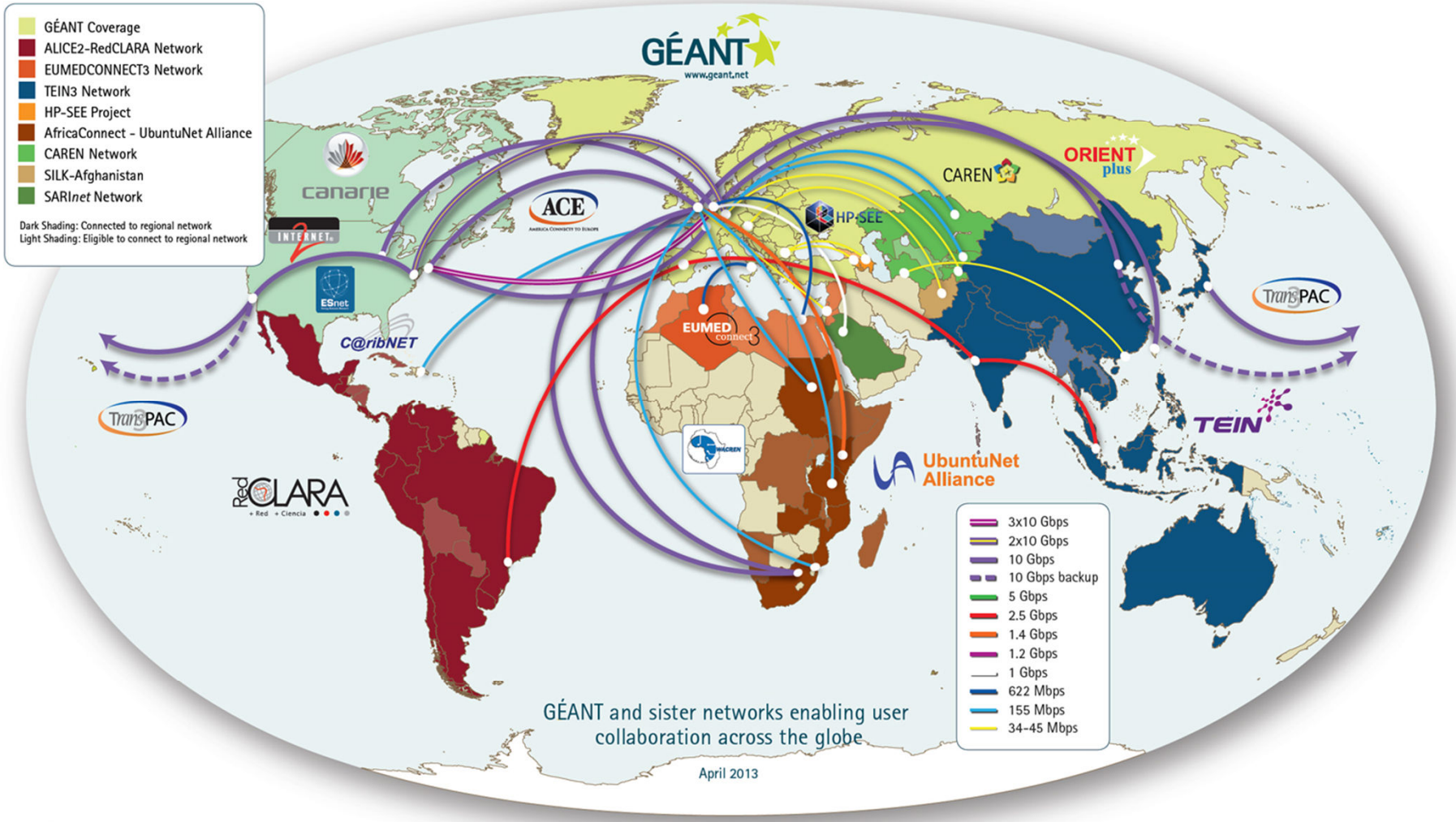
cin

GÉANT At the Heart of Global Research Networking



DANTE www.dante.net GÉANT www.geant.net

connect • communicate • collaborate

GÉANT is co-funded by the European Union within its 7th R&D Framework Programme.

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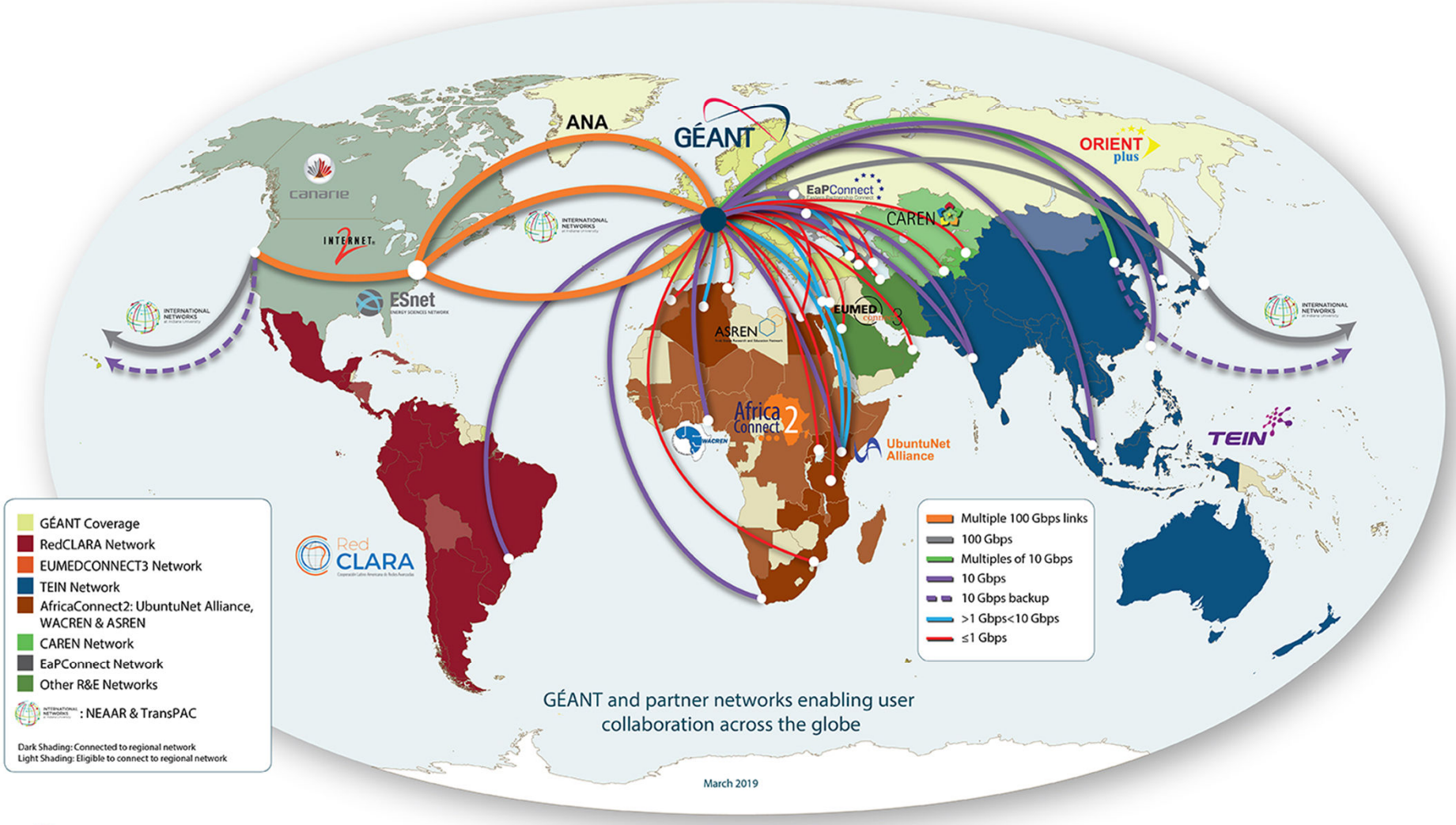
SEVENTH FRAMEWORK PROGRAMME

Co-funded by the European Union

At the Heart of Global Research and Education Networking



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Networks • Services • People
www.geant.org

This document is produced as part of the GÉANT Specific Grant Agreement GN4-3 (No. 856726), that has received funding from the European Union's 2020 research and innovation programme under the GÉANT2020 Framework Partnership Agreement (No.653998).
In addition to GN4-3, the following projects have received funding from the European Union: AfricaConnect2, CAREN3, Asi@Connect (DG DEVCO); EaPConnect and EUMEDCONNECT3 (DG NEAR).
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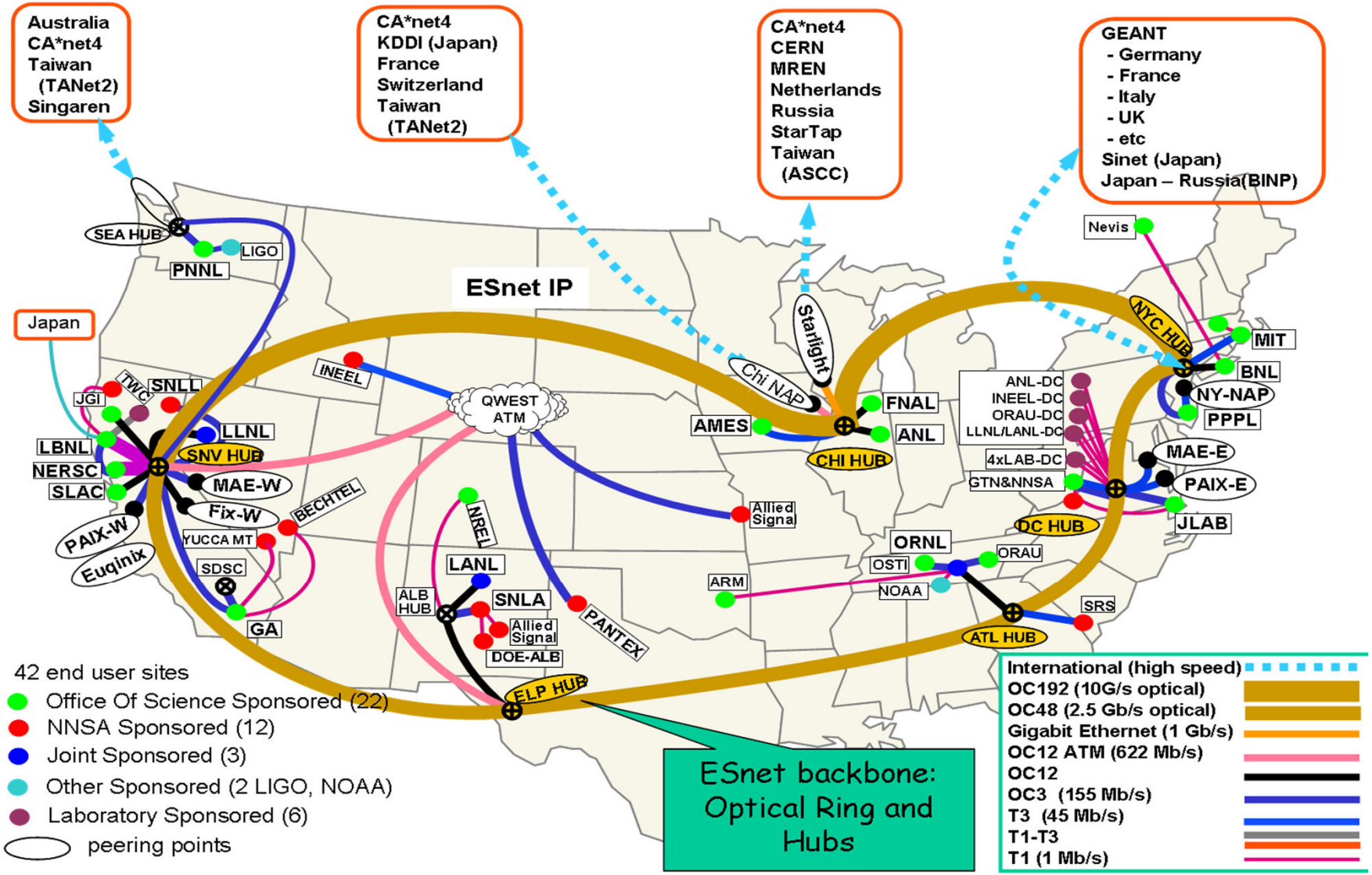
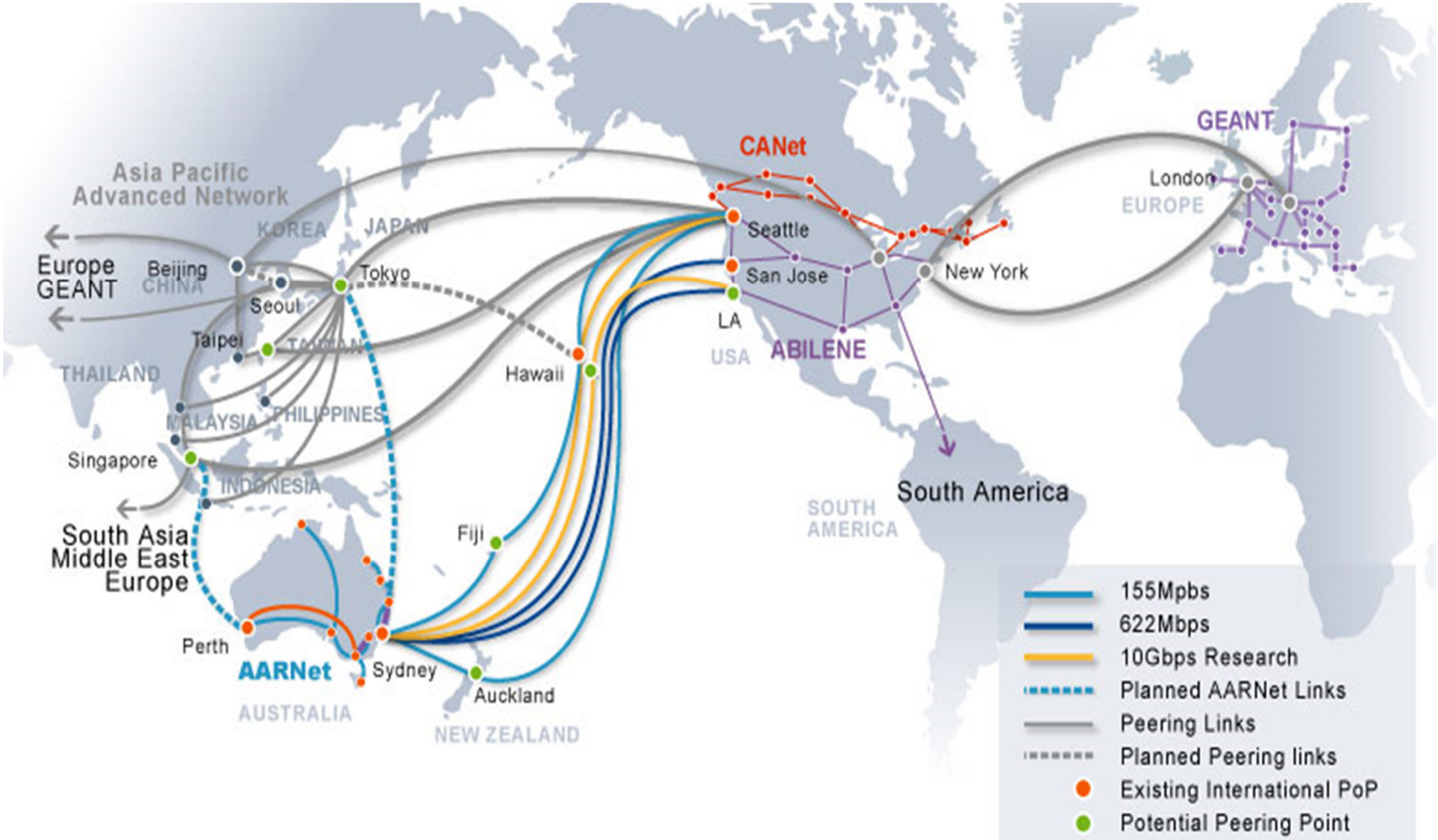
Funded by the European Union

ESnet (2003)



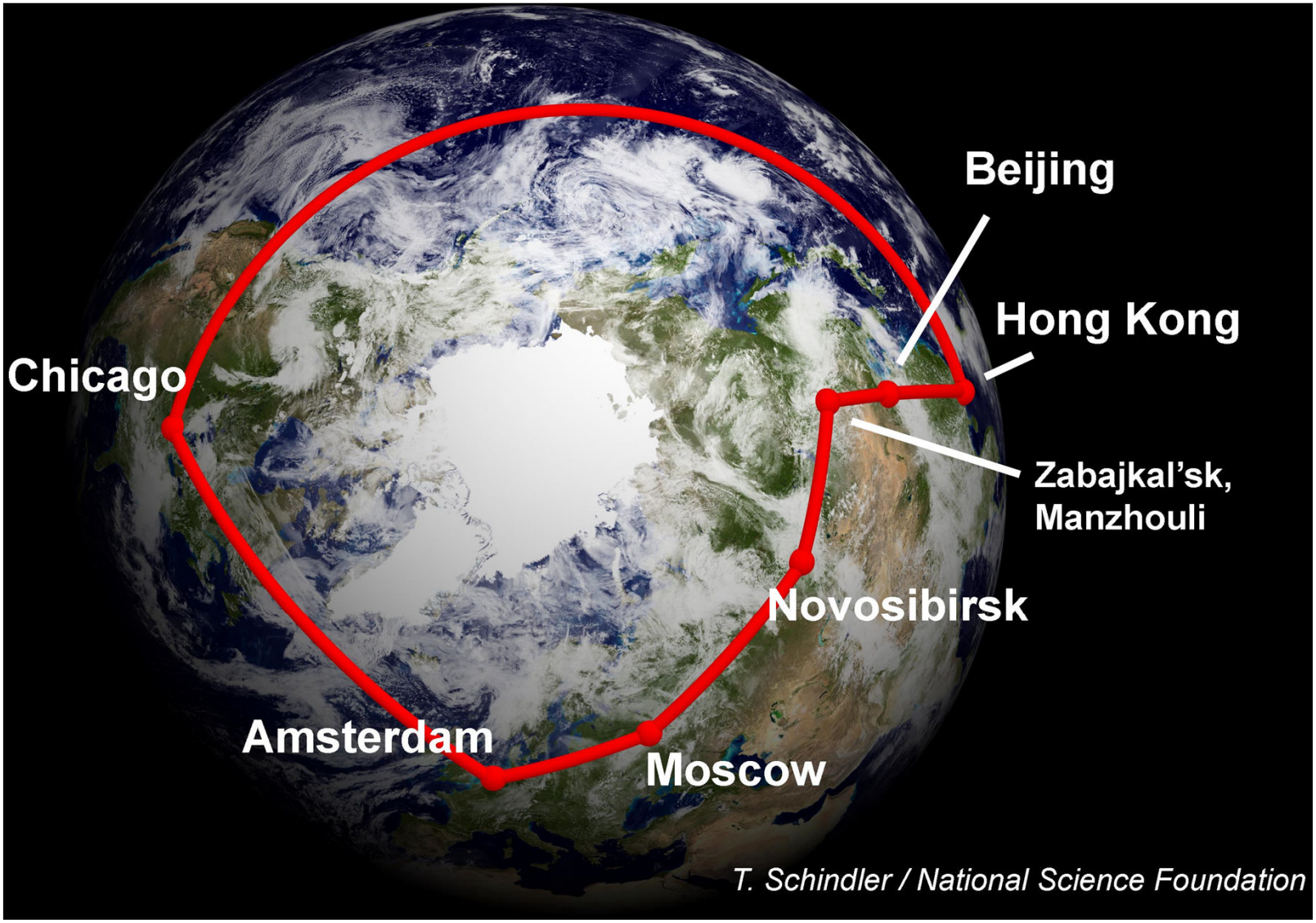
Source: H.B.Newman, GNEW2004

AArnet (Australia 2004) + SXTransPORT (Trans Pacific Optical Research Testbed)



GLORIAD: Global Optical Ring

(USA-Europe-Russia-China, 10 Gb/s)

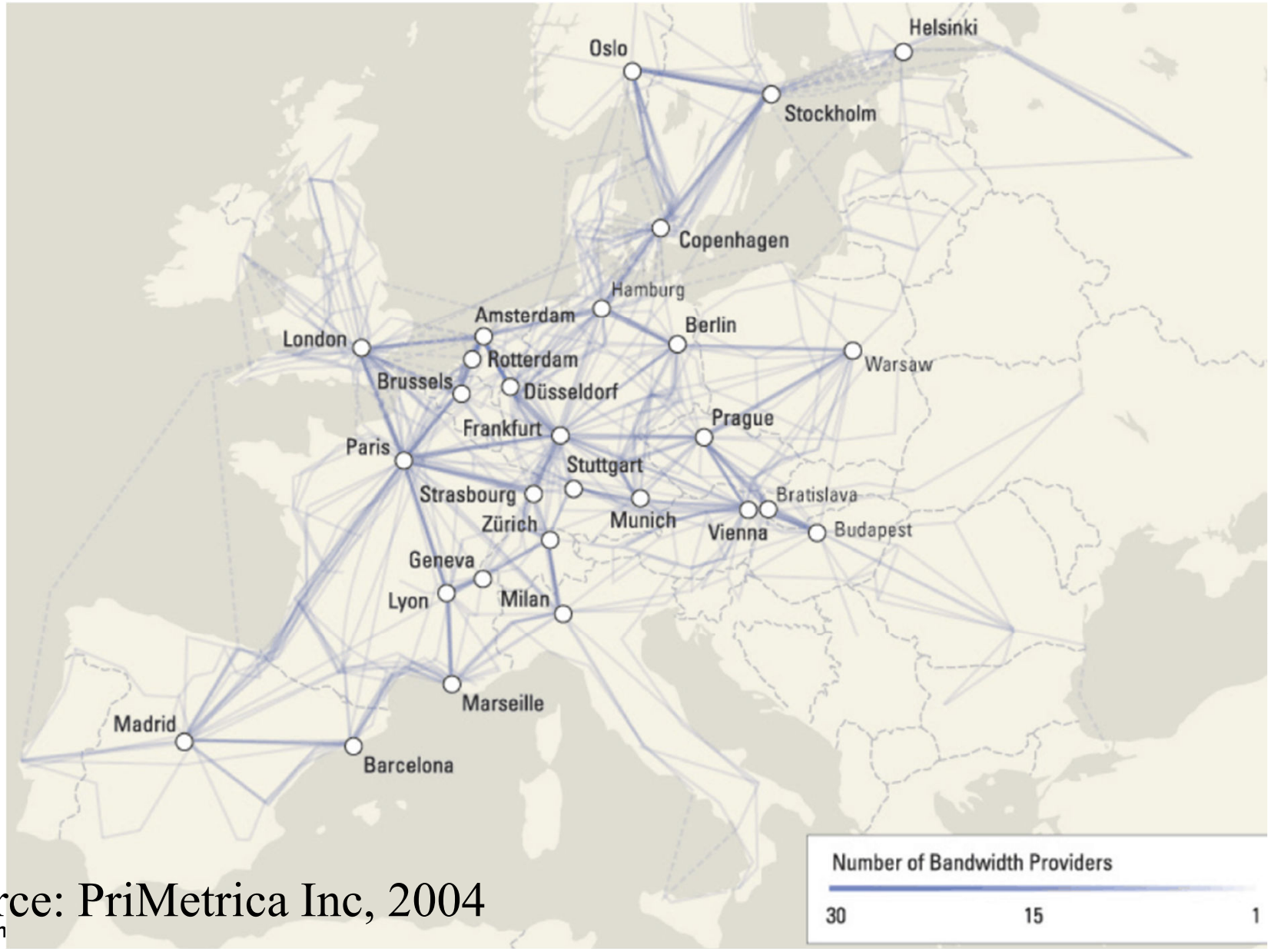


Optical cable systems of Americas

- Americas 1
- Americas II
- South American Crossing
- Columbus II
- Columbus III
- Emergia (Telefonica)
- ARCOS
- Maya-1
- 360 Americas

Source:
H.B.Newman, GNEW2004

Pan-European Networks



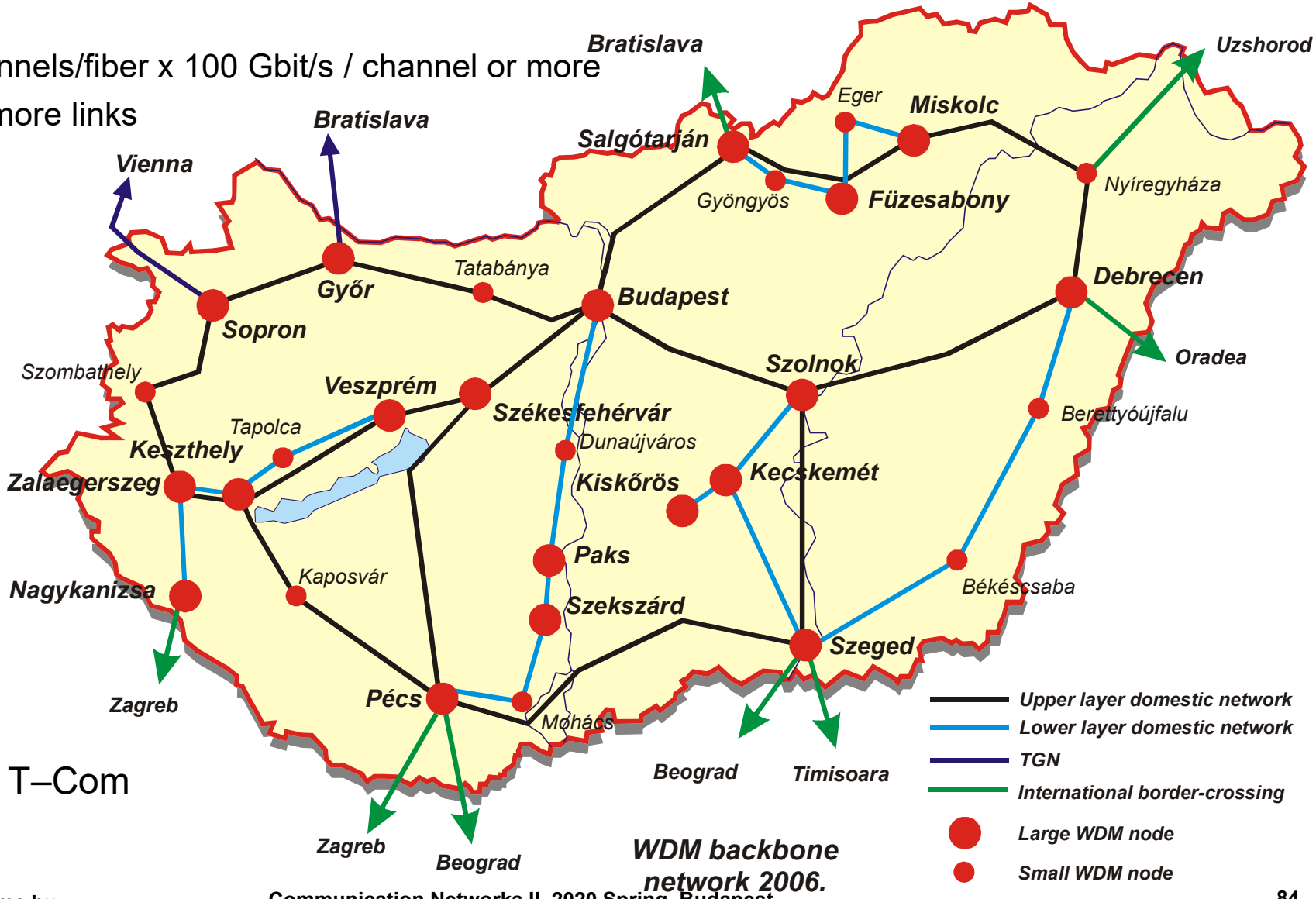
Source: PriMetrica Inc, 2004

Magyar WDM gerinc

- Since 2001
- 24 /32 + 10 Gbit/s
- 100 GHz channel spaceing

Today:

- 96 channels/fiber x 100 Gbit/s / channel or more
- Many more links



Source: T–Com

submarine-cable-map-201x

https://submarine-cable-map-2019.telegeography.com/

http://submarine-cable-map-2015.telegeography.com/
http://submarine-cable-map-2014.telegeography.com/
http://submarine-cable-map-2013.telegeography.com/

Interesting Videos

Optical cable production video:

https://www.youtube.com/watch?v=uSnjo5tOGQA

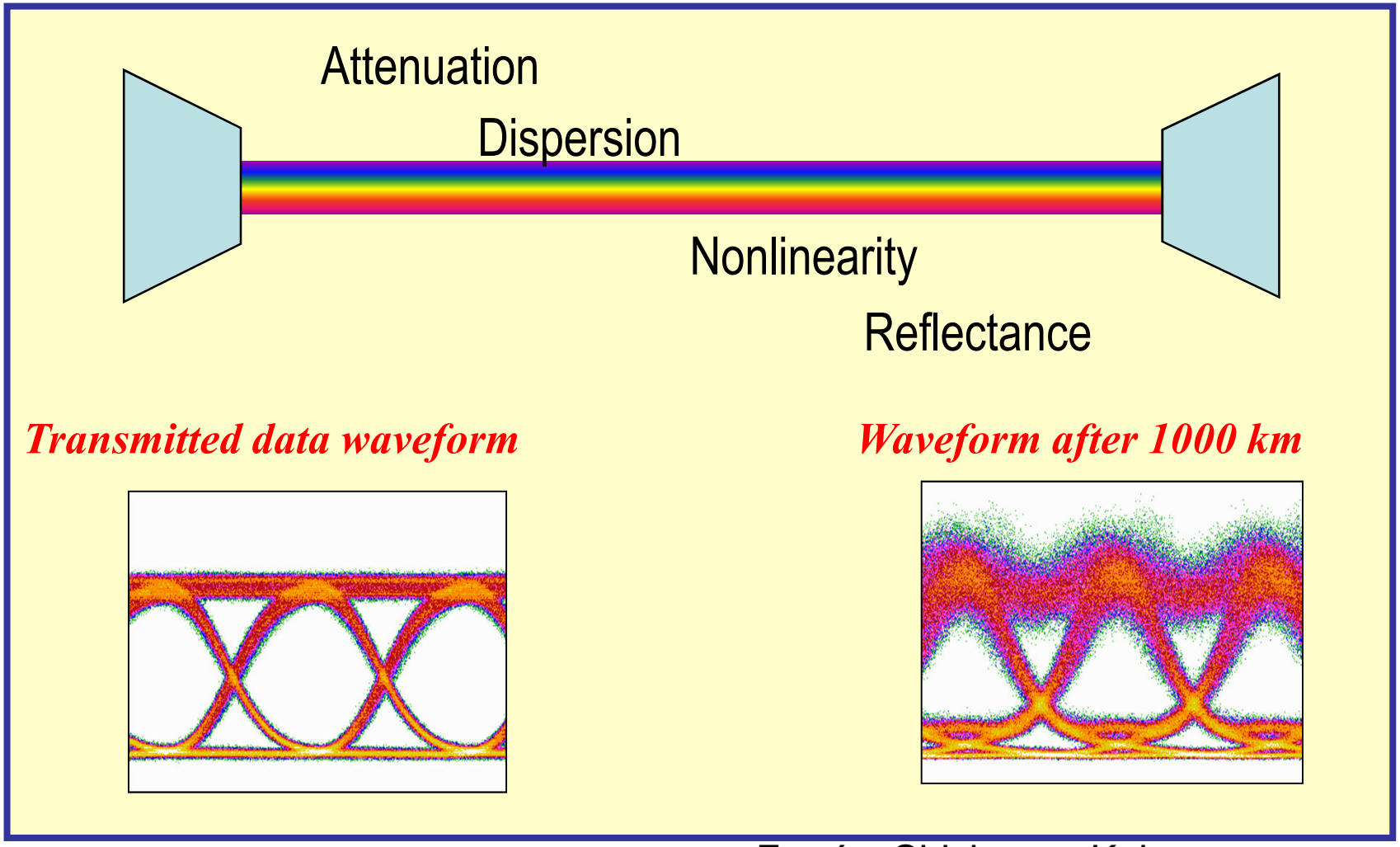
Laying undersea cables

https://www.youtube.com/watch?v=v1JEuzBkOD8
https://www.youtube.com/watch?v=XQVzU_YQ3IQ
https://www.youtube.com/watch?v=GUN9J9_HtbQ
https://www.youtube.com/watch?v=JLVFKHJcBMM old

Shark attacks a cable

https://www.youtube.com/watch?v=XMxkRh7sx84

Optical Transmission Impairments

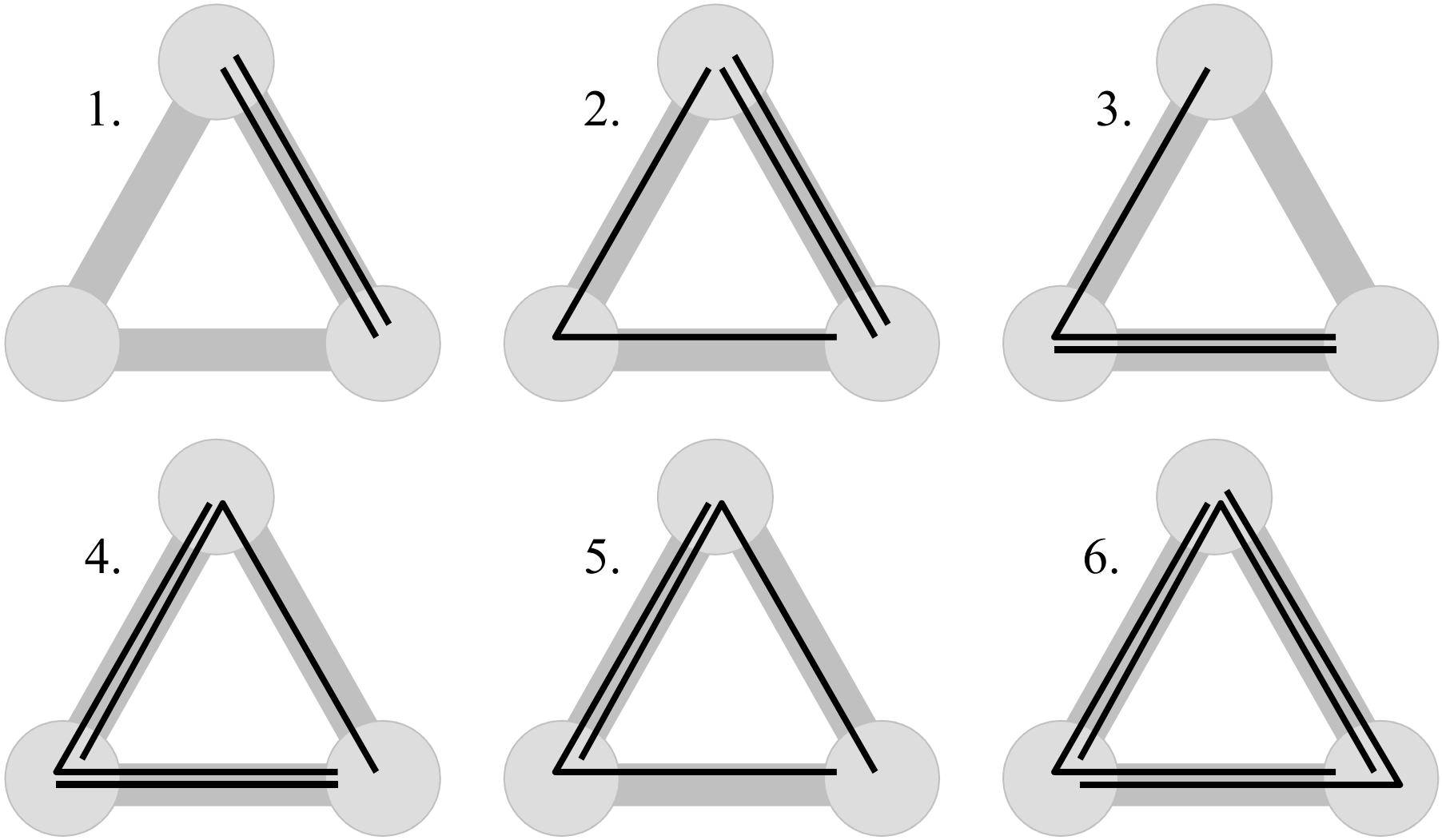


Forrás: Shivkumar Kalyanaraman

II. Dynamic

- ATM, MPLS (First Generation)
  - PVC→ SVC, Dynamic LSPs
- MPλS, ASON (Second Generation)
- Static or Dynamic?
  - **Static** (configuration, cross-connection) → MP
    - For steady or very high load
    - Slow provisioning, no delay to send
  - **Dynamic** (on-line routing, switching) → CP
    - For lower but heavily changing traffic conditions

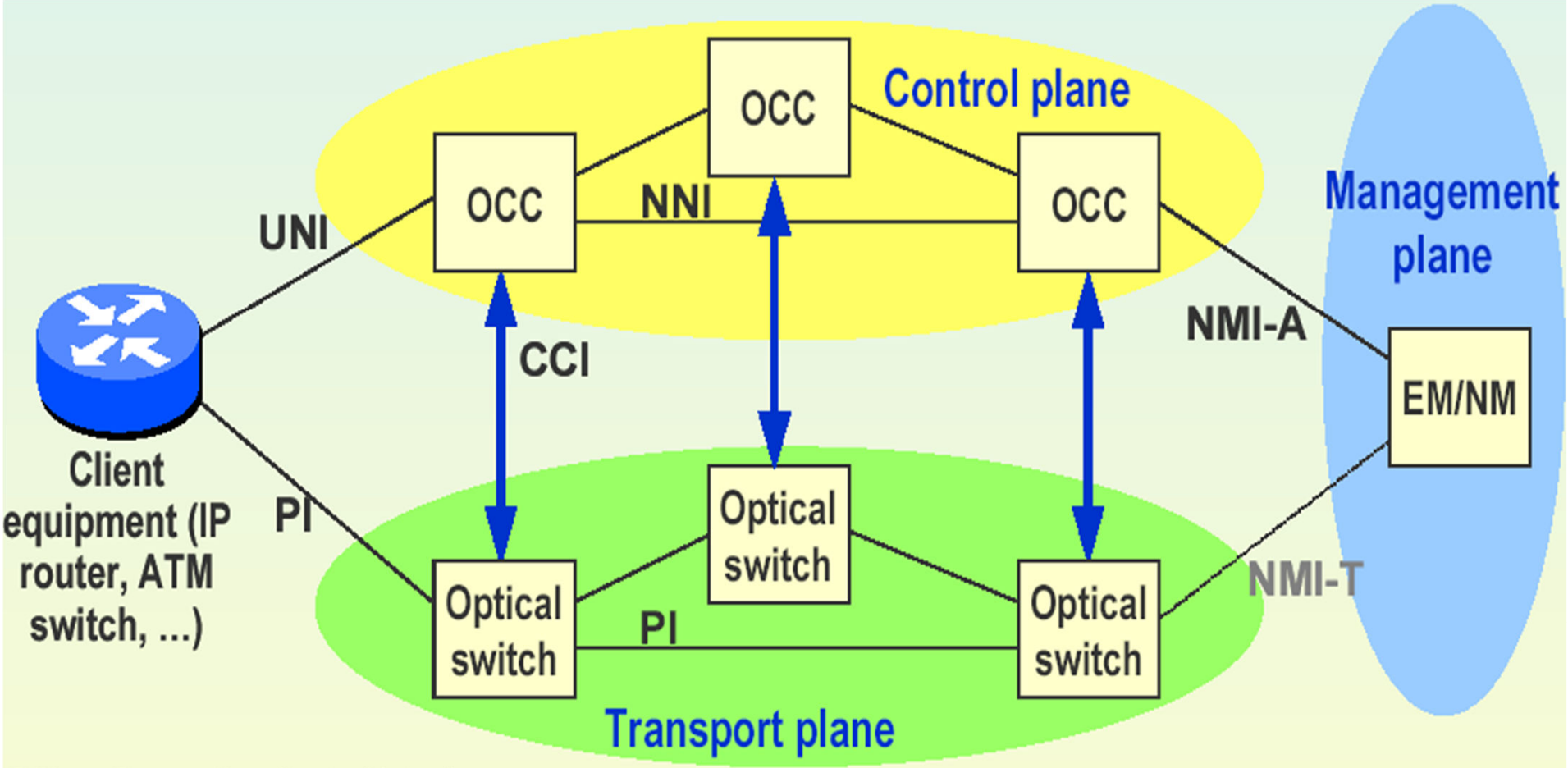
A Negative Example for Dynamic Networks



Dynamic Connection Establishment

- Distributed preferred to centralised
  - More scalable
  - Required Functions (**Control Plane**):
    - Neighbour Discovery
    - Link State Advertisement
    - Path Computation
    - Resource Allocation, De-allocation
    - Resilience
- IETF MPλS (MPLambdaS)
- ITU-T ASON (Automatically Switched Optical Network)
- w/wo Wavelength Conversion

ITU-T ASON



CCI: Connection Control Interface
NMI-A: Network Management Interface for the ASON Control Plane
NMI-T: Network Management Interface for the Transport Network
NNI: Network to Network Interface
OCC: Optical Connection Controller
PI: Physical Interface
UNI: User to Network Interface

ITU-T ASON

ASON architecture:

- Architecture for Automatically Switched Optical Networks: ***G.8080, (G.ason)***

Signalling:

- Distributed Call and Connection Control: ***G.7713, (G.dccm)***

Routing:

- Architecture and Requirements for Routing in the Automatic Switched Optical Networks ***(G.7715, G.rtg)***

Discovery

- Generalized Automated Discovery Techniques ***G.7714, (G.disc)***

Functions of CP & MP

- Policy Management
- Accounting
- End-to-End Path Management
- Alarm Correlation and Supervision
- Performance Management

MP (NMS)

- Routing
- Traffic Engineering
- Preparing Restoration

Combined CP & MP

- Resource Discovery
- Restoration
- Multi-Vendor Path Set-Up

CP real time actions e.g., GMPLS

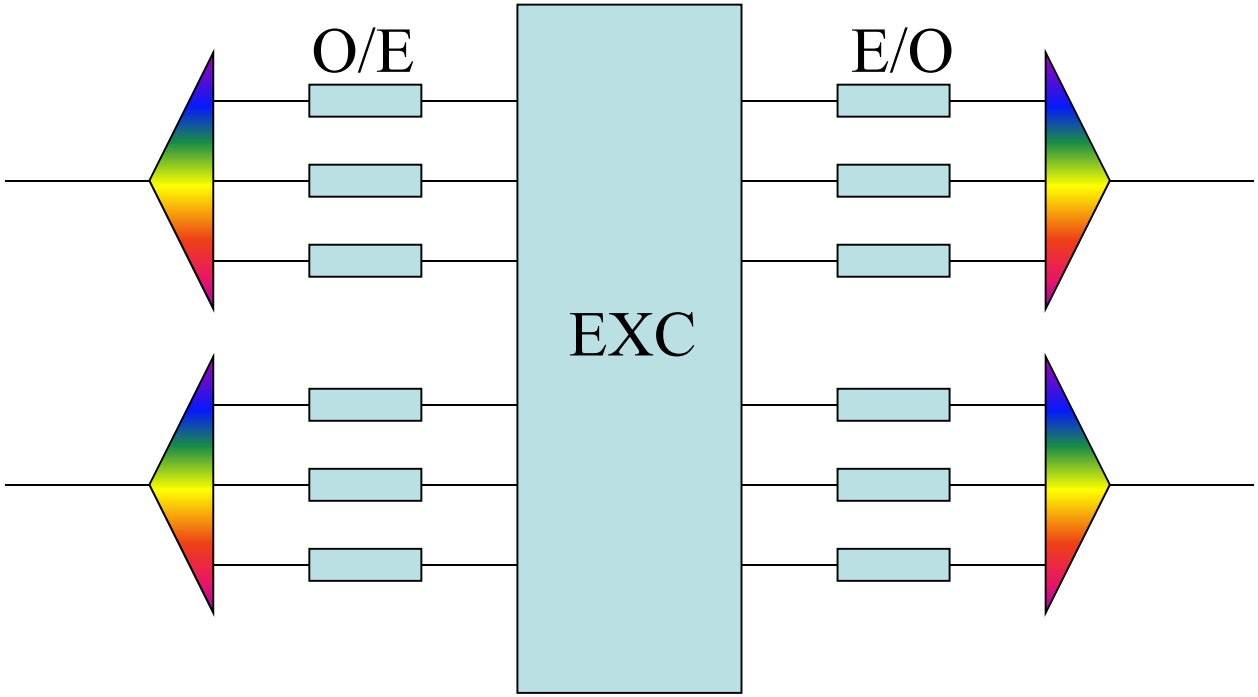
Switching vs. Cross-Connecting

- Management Plane (MP)
  - Typically centralised
  - Slower, but optimal
- Control Plane (CP)
  - User signalling initiated connections
  - Typically distributed, source routing
  - Faster, more complex, worse performance

Connections:

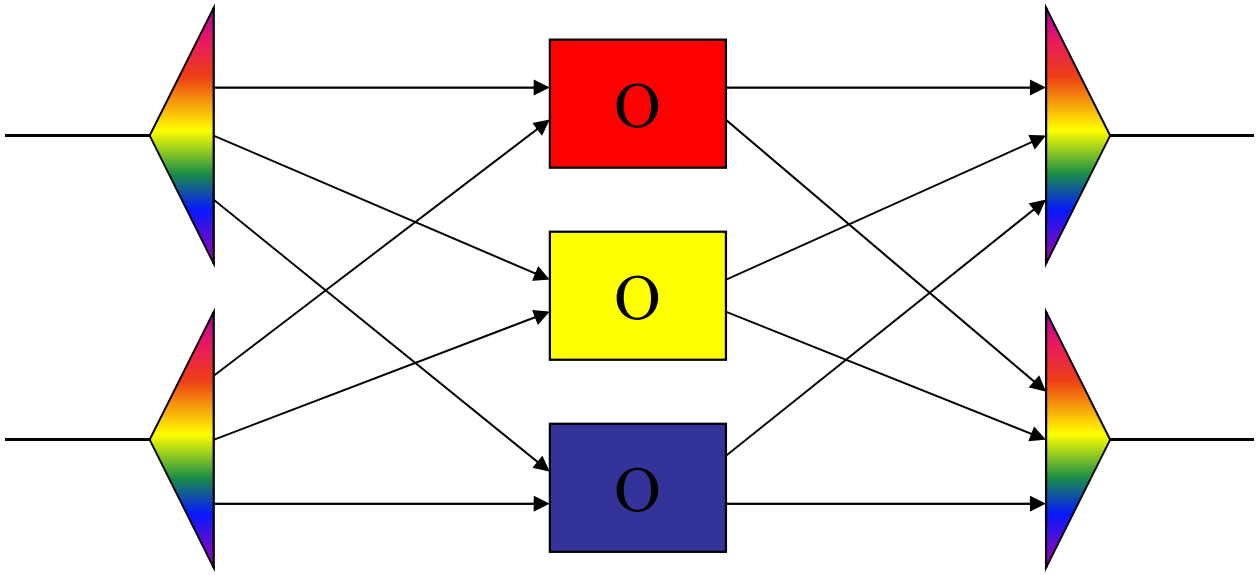
- Permanent
- Soft – Permanent
- Switched

Electro - Optical Cross Connect (EOXC)



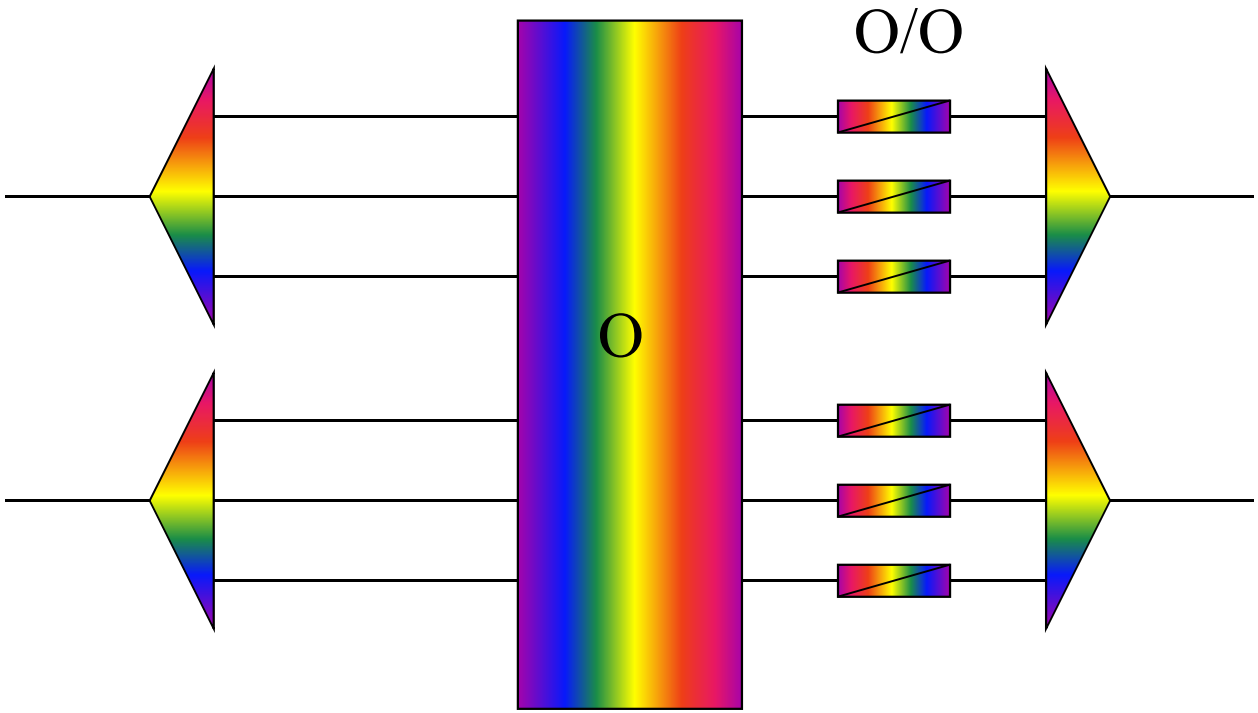
- Full Wavelength Conversion Capability (Property)
- Expensive Transponders
- Cheap, fast electronic core (space switching: EXC)
- Not transparent

Optical Cross Connect (OXC)
No λ conversion capability



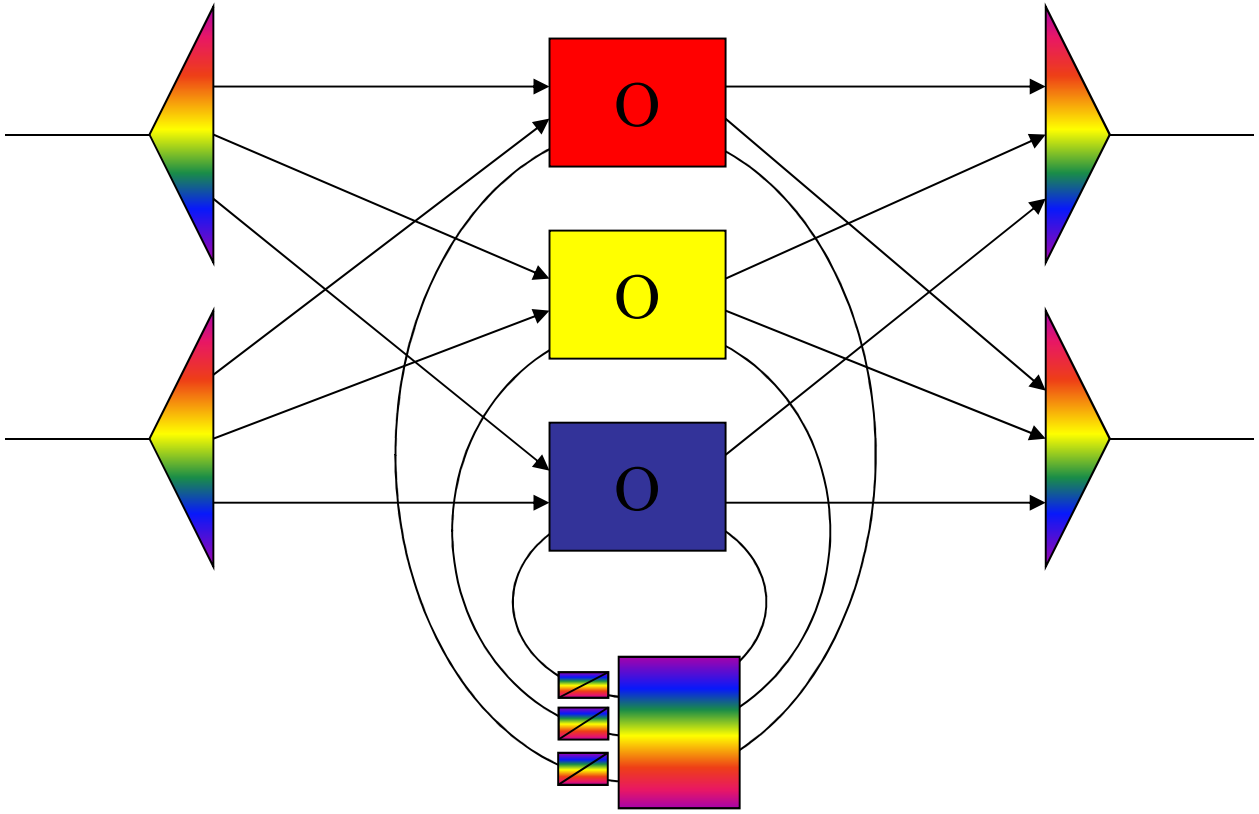
- All-Optical (optical core: 3 x 2x2 = 12)
- No λ conversion capability
- Transparent, but complex routing!

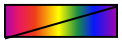
Optical Cross Connect (OXC)
Full λ conversion capability



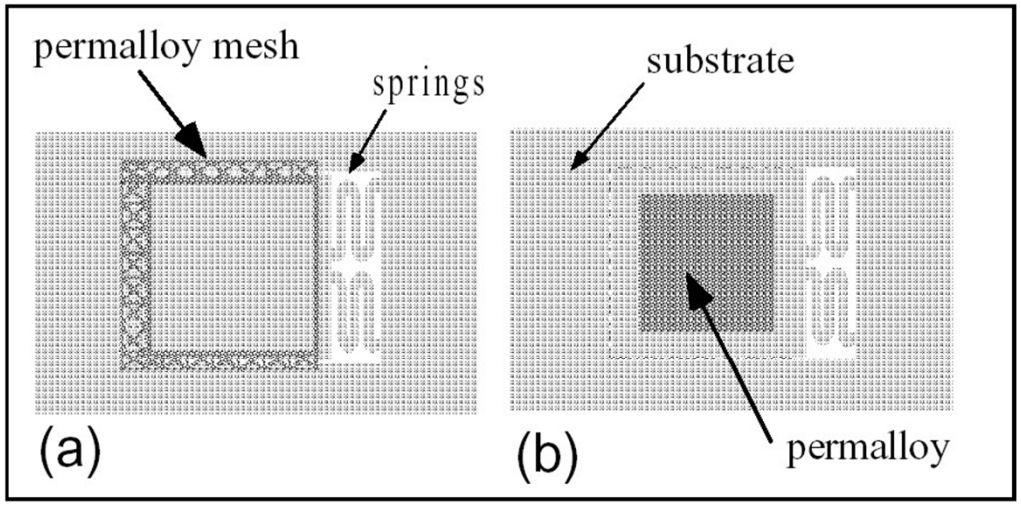
- All-Optical (optical core: 6 x 6 = 36 > 3 x 2x2 = 12)
- Full λ conversion capability
- Expensive optical λ converters
- “Opaque”

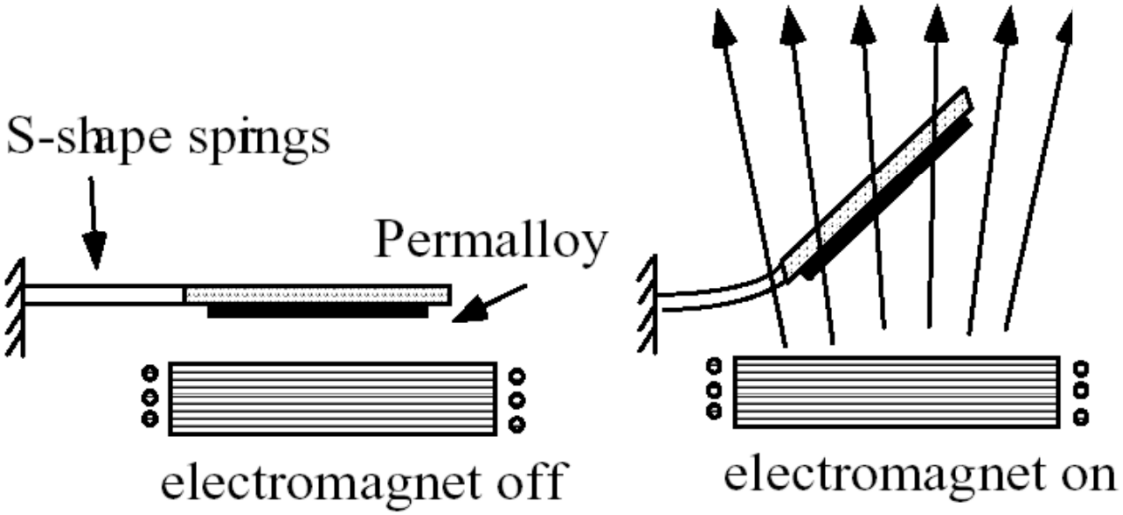
Optical Cross Connect (OXC) Limited λ conversion capability

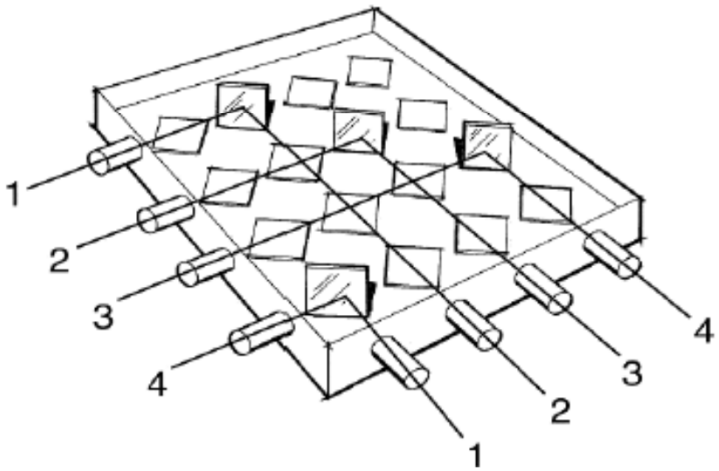


- Limited number of λ converters (Limited Conversion Capacity)
- Can be also limited in range if  is limited in range
- 4 x 3x3 = 36, but only 3 λ converters instead of 6

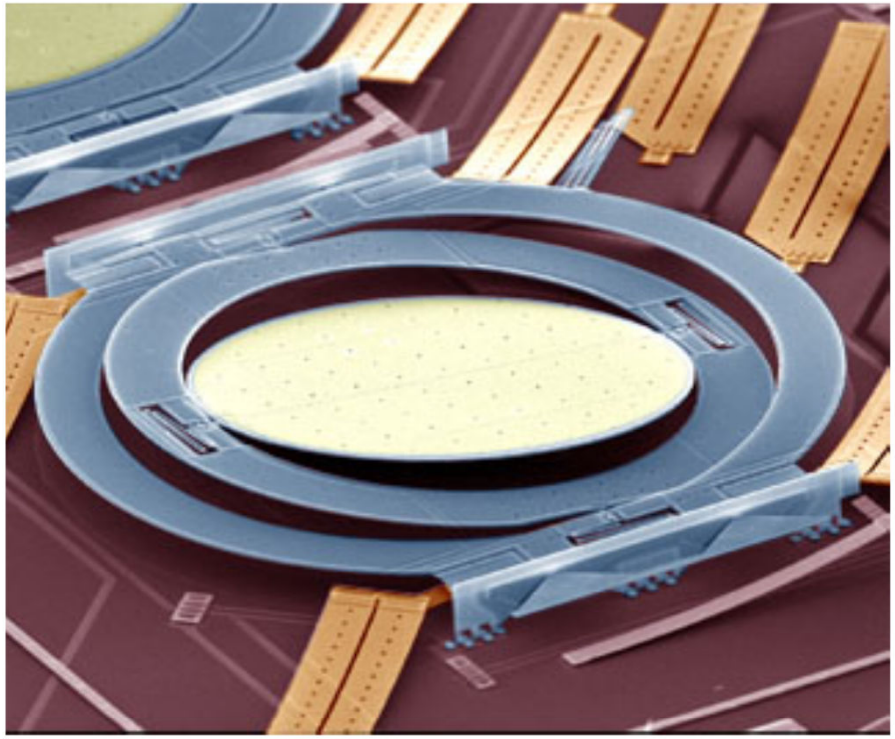
2D MEMS


permalloy mesh
springs
substrate
(a)
(b)
permalloy

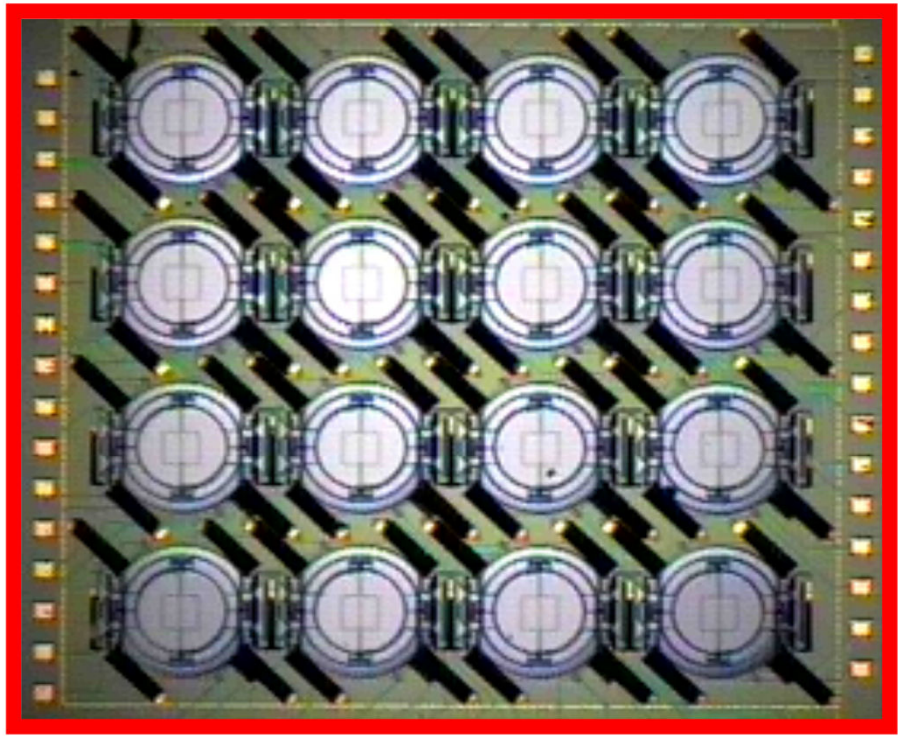

S-shape springs
Permalloy
electromagnet off
electromagnet on


1
2
3
4
4
3
2
1

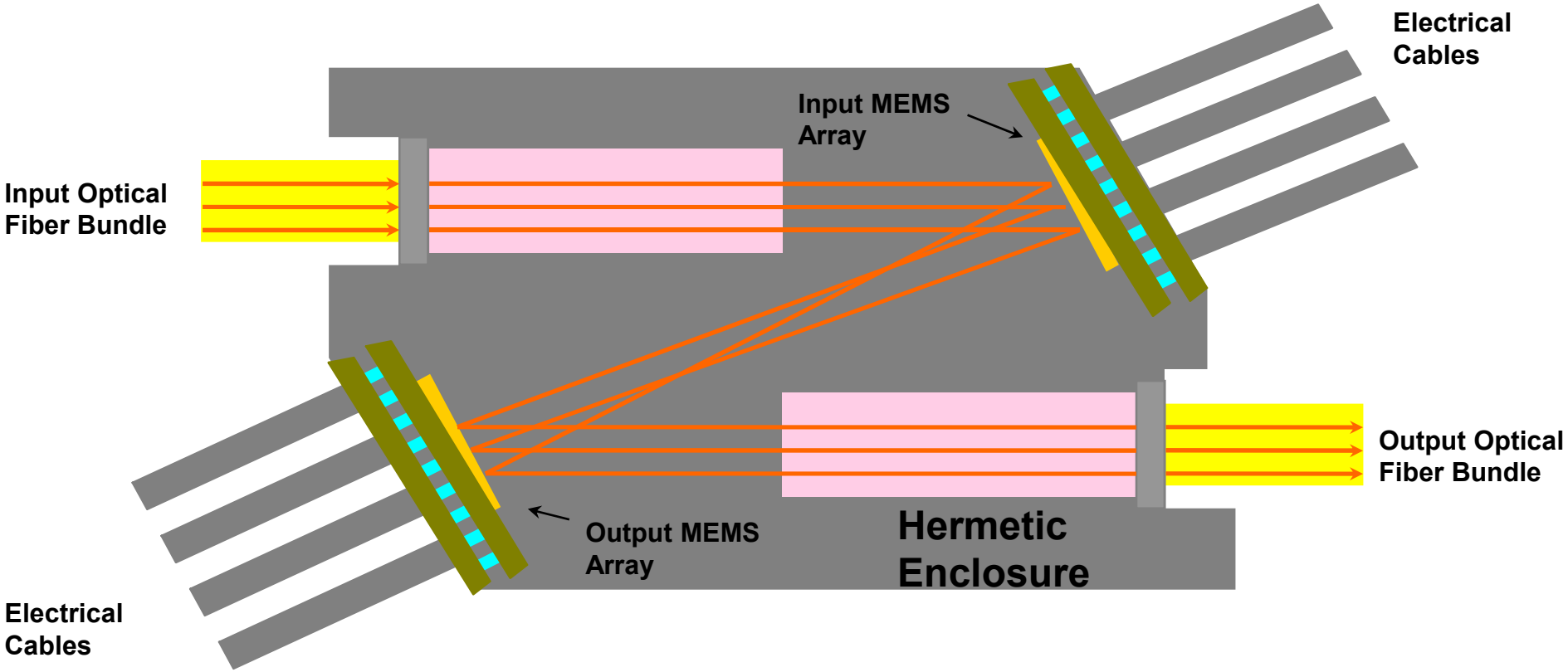
3D MEMS – micro-mirrors



Source: Lucent

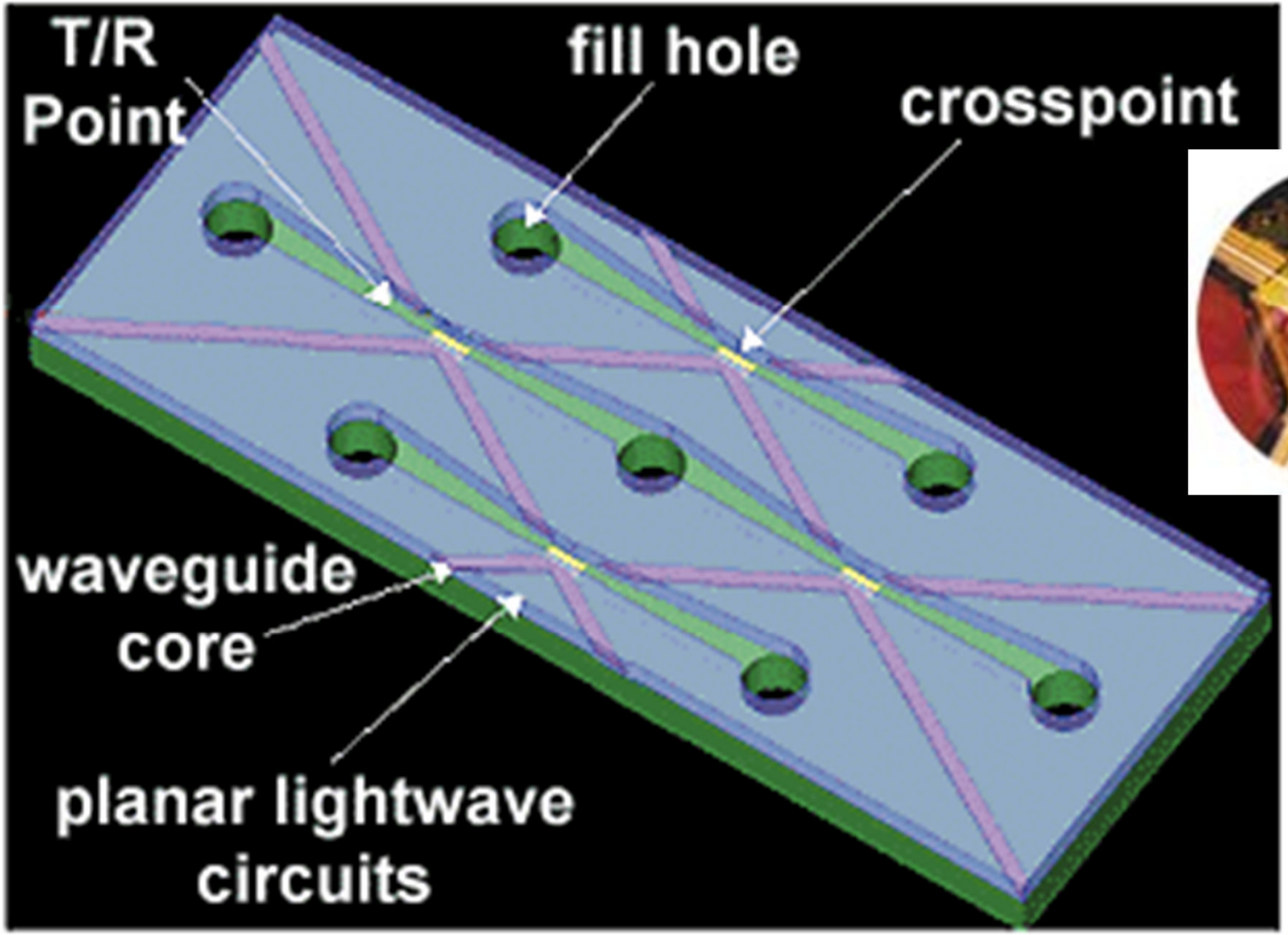


3D MEMS – working principle



Source: Lucent

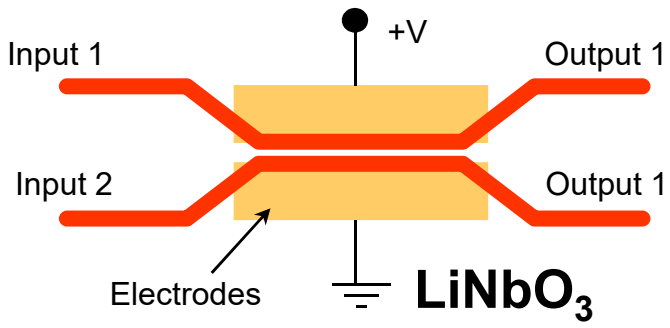
Buble-switch

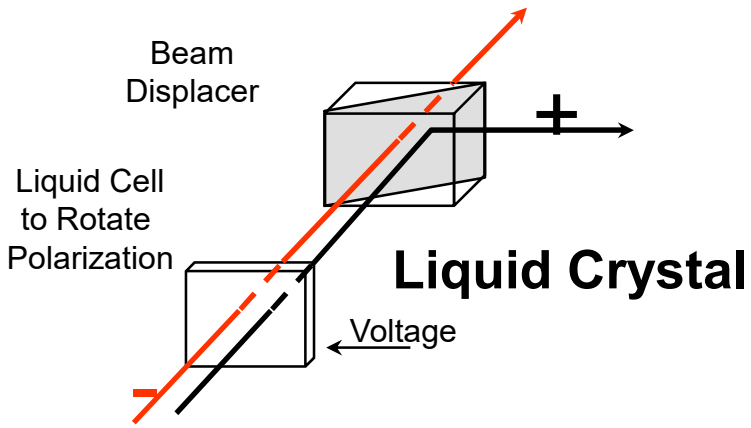


Source:
Agilent

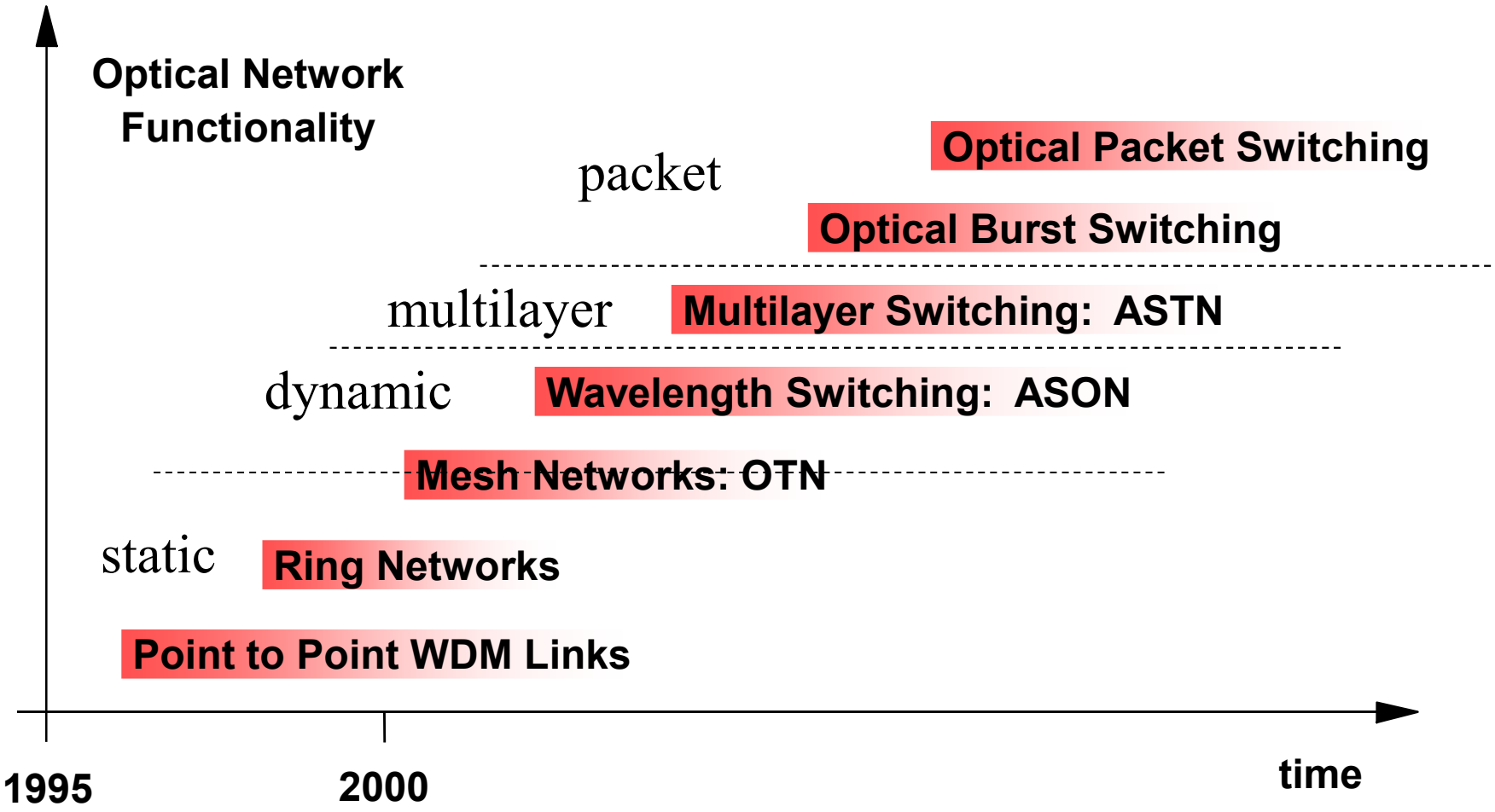
Some other Switch / Cross-Connect Solutions

- Prisma Switch
- Thermo-optical
- Liquid Chrystal
- Accusto-optical
- Piezo-electric
- ...





Optical Networking Evolution Roadmap III. Multi-Layer



III. Multi-Layer

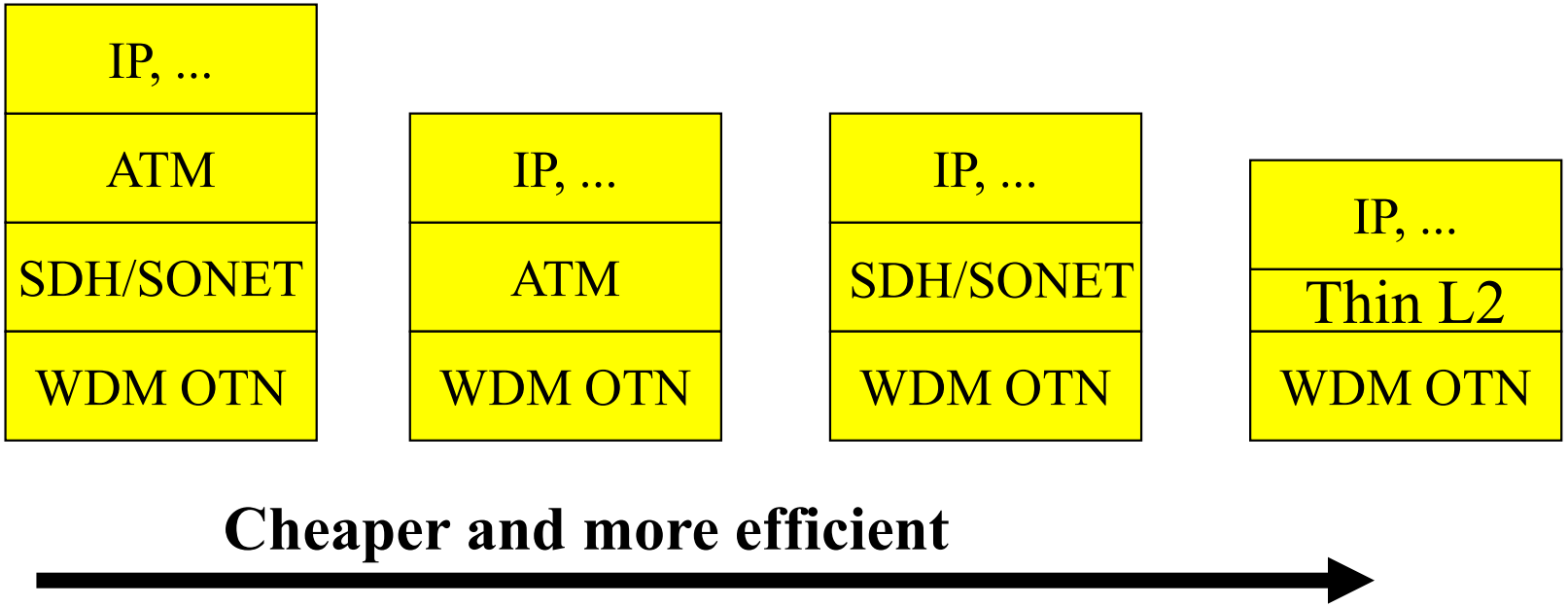
Single Layer:

- Poor granularity
  - 1 fiber: 1-10 Tbit/s (DWDM: 100-200 λ)
  - 1 λ channel: 2.5 or 10 Gbit/s
  - 1 STM-64: 64 x STM-1
  - Use additional layers that offer finer granularity

Multiple Network Layers:

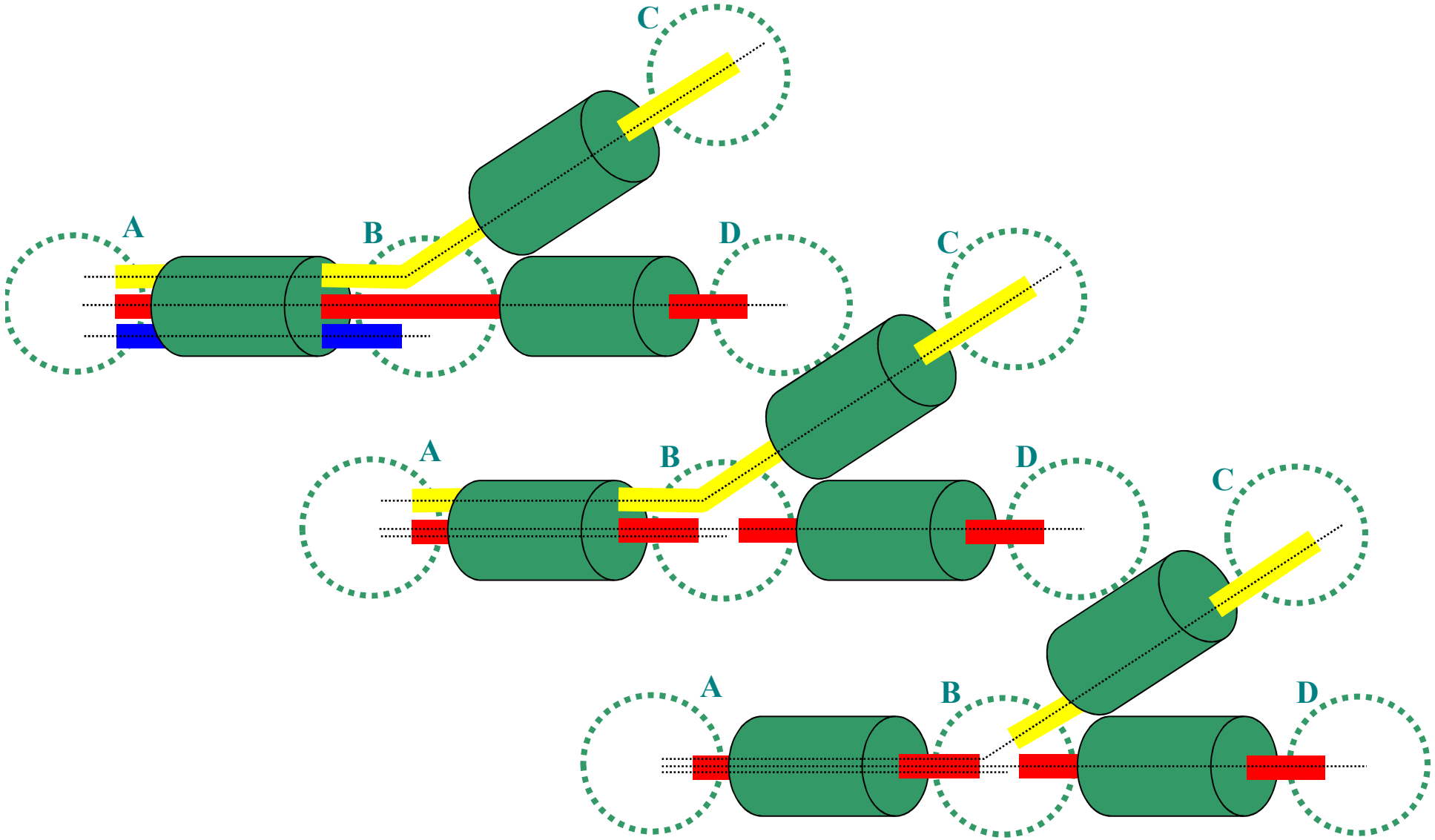
- Complex Control and Management
  - Routing
  - Resilience, etc.
- Duplicated or Multiplied Functions

Layers



- Transport functions should be implemented once only
- Control plane optimised for, e.g., IP, more scalable
- Layers should cooperate

What is Grooming?



Grooming is not new..

No grooming if single layer!

- FDM systems
- PCM/PDH systems (TDM)
- SDH/SONET (VC-12 → VC-3 → VC-4 → STM-16)
- ATM (VC→VP)
- MPLS (LSP→LSP→...→LSP) („stacking” instead of „swapping”)
- GFP+VC+LCAS (NG SDH/SONET) multiservice-grooming
  - GFP (Generic Framing Procedure) (IP, Ethernet, …)
  - VC (Virtual Concatenation) inverse multiplexing (e.g., 1GbE)
  - LCAS (Link Capacity Adjustment Scheme) dynamic ctrl (e.g., 1GbE)

Grooming: "Pro et contra"

Transparent channels → No Grooming:

- Lower throughput
- More λs required
- More Optical switch ports
- Poor granularity
- Low utilisation
+ Lower Delay (no TDM - no buffering)
+ Arbitrary upper layer
+ Simple routing

Shared channels → Grooming:

+ Higher throughput
+ Less λ required
+ Less ports (smaller matrix)
+ Fine granularity (sub-λ)
+ Higher utilisation
– Higher Delays through TDM and buffering
– Uniform upper layer required
– Complex Routing
– Capacity reservation and Traffic policing required

Communication Networks II

BMEVITMA310 in English

Tibor Cinkler (**5.**) May 4, 2020

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

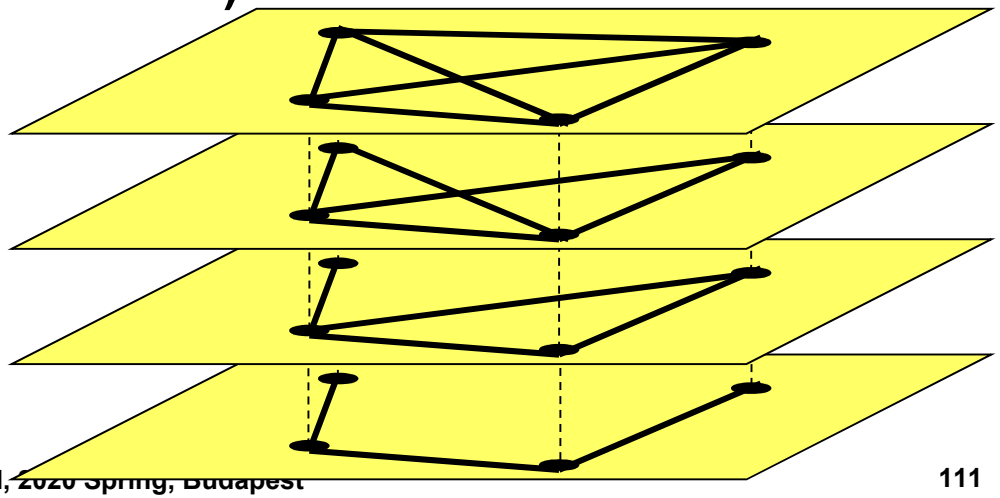
http://opti.tmit.bme.hu/~cinkler/TNS

GMPLS/ASTN

Dynamic (switched) & Multilayer

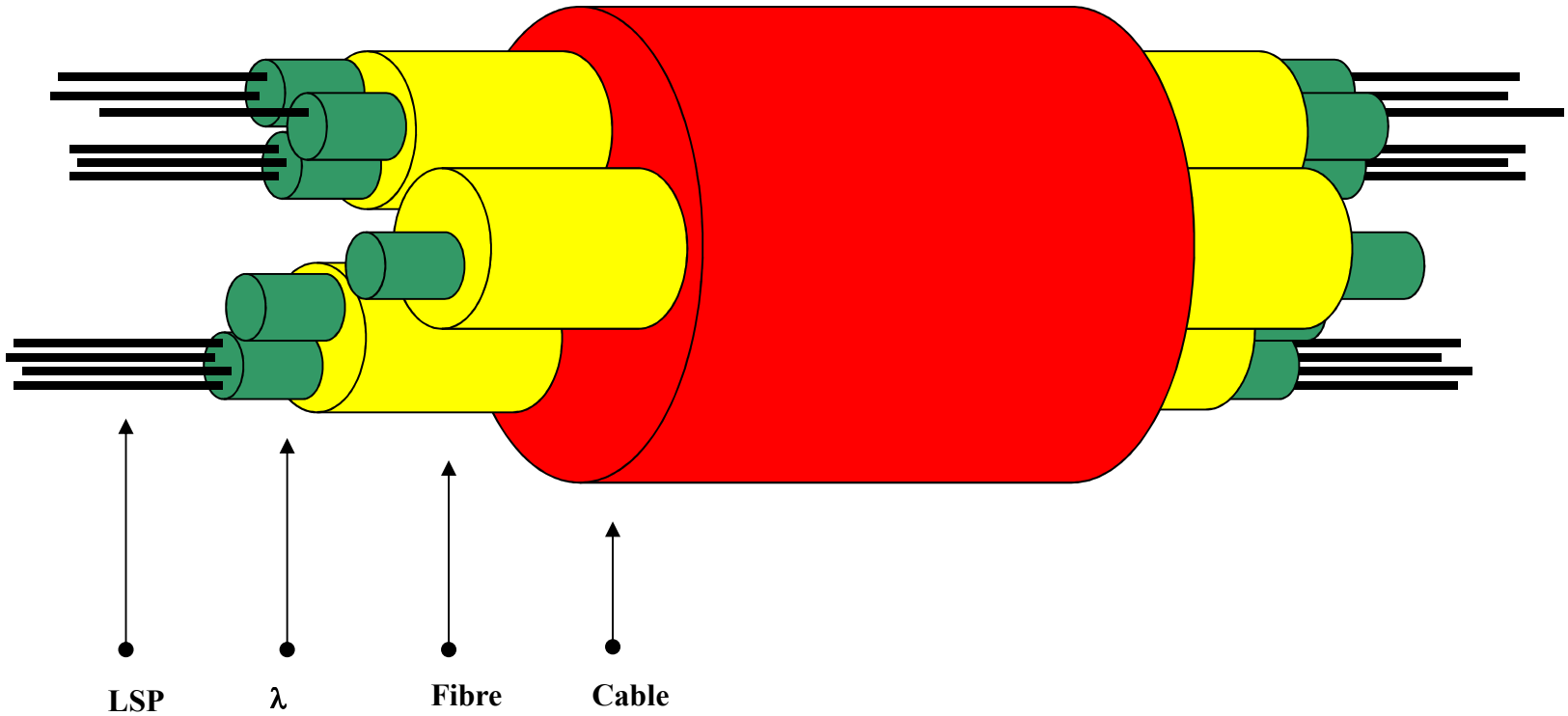
IETF GMPLS: Generalised Multiprotocl Label Switching
ITU-T ASTN: Automatic Switched Transport Network

PSC	**(Packet Switching Capable, e.g., IP)**
L2	**(Layer 2 SC, e.g., GbEth)**
TSC	**(TDM SC, e.g., SDH VC-4-4c)**
λSC	**(Wavelength SC)**
WBSC	**(WaveBand SC)**
FSC	**(Fiber SC)**

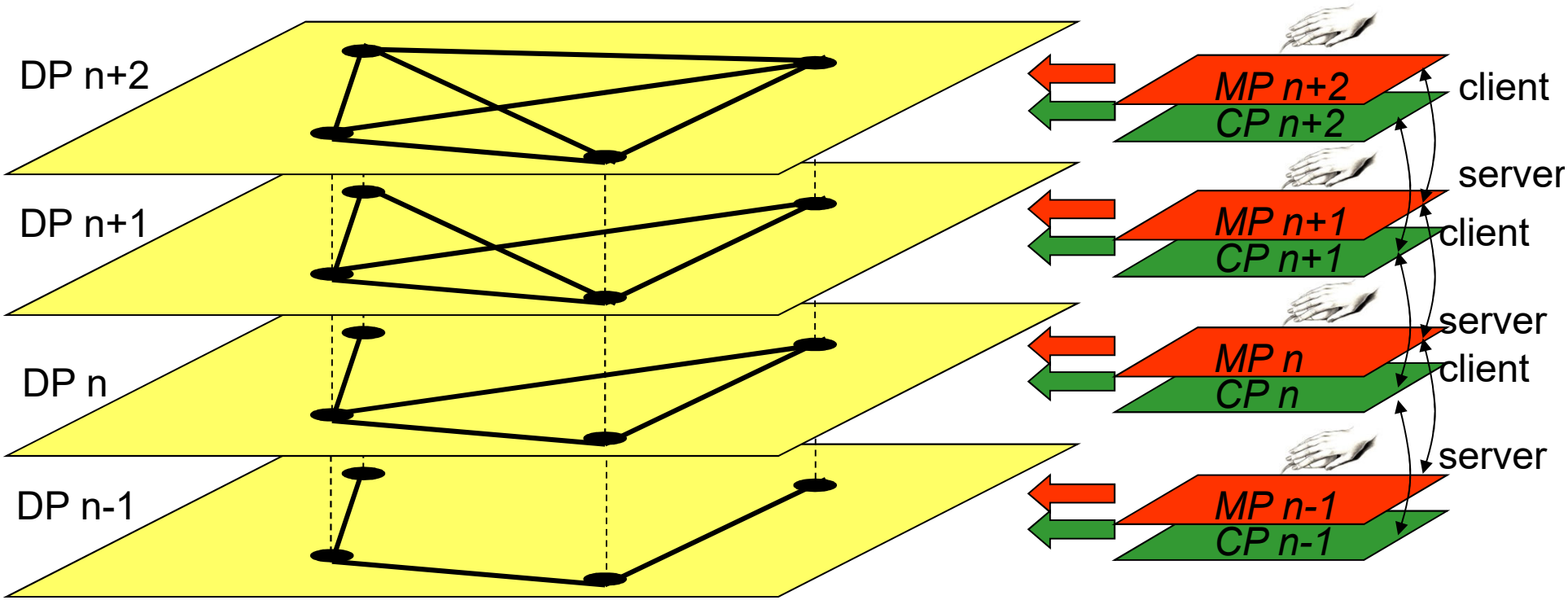


Generalised Label Stacking

Multilayer Architecture → Generalised LSPs

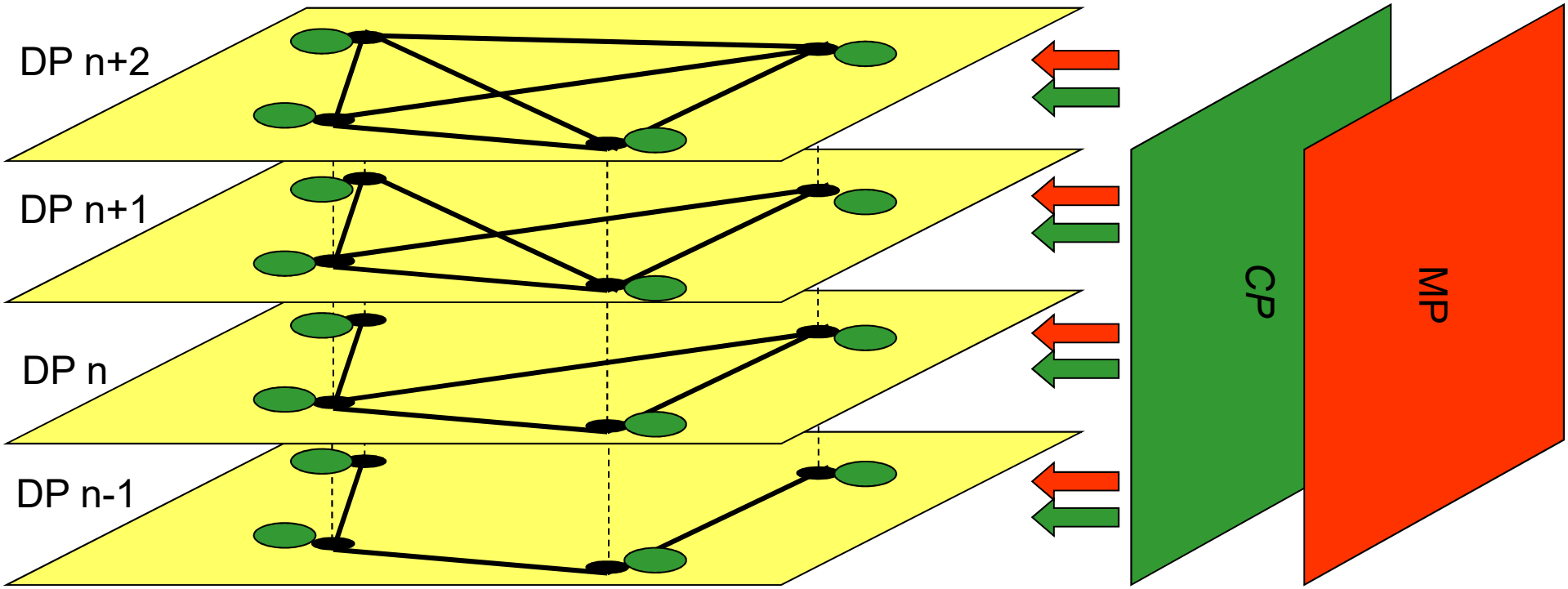


Routing, TE & Resilience nowadays: Client-Server, partly manual



Routing, TE & Resilience desire:

Integrated, automated, distributed



Multi-Layer (Vertical) Interconnection Models (RFC 3717)

- Overlay Model
  - The control of layers is independent
  - “Server-Client” approach
  - like “classical IP over ATM” or “MPOA” models
  - optical layer can be statically configured
- Peer Model
  - Interoperable control plane (e.g., Optical layer is also IP addressable)
- Augmented (Hybrid)
  - Something between
  - Hides confidential provider information
  - Some information of one routing instance passed through the other
  - E.g., IP addresses could be carried within the optical routing protocol

Vertical Integration: Multi-Layer Integrated Model

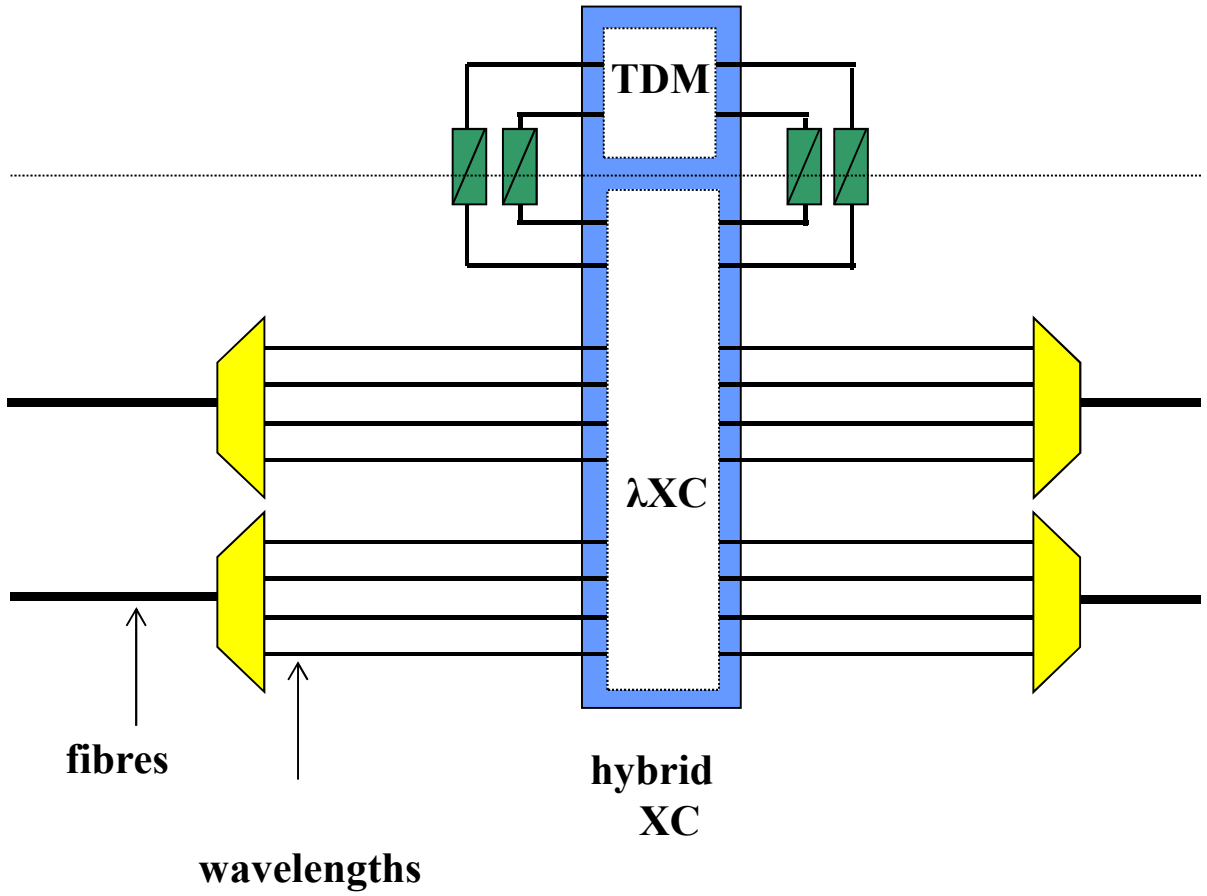
- The layers owned by the same operator
- Full interlayer information exchange possible
  (No interface needed in between)
- Can be operated by a single CP and a single MP
- Routing, TE, Resilience → more complex
- MRN: Multi Region Network

(Region: interconnected nodes of the same networking technology – a bit missleading)

Integrated Traffic-Grooming Node Architecture

TDM electrical switch
- IP core router
- **MPLS**
  LSR/LER
- ng SDH
- ATM

λXC
- **optical core**
- electrical core



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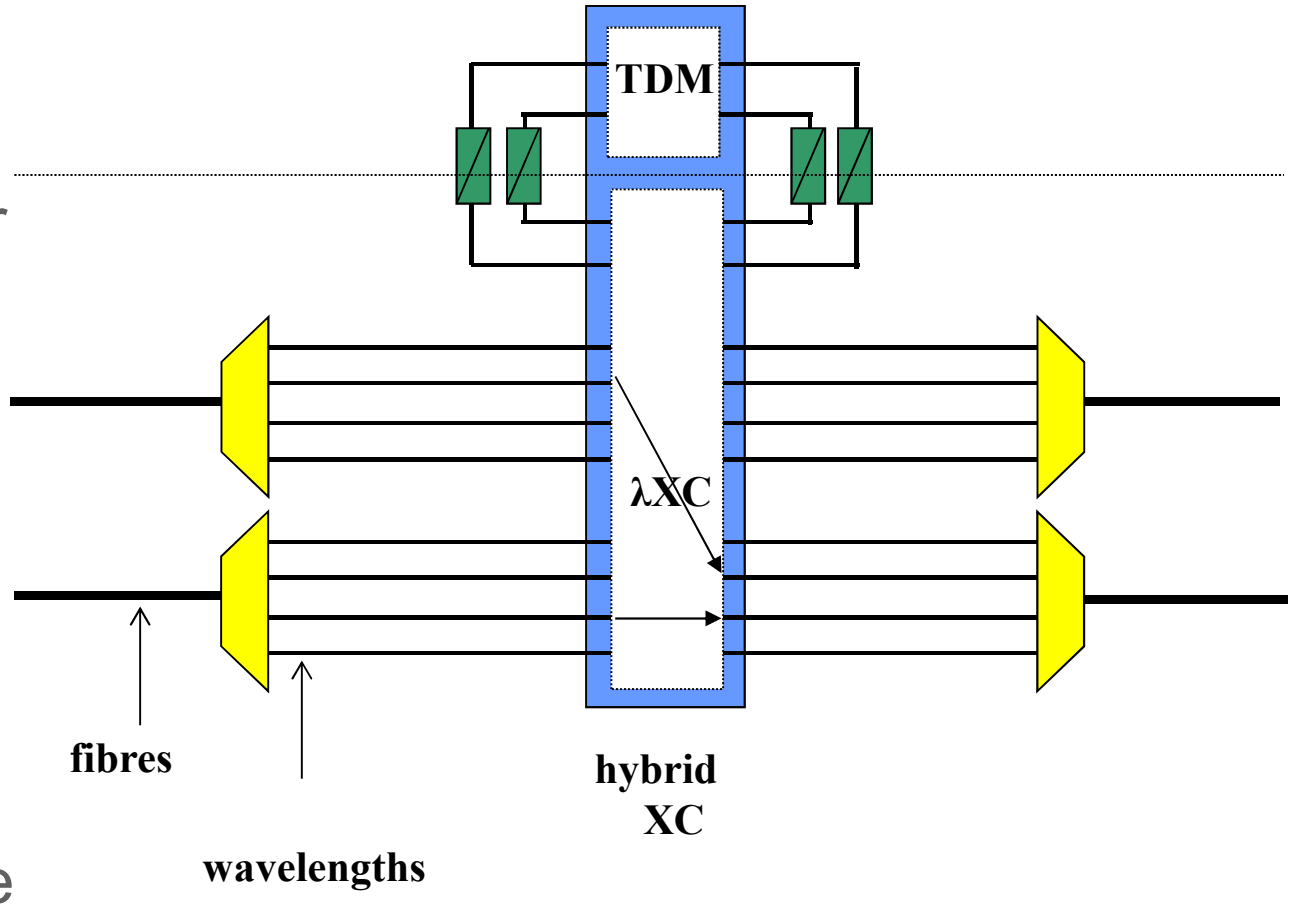
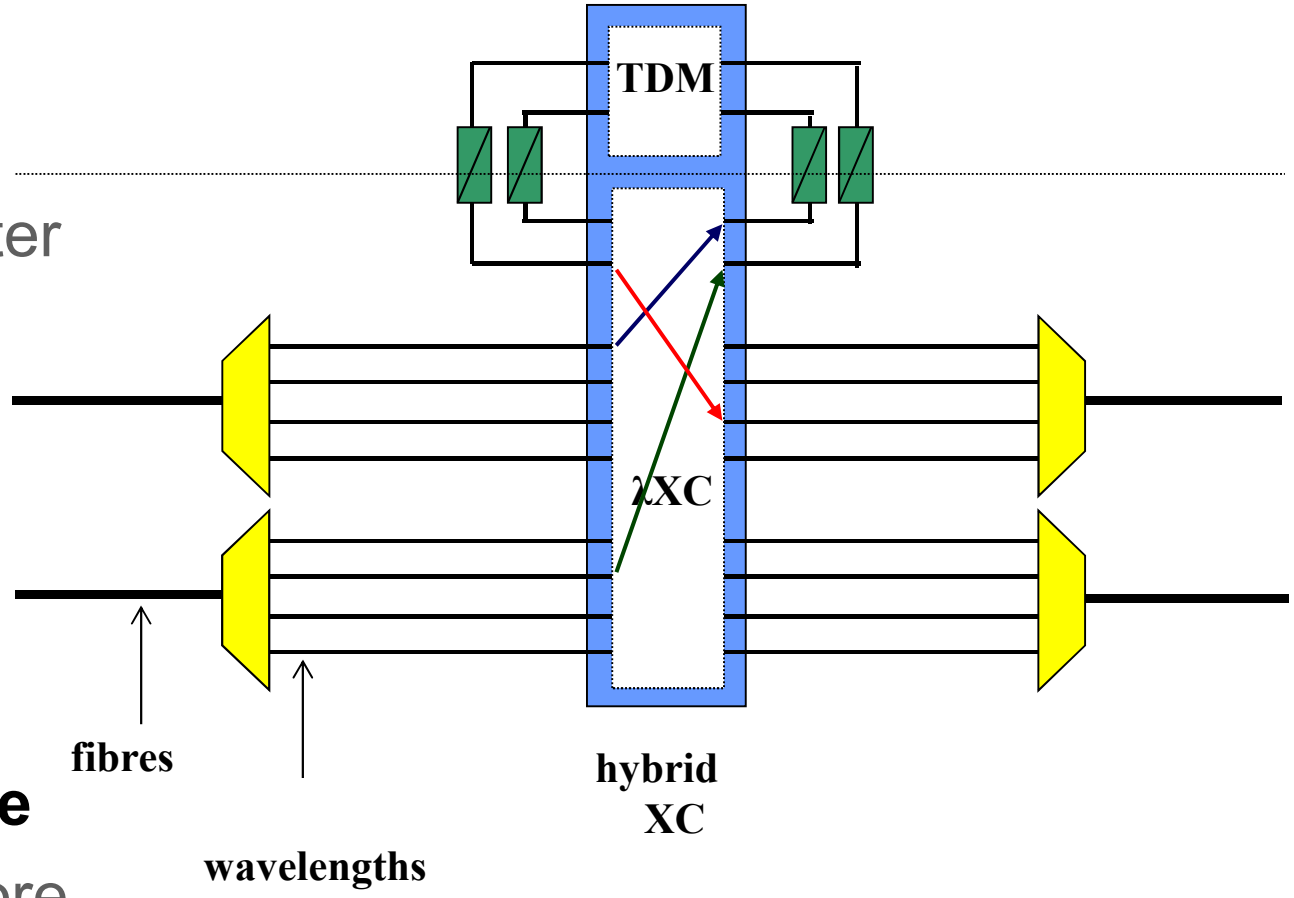


λ transition

Integrated Traffic-Grooming Node Architecture

TDM electrical switch
- IP core router
- **MPLS**
  LSR/LER
- ng SDH
- ATM

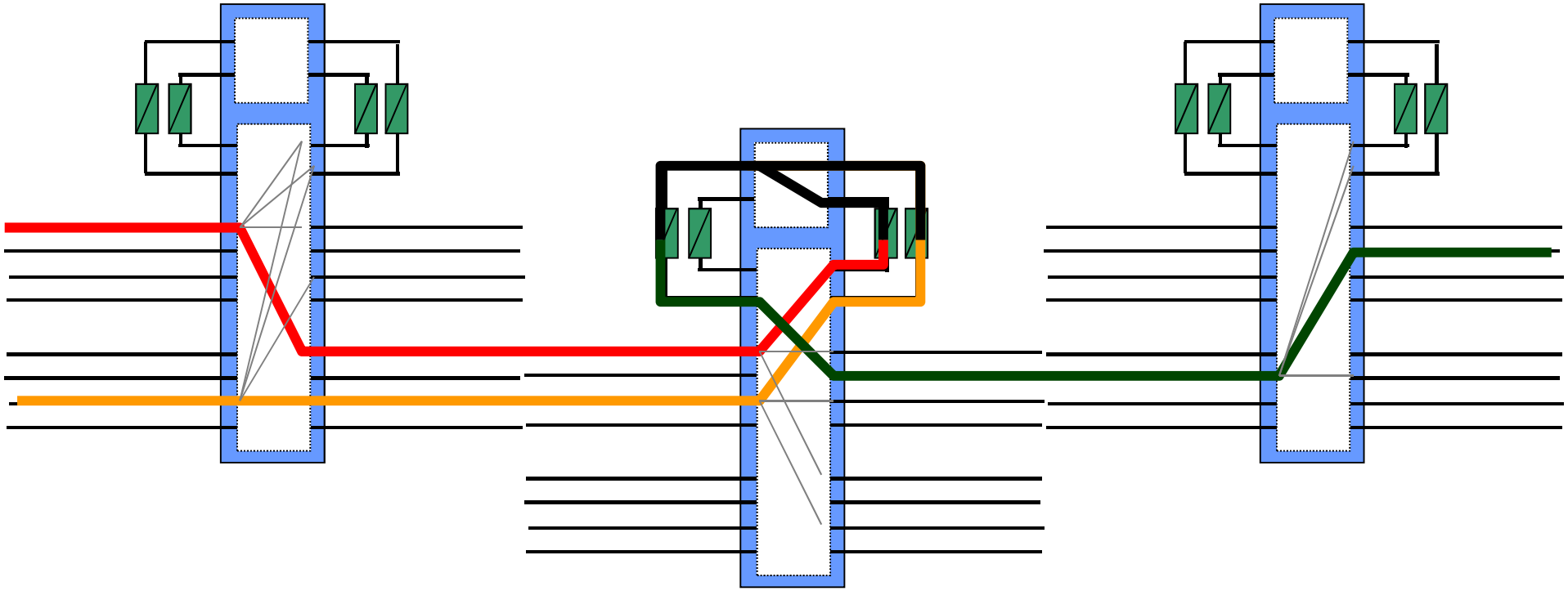
λXC
- **optical core**
- electrical core



Traffic grooming

A Routing Example for the Integrated Model

2 λ transitions → Grooming → 1 λ transition



Multiplexing Solutions in Optical Networks (REPEATED)

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

Optical Orthogonal Frequency-Division Multiplexing (O-OFDM)

OFDM: Orthogonal Frequency-Division Multiplexing

O-OFDM: Optical OFDM

- **SpectrumElasticMukherjee_06148192_002.pdf**
- **G. Zhang, M. De Leenheer, A. Morea, B. Mukherjee**
- **A Survey on OFDM-Based Elastic Core Optical Networking**
- **IEEE COMMUNICATIONS SURVEYS & TUTORIALS**

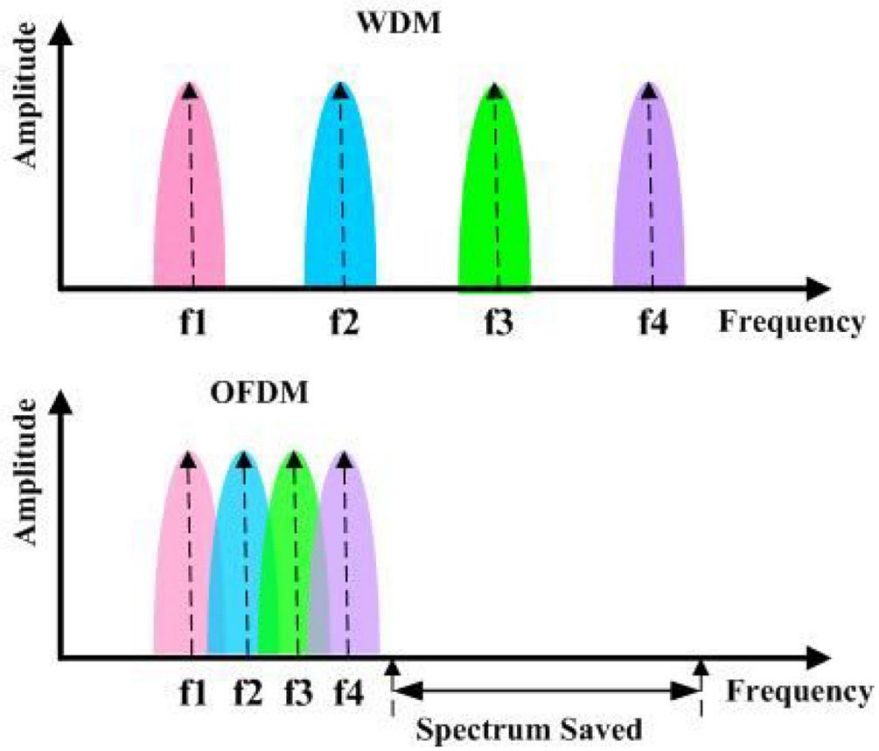
Already used:

- **IEEE 802.11 a/g WiFi**
- **WiMAX**
- **LTE**
- **DAB és DVB**
- **DSL**

How does OOFDM work?

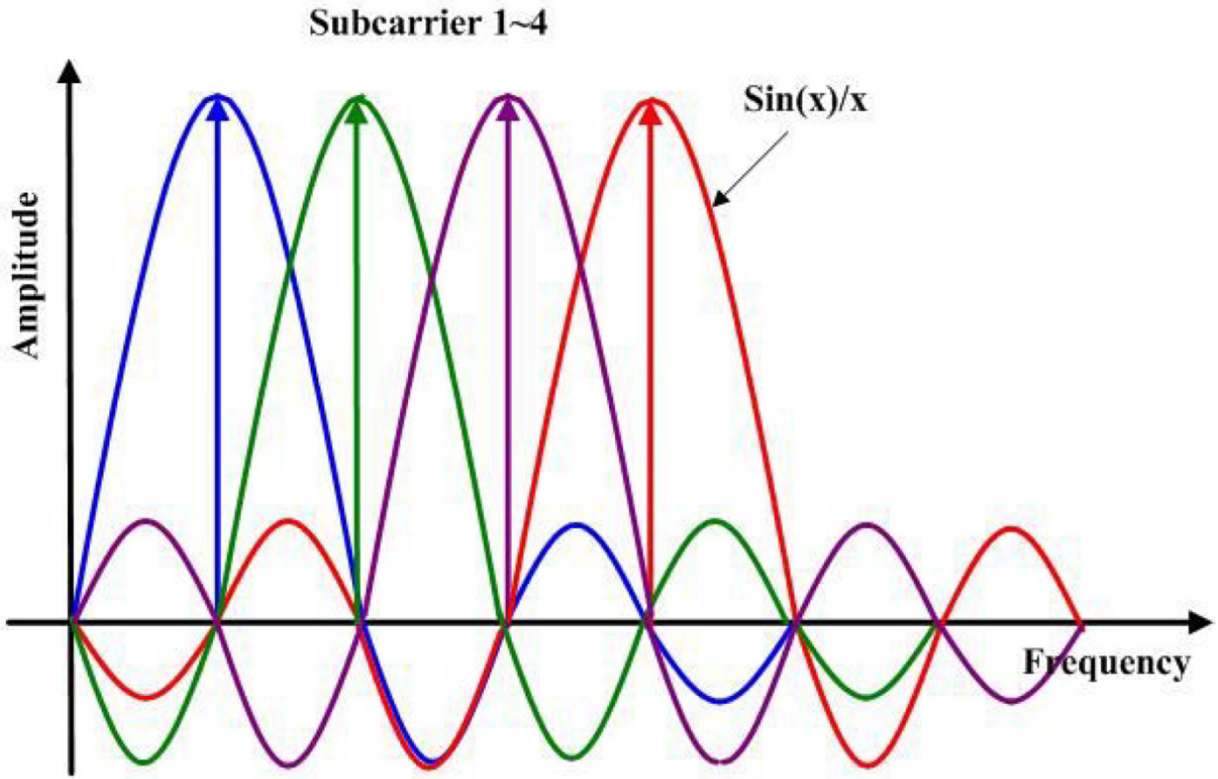
- Multi-Carrier Modulation
- Each carrier carries lower data rate stream
- In WDM large frequency gap needed
- In OFDM frequency band of carriers overlap

WDM and O-OFDM spectrum

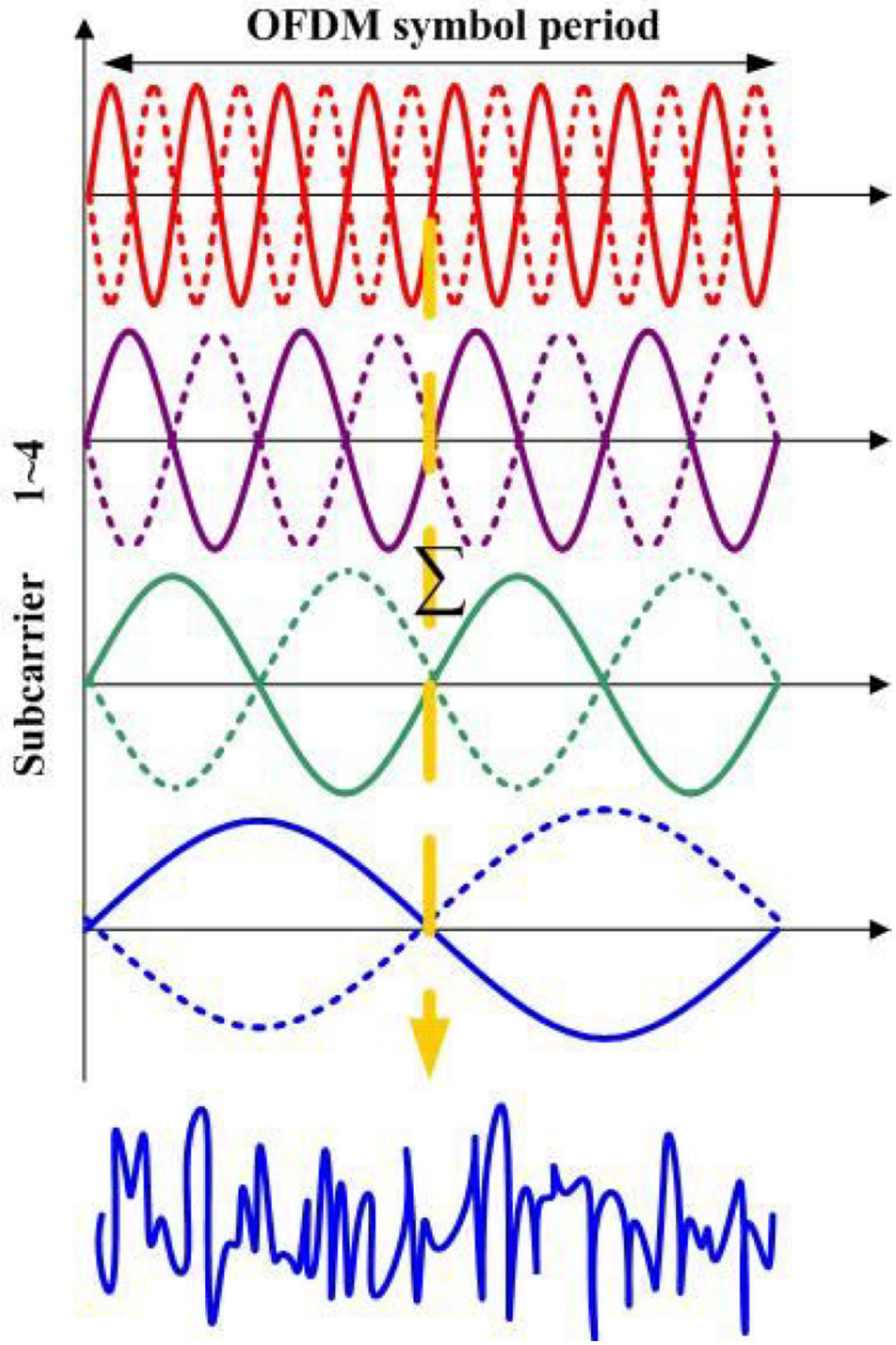


Ortogonality

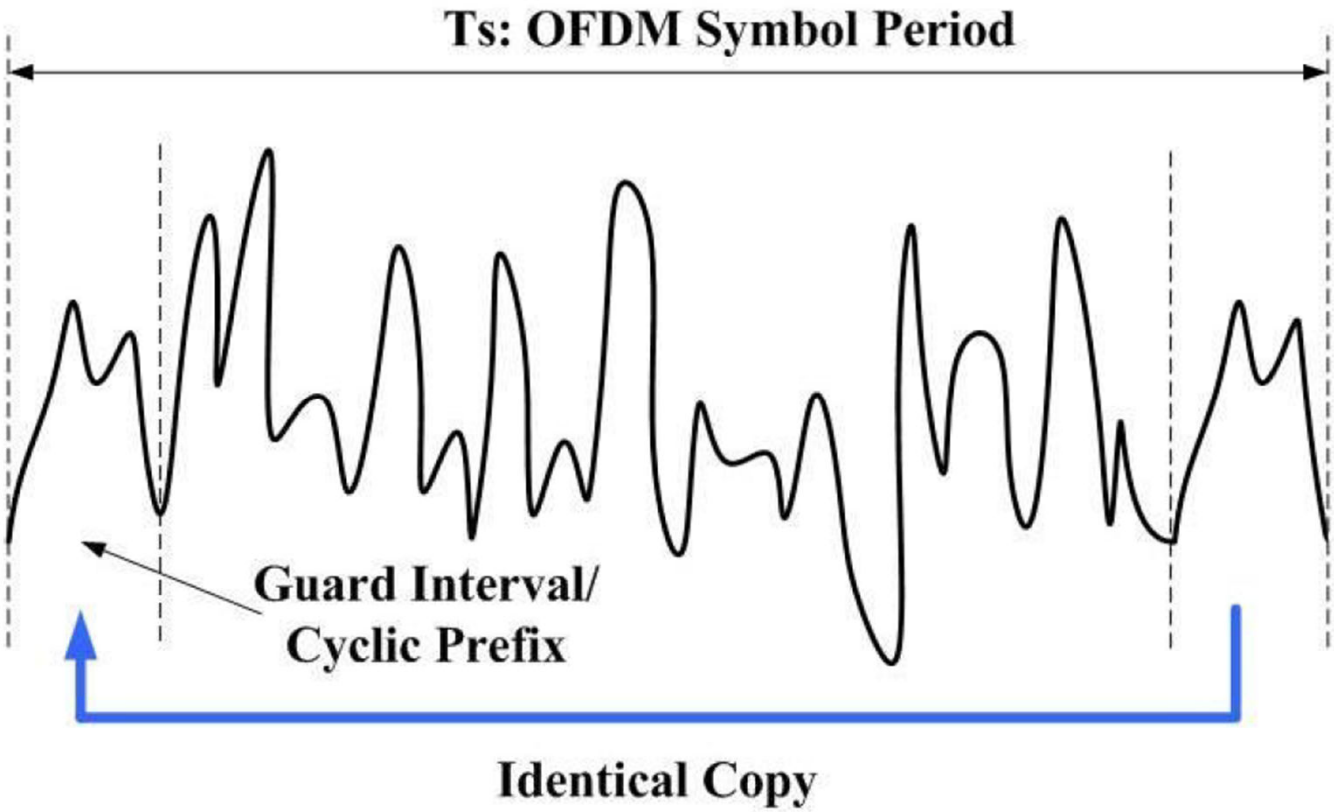
- Where the peak of subcarrier spectrum is
- There other subcarrier spectrums have 0
- Sampling at those frequencies
- Ortogonality → Efficient use of the Spectrum



Time Domain

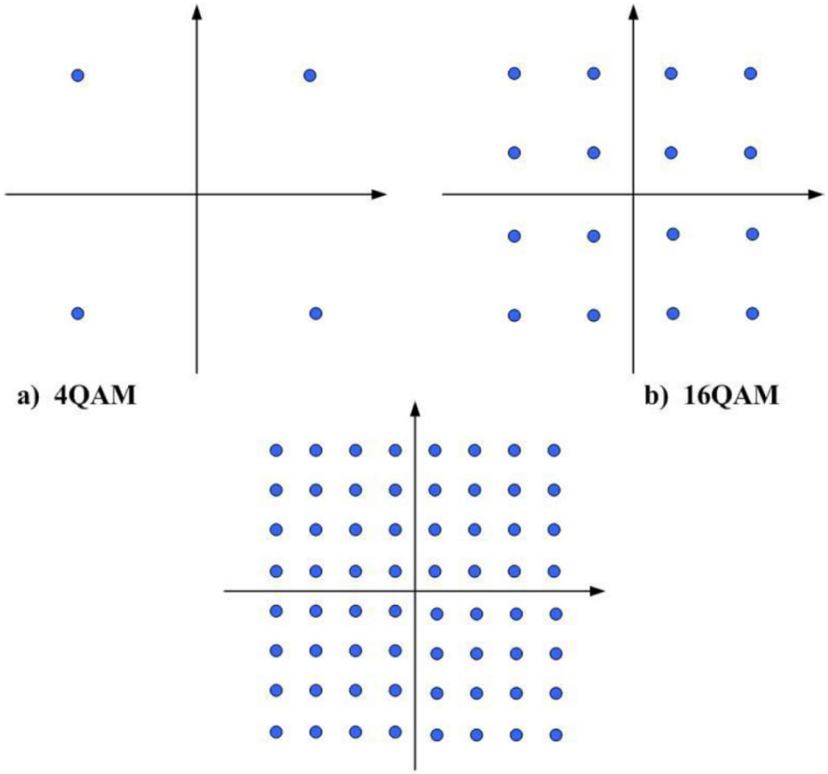


Guard Times

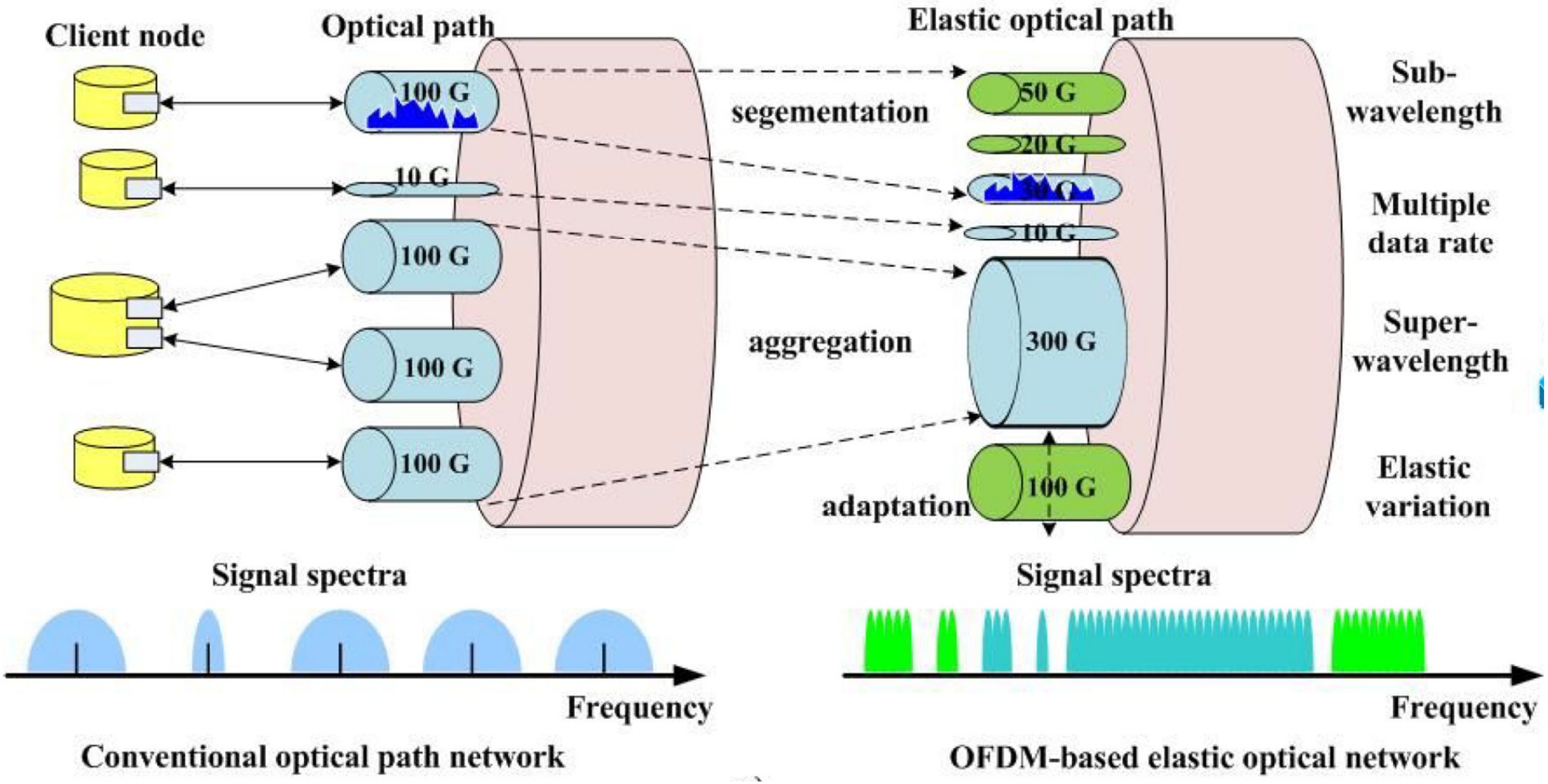

Ts: OFDM Symbol Period
Guard Interval/
Cyclic Prefix
Identical Copy

QAM

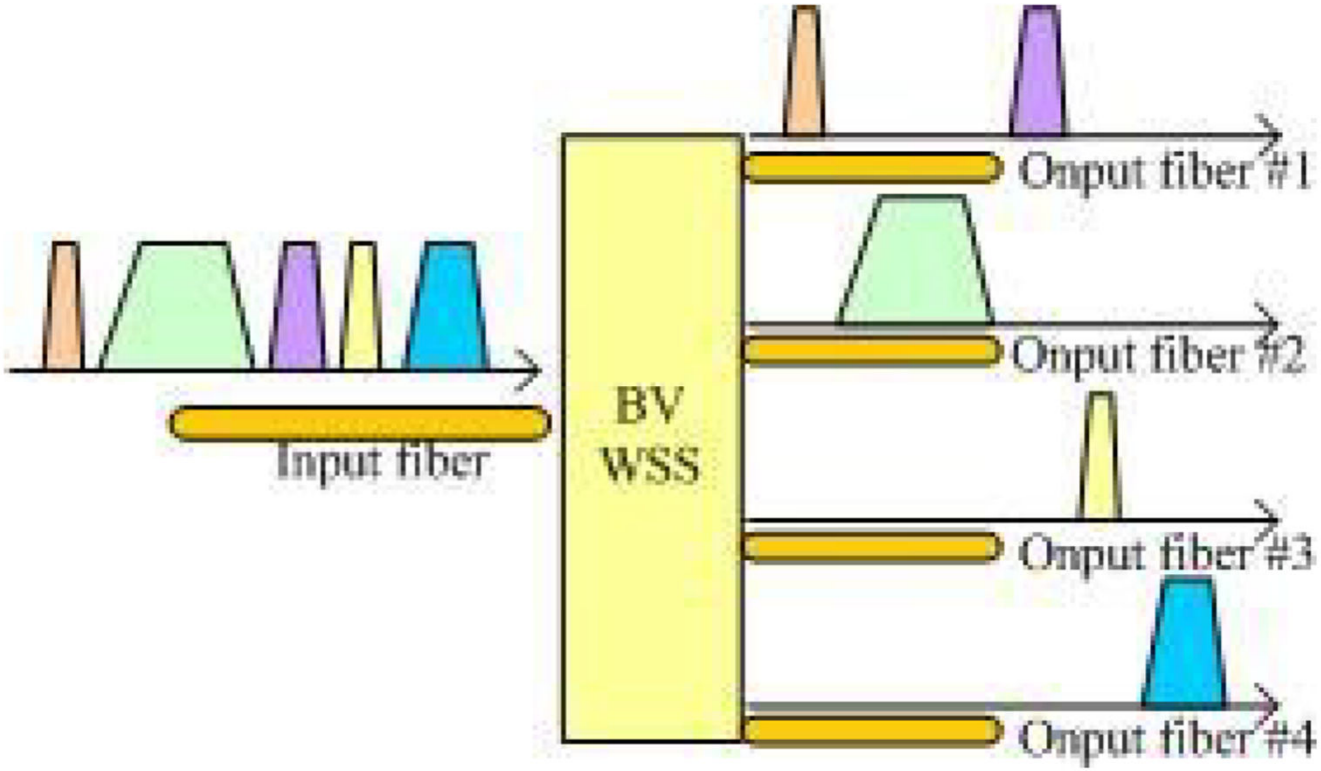
- Quadrature Amplitude Modulation
- 4, 8, 16, 32, 64



WSON and SSON



Spectrum-Elastic Switch

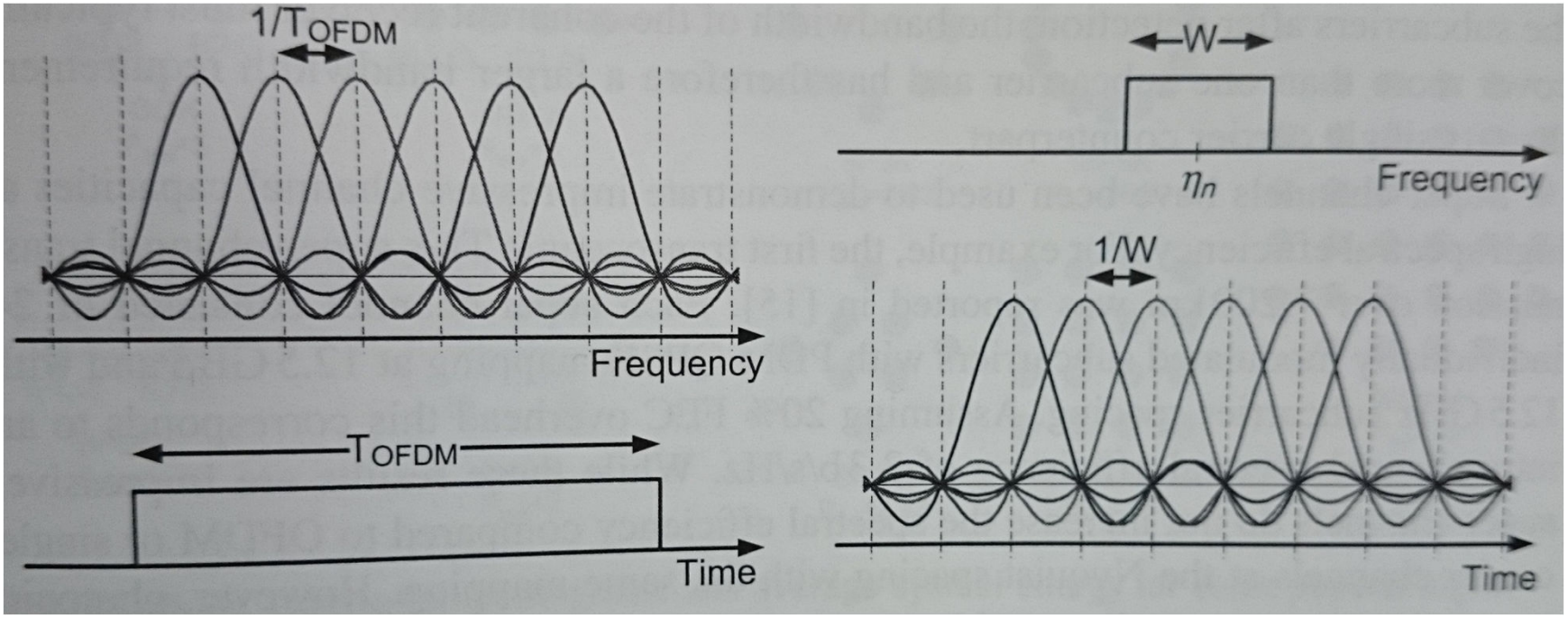


Nyquist WDM

- http://www.hhi.fraunhofer.de/en/fields-of-competence/photonic-networks-and-systems/research-topics/optical-core-networks/optical-transport-networks/ofdm-nyquist-wdm.html

- Nyquist Pulse Sahping
  - Nyquist wavelength-division multiplexing (N-WDM), is based on the use of optical pulses having an “almost” rectangular spectrum, with bandwidth ideally equal to the Baud-rate.
  - (http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=5471215&tag=1)

O-OFDM and Nyquist WDM

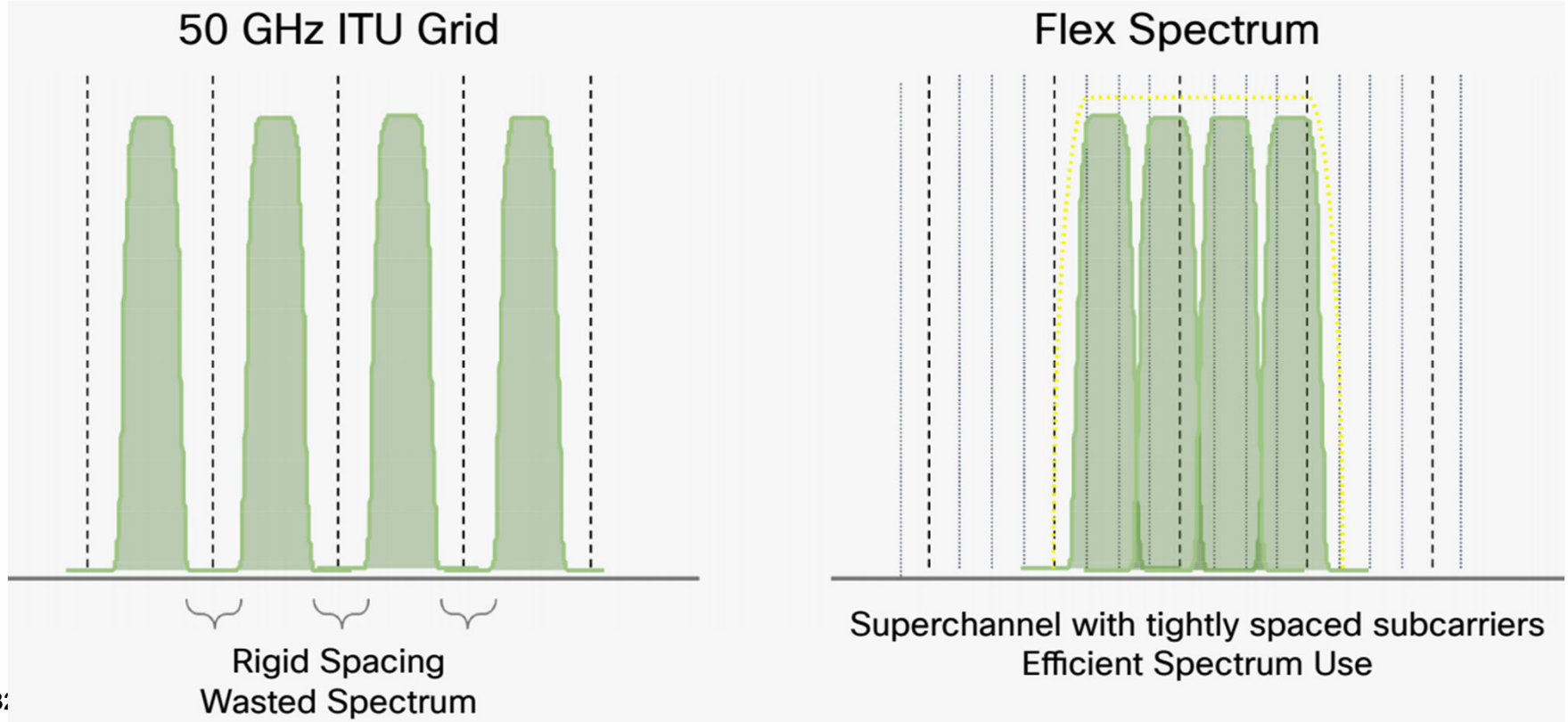


- O-OFDM: Squared in Time - sin(x)/x in Frequency
  - Subcarriers orthogonal in the frequency domain
  - Better spectral efficiency
- N-WDM: Squared in Frequency - sin(x)/x in Time
- Source: I.P. Kaminov: Optical Fiber Telecommunications, systems and networks, Elsevier 2013

Flex Channels of Flex Grid

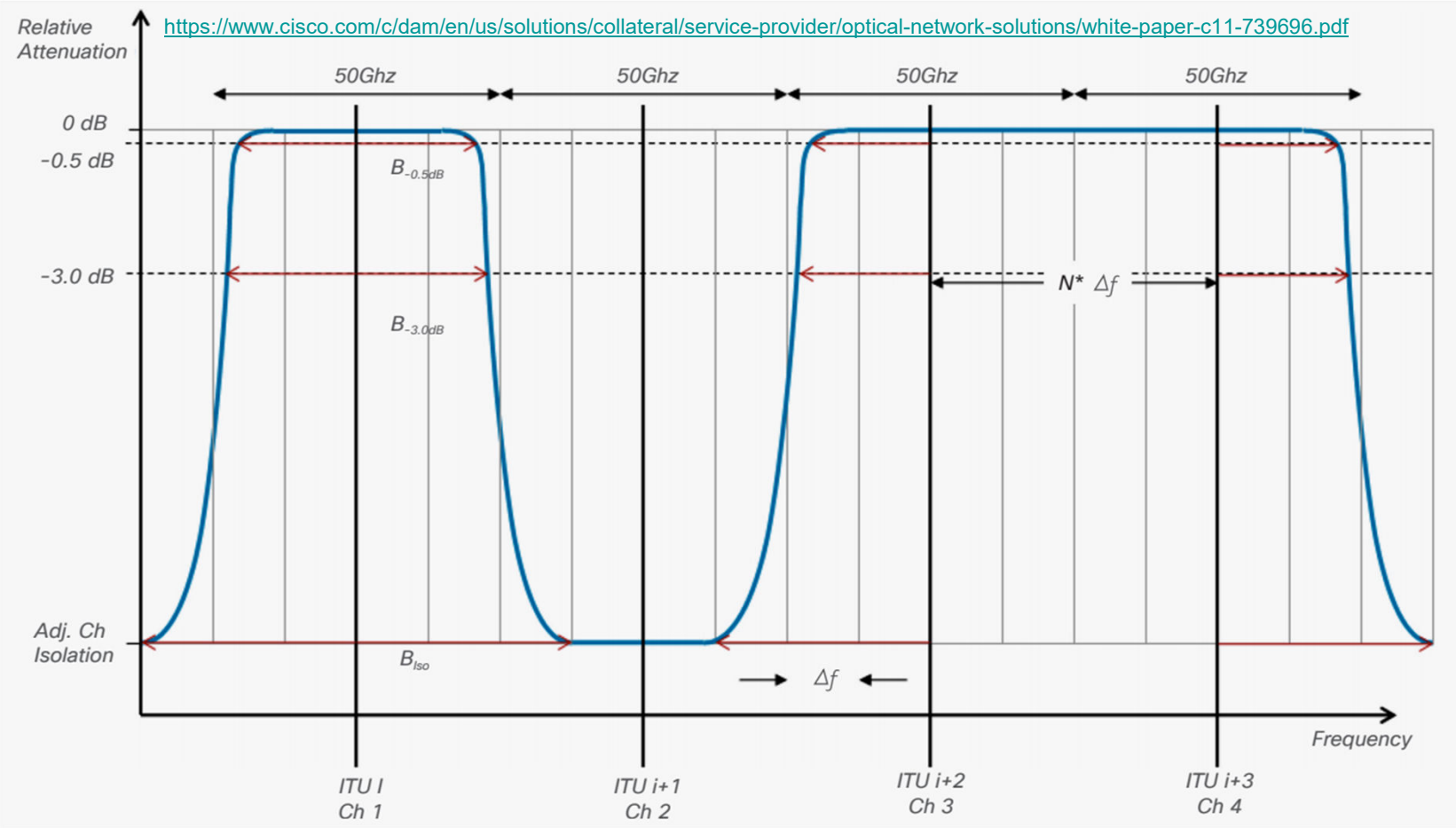
- 12,5 GHz subcarriers
- Typically 37,5 -100 GHz channels
  - Generally 3-8 subcarriers
  - 4, 6, 8 is most typical… (50-75-100 GHz)

https://www.cisco.com/c/dam/en/us/solutions/collateral/service-provider/optical-network-solutions/white-paper-c11-739696.pdf



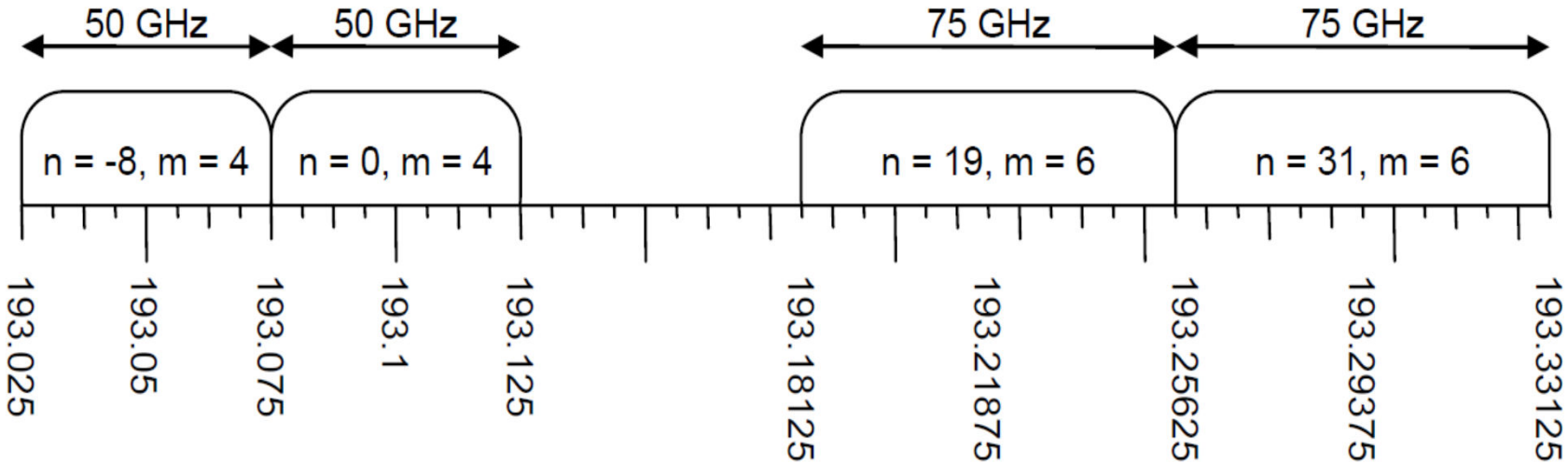
WSON vs SSON

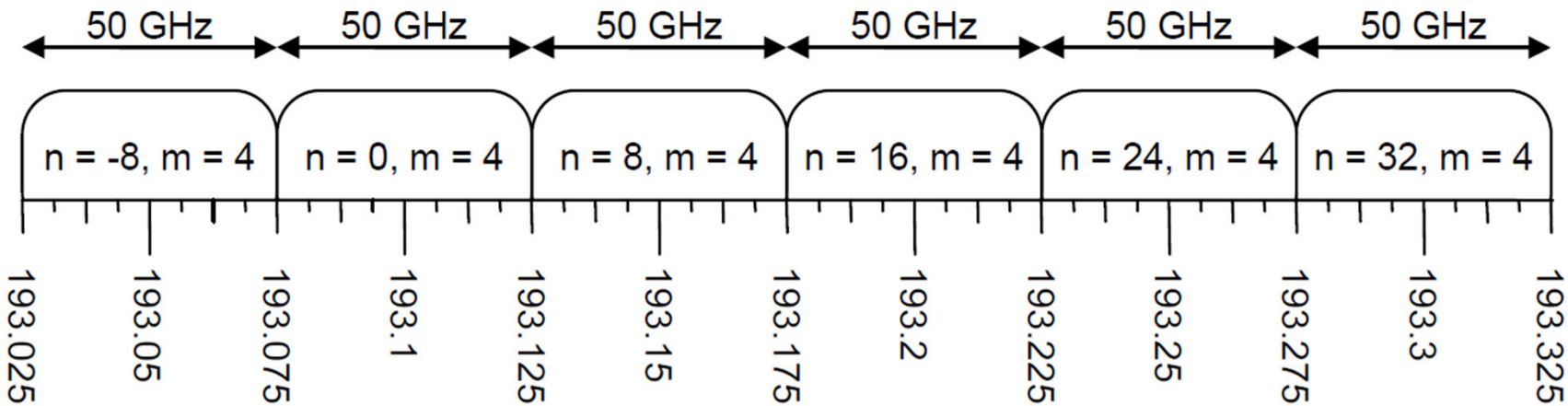
- WSON vs SSON
  - Wavelength Switched Optical Networks (WSON)



Recommendation ITU-T G.694.1

$$193.1 + n \times 0.0125 \text{ THz}$$



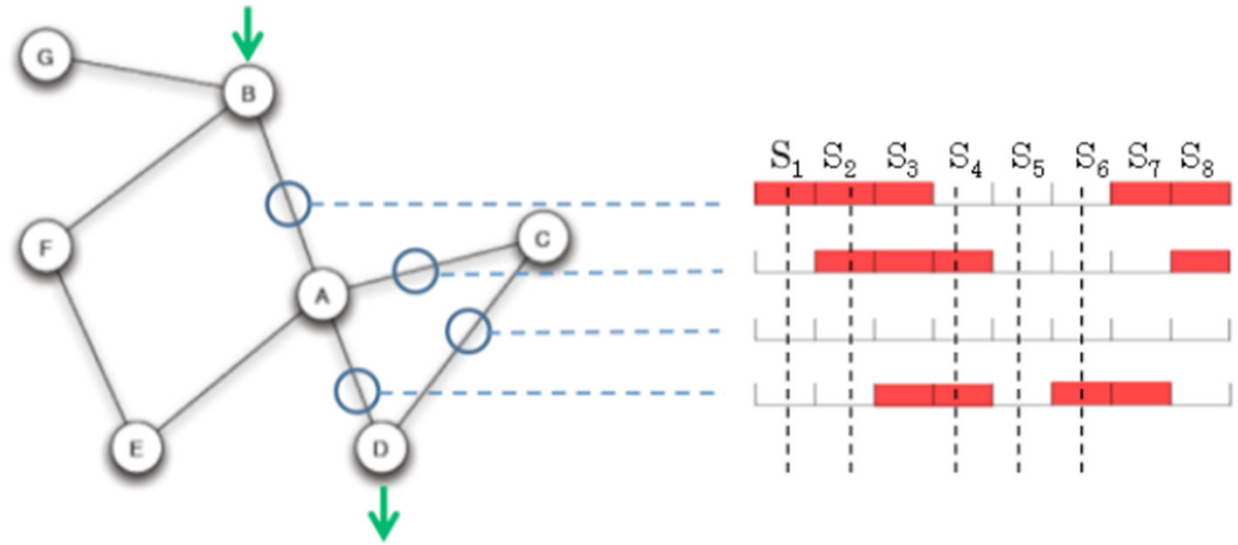


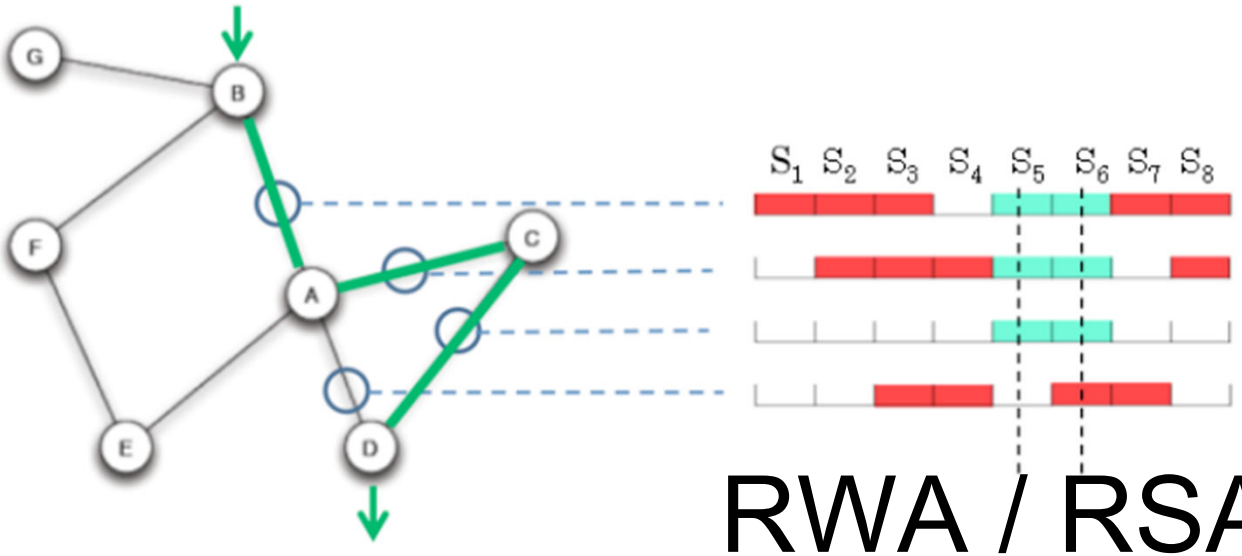
https://www.itu.int/rec/dologin_pub.asp?lang=e&id=T-REC-G.694.1-201202-I!!PDF-E&type=items

Thierry Zami, Annalisa Morea, Giovanni Bellotti, B. Lavigne:
Is Mixing 50 GHz-Spaced 32 GBaud Channels and 75GHz-Spaced 64 GBaud Ones Useful in a WDM Elastic Network? September 2018, OI: 10.1109/ECOC.2018.8535149, Conference: 2018 European Conference on Optical Communication (ECOC)

Carrier modulation *with lower FEC code rate	**Channel space (GHz)**	**Reach (km)**
100 Gb/s **32** GBaud PDM-QPSK	**50 or 75**	**4200**
150 Gb/s **32** GBaud PDM-8QAM	**50 or 75**	**1600**
200 Gb/s **32** GBaud PDM-16QAM	**50 or 75**	**800**
250 Gb/s **32** GBaud PDM-32QAM	**50 or 75**	**300**
200 Gb/s **64** GBaud PDM-QPSK	**75**	**2500**
250 Gb/s **64** GBaud PDM-8QAM*	**75**	**1600**
300 Gb/s **64** GBaud PDM-8QAM	**75**	**1100**
350 Gb/s **64** GBaud PDM-16QAM*	**75**	**700**
400 Gb/s **64** GBaud PDM-16QAM	**75**	**500**
450 Gb/s **64** GBaud PDM-32QAM*	**75**	**300**
500 Gb/s **64** GBaud PDM-32QAM	**75**	**200**

Routing one demand: WSON - SSON



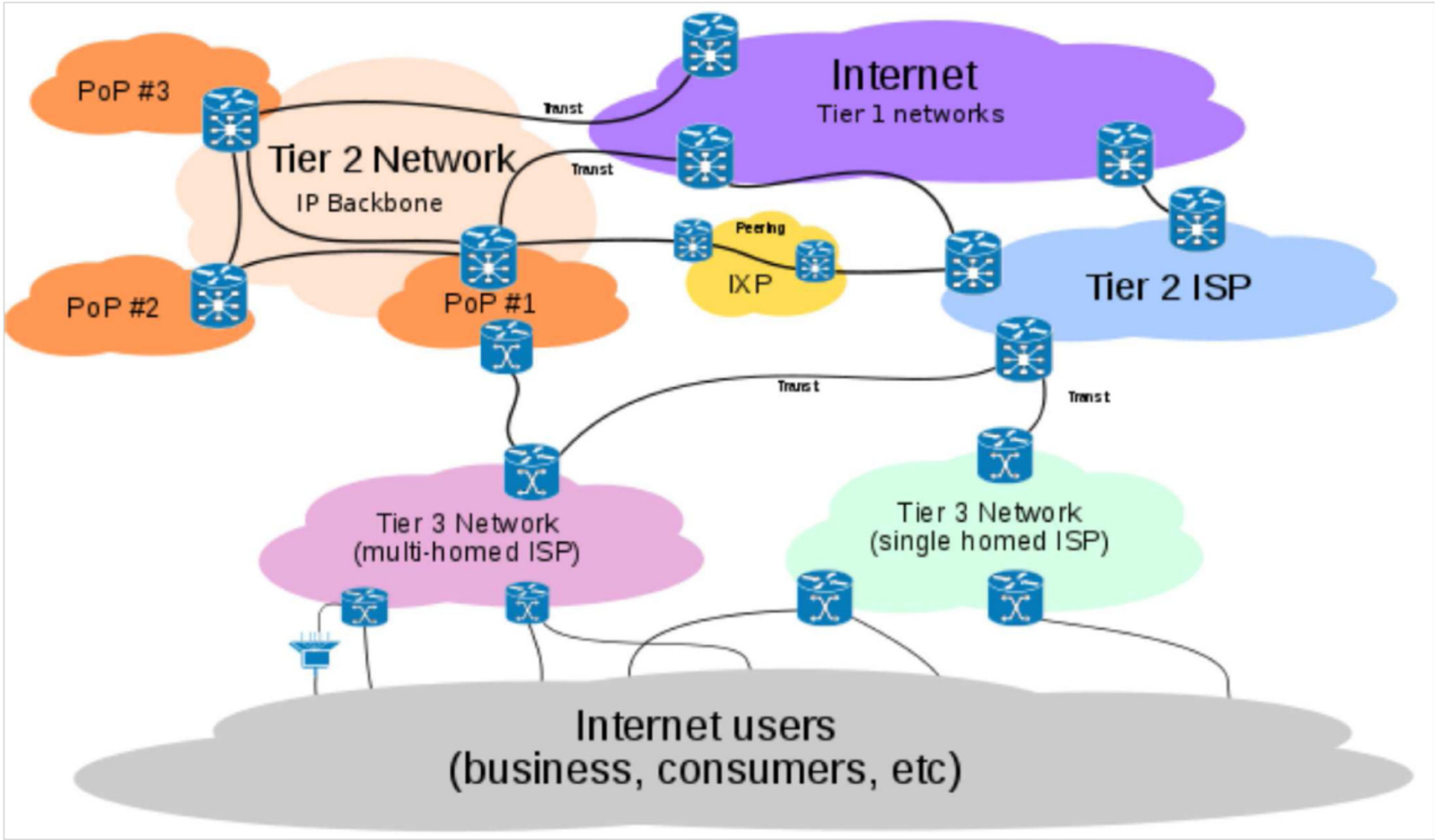


RWA / RSA:

Routing and Wavelength / Spectrum Assignment

Internet Structure: Transit vs. Peering, Tier 1, 2, 3

http://en.wikipedia.org/wiki/Tier_1_carrier



Transit vs. Peering – Internet Architecture

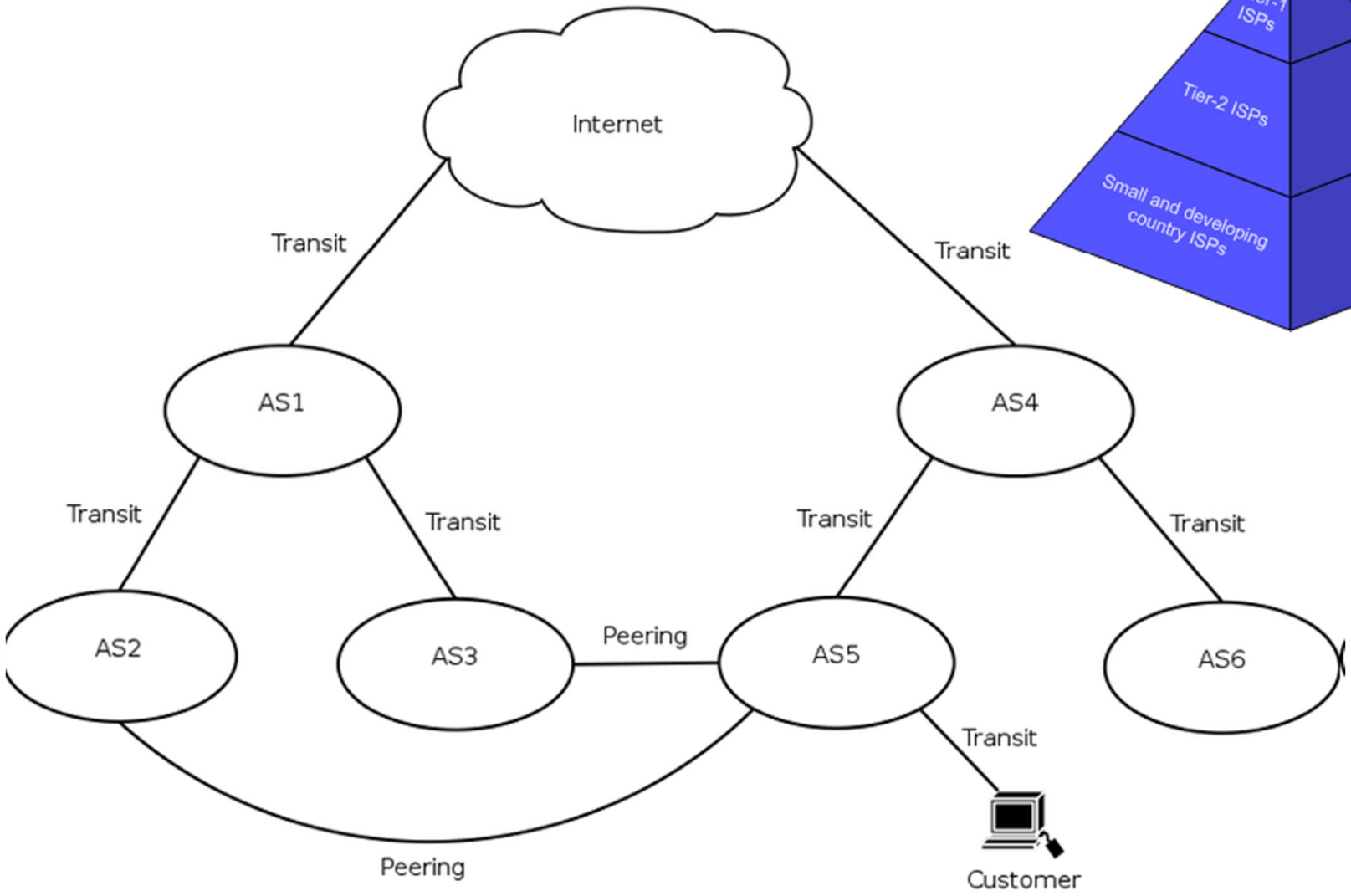
- **Peering** is voluntary interconnection of administratively separate Internet networks for the purpose of exchanging traffic between the customers of each network.
  - The pure definition of peering is settlement-free or "sender keeps all" meaning that **neither party pays the other for the exchanged traffic**, instead, each derives revenue from its own customers.
  - Two networks exchange traffic between each other's customers freely, and for mutual benefit.
- **Transit** provider:
  - pay money (or *settlement*) to another network for Internet access (or *transit*)
  - Only ISPs as customer
  - Charge transit fee

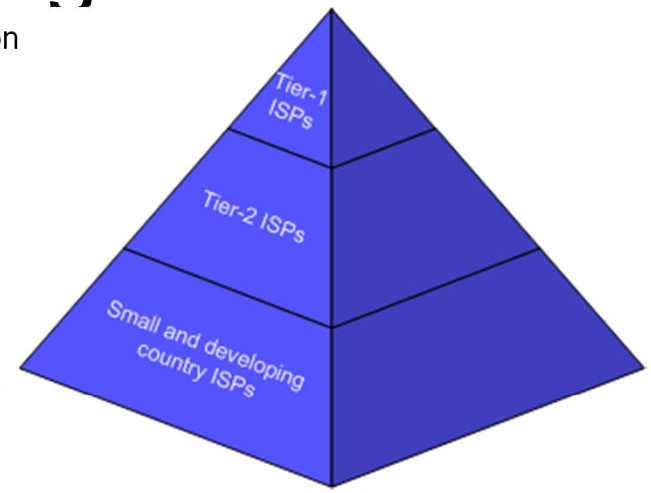
Depeering

- peering is the voluntary and free exchange of traffic between two networks, for mutual benefit.
- If one or both networks believe that there is no longer a mutual benefit, they may decide to cease peering: this is known as **depeering**.
- Some of the reasons why one network may wish to depeer another include:
  - A desire that the other network pay settlement, either in exchange for continued peering or for transit services.
  - A belief that the other network is "profiting unduly" from the settlement free interconnection.
  - Concern over *traffic ratios*, which related to the fair sharing of cost for the interconnection.
  - A desire to peer with the upstream transit provider of the peered network.
  - Abuse of the interconnection by the other party, such as *pointing default* or utilizing the peer for transit.
  - Instability of the peered network, repeated routing leaks, lack of response to network abuse issues, etc.
  - The inability or unwillingness of the peered network to provision additional capacity for peering.
  - The belief that the peered network is unduly peering with your customers.
  - Various external political factors (including personal conflicts between individuals at each network).

Transit vs Peering

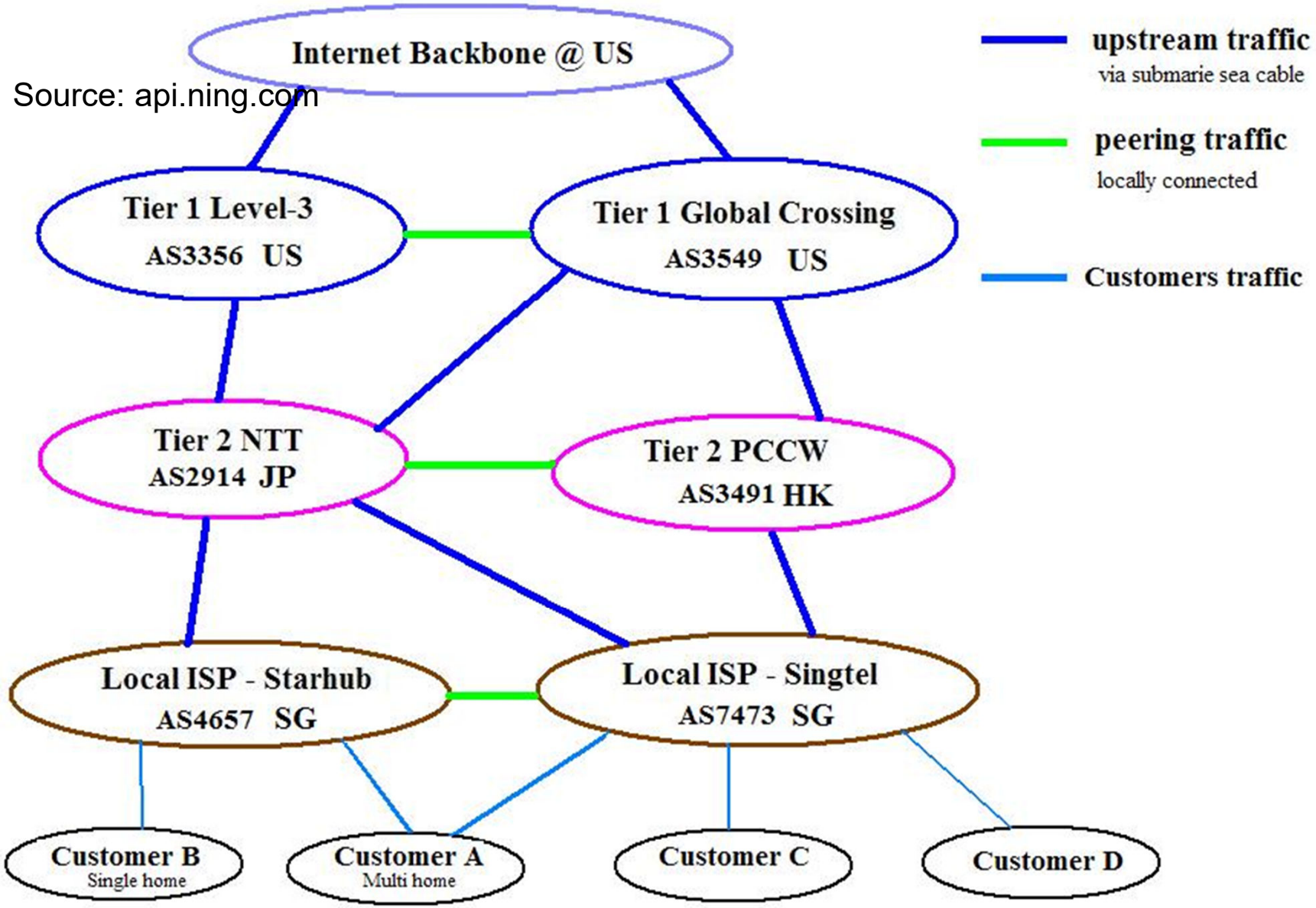
(http://upload.wikimedia.org/wikipedia/commons/thumb/2/2e/AS-interconnection





Tier 1, 2, 3 ISPs

Source: api.ning.com



ISP hierarchy: Tier 1, Tier 2, Tier 3

- **Tier 1 networks** are those networks that don't pay any other network for transit yet still can reach all networks connected to the Internet.
  - A Tier 1 is constantly faced with customers trying to bypass it, and this is a threat to its business. (de-peering).

  (http://arstechnica.com/old/content/2008/09/peering-and-transit.ars/4)

- A **Tier 2 Network** is an Internet service provider who engages in the practice of peering with other networks, but who still purchases IP transit to reach some portion of the Internet.

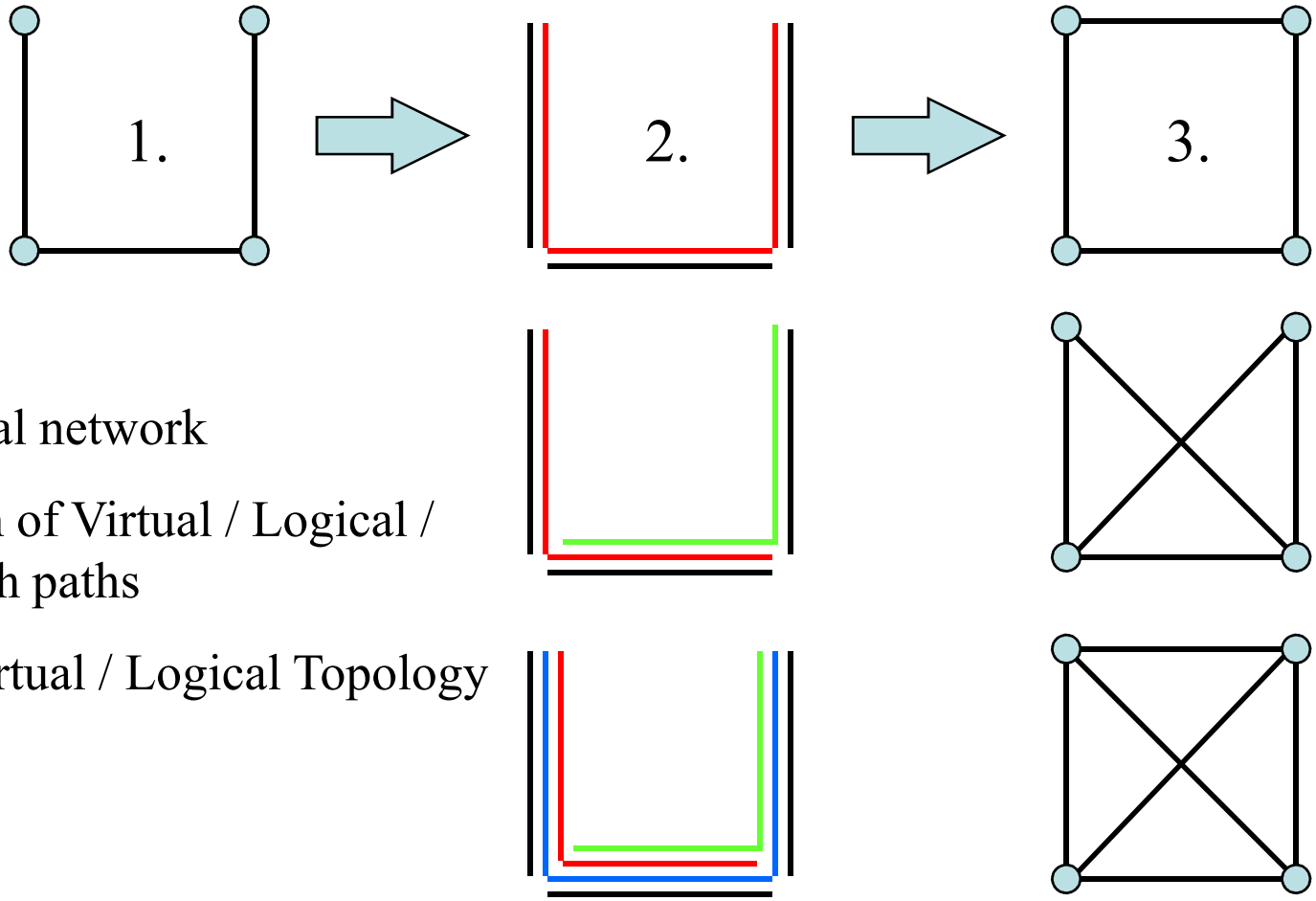
- **Tier 3** is sometimes also used to describe networks who solely purchase IP transit from other networks (typically Tier 2 networks) to reach the Internet. Single or Dual Homing. (de-peering)
- Nice maps at: http://www.nthelp.com/maps.htm

ISP hierarchy: Tier 1, Tier 2, Tier 3

- Tier 1 networks usually have only a small number of peers (typically only other Tier 1s and very large Tier 2s), while Tier 2 networks are motivated to peer with many other Tier 2 and end-user networks. Thus a Tier 2 network with good peering is frequently much "closer" to most end users or content than a Tier 1.
- By definition, there are networks which Tier 1 networks have only one path to, and if they lose that path, they have no "backup transit" which would preserve their full connectivity.
- Some Tier 2 networks are significantly larger than some Tier 1 networks, and are often able to provide more or better connectivity.
- Only Tier 3 networks (who provide Internet access) are true "resellers", while many large Tier 2 networks peer with the majority or even vast majority of the Internet directly except for a small portion of the Internet which is reached via a transit provider.

  (http://en.wikipedia.org/wiki/Tier_1_carrier)

How Optical networks interconnect IP Routers? Virtual Topology made Denser



1. Physical network
2. System of Virtual / Logical / Wavelength paths
3. The Virtual / Logical Topology