Telecommunication Networks and Services

BMEVITMA310 in English

Tibor Cinkler (**5.**) May 5, 2016

Thursday 12:30 – 14:00 (I.B.144)

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

Backbone / Transport Networks

Outline:

1.: PCM/PDH (http://www.hte.hu/ob/2.pdf: 2.1.1.1, 2.1.1.2)

2.: SDH/SONET (http://www.hte.hu/ob/2.pdf: 2.1.1.3)

3.: ATM

4.: MPLS

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

6.: OTN

7.: Optical Networks

6. 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...”

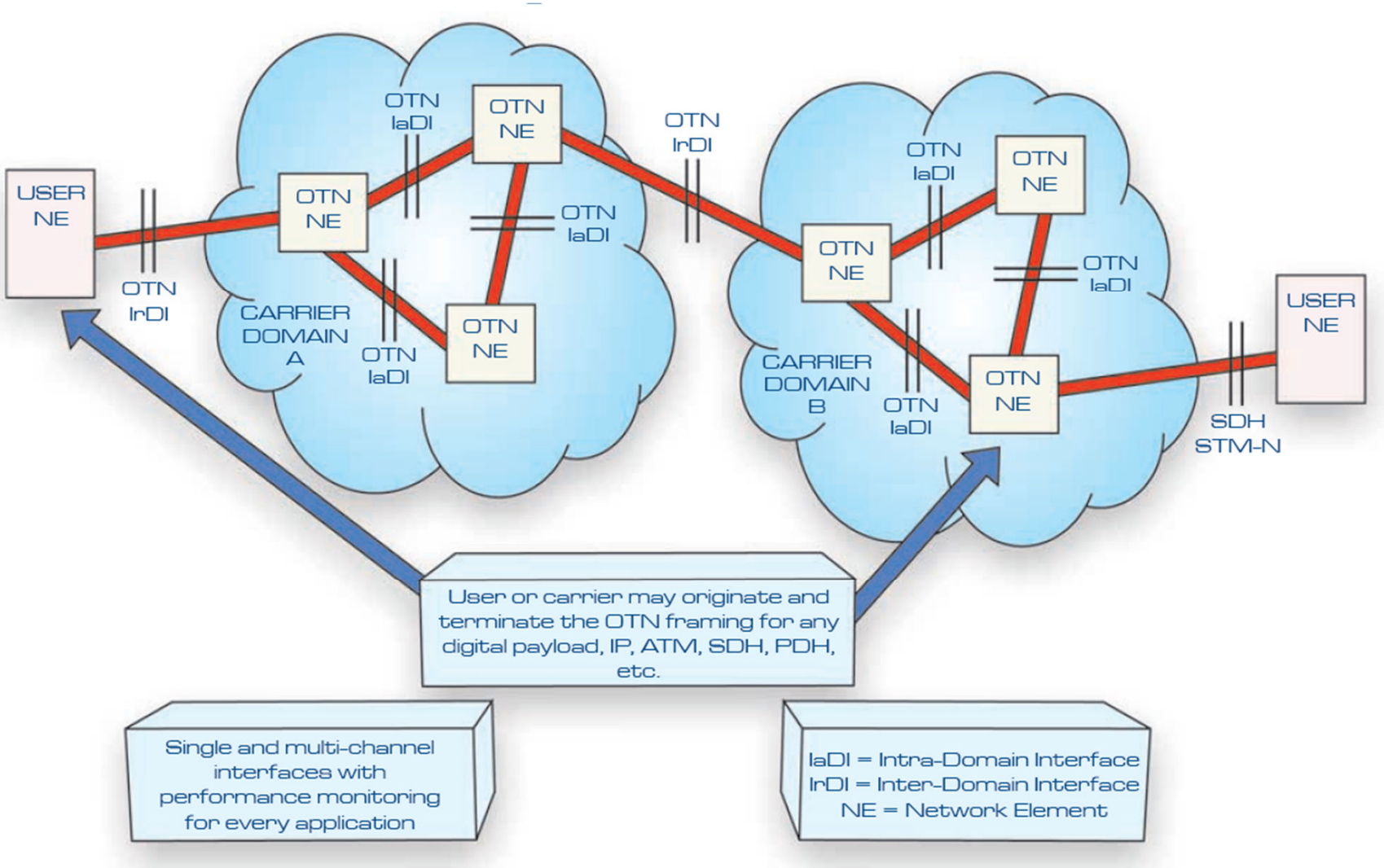
- **ITU-T G.709** (01/03) Interfaces for the **OTN**
- **ITU-T G.798** (5/02) Characteristics of **OTN** Hierarchy Equipment Functional Blocks
- **ITU-T G.872** (10/01) Architecture for the **OTN**
- **ITU-T G.8251** (10/01) The Control of Jitter and Wander within the **OTN**

General: Optical Transport Networks & Technologies (OTNT)

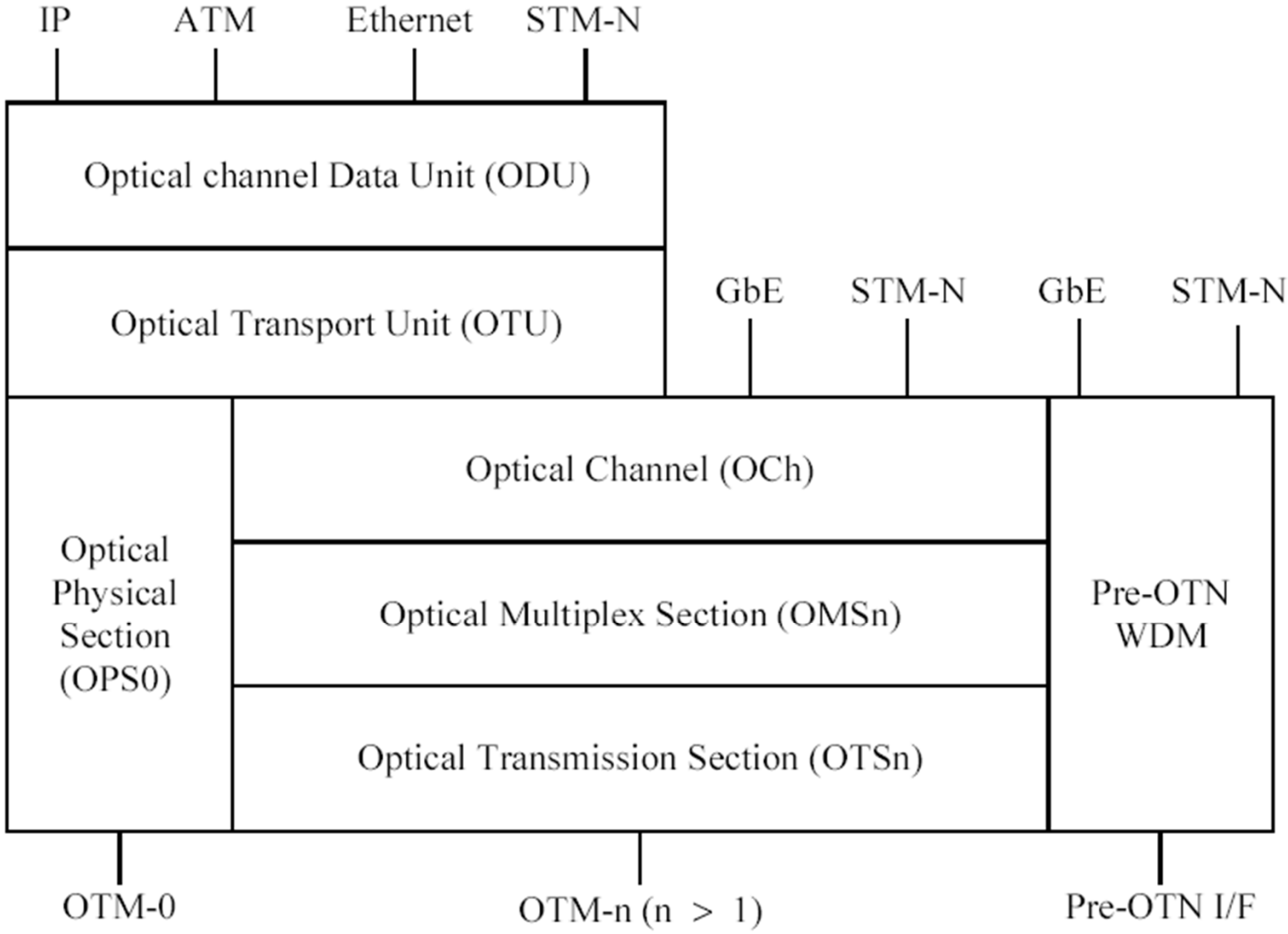
- All network functionality and related technologies that are based on optical transport
- E.g., SDH also falls into this category

Global Optical Transport Network

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



OTN and WDM

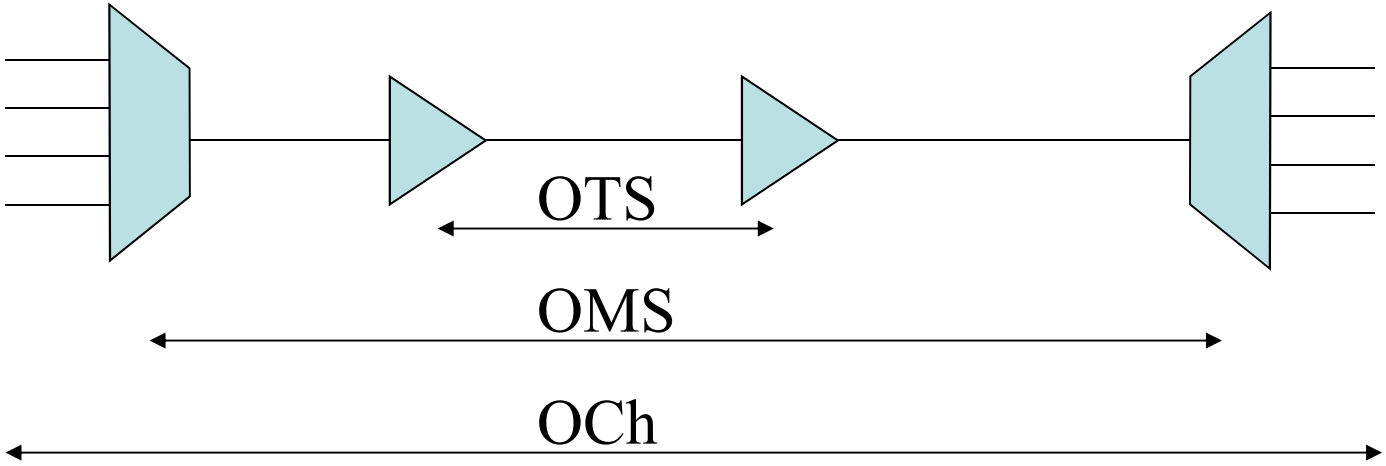


Source: ITU-T G.872: Relationship between OTN and WDM

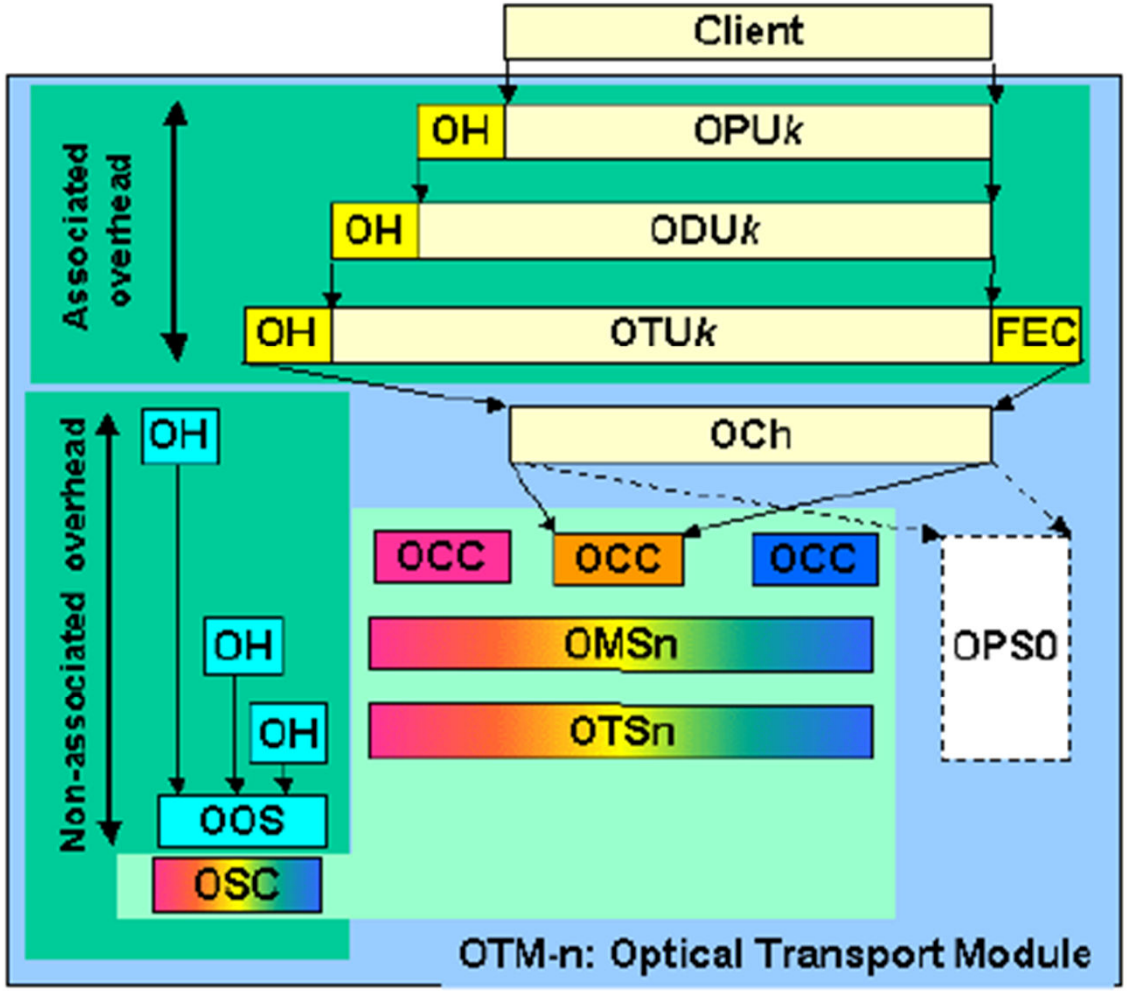
G.709 OTN

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

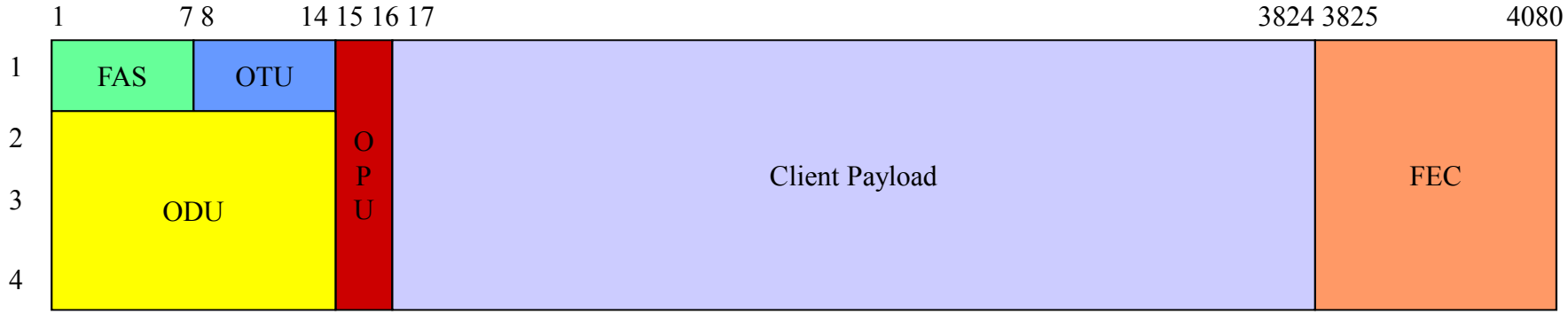
Source: Alcatel

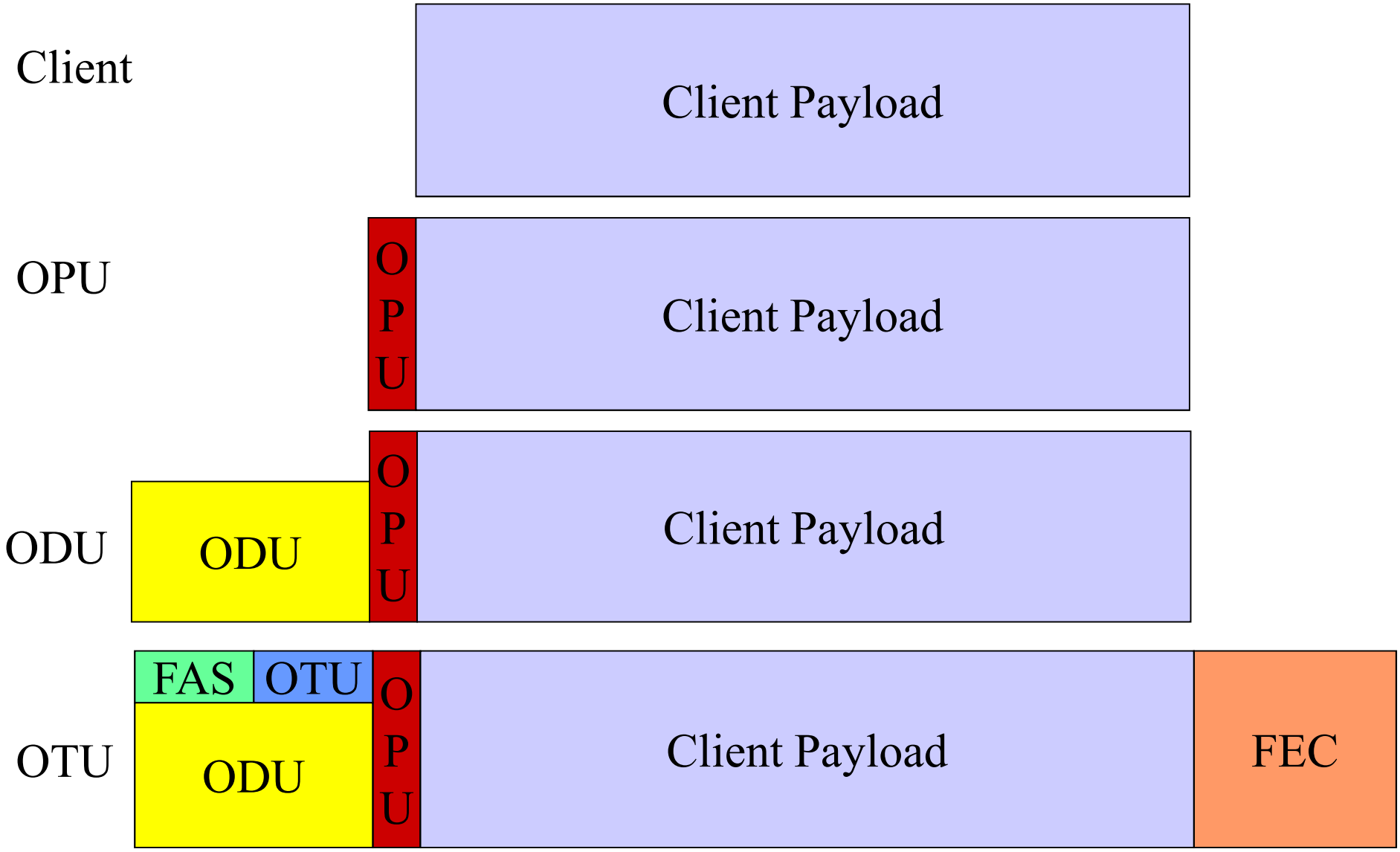
OCh frame

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

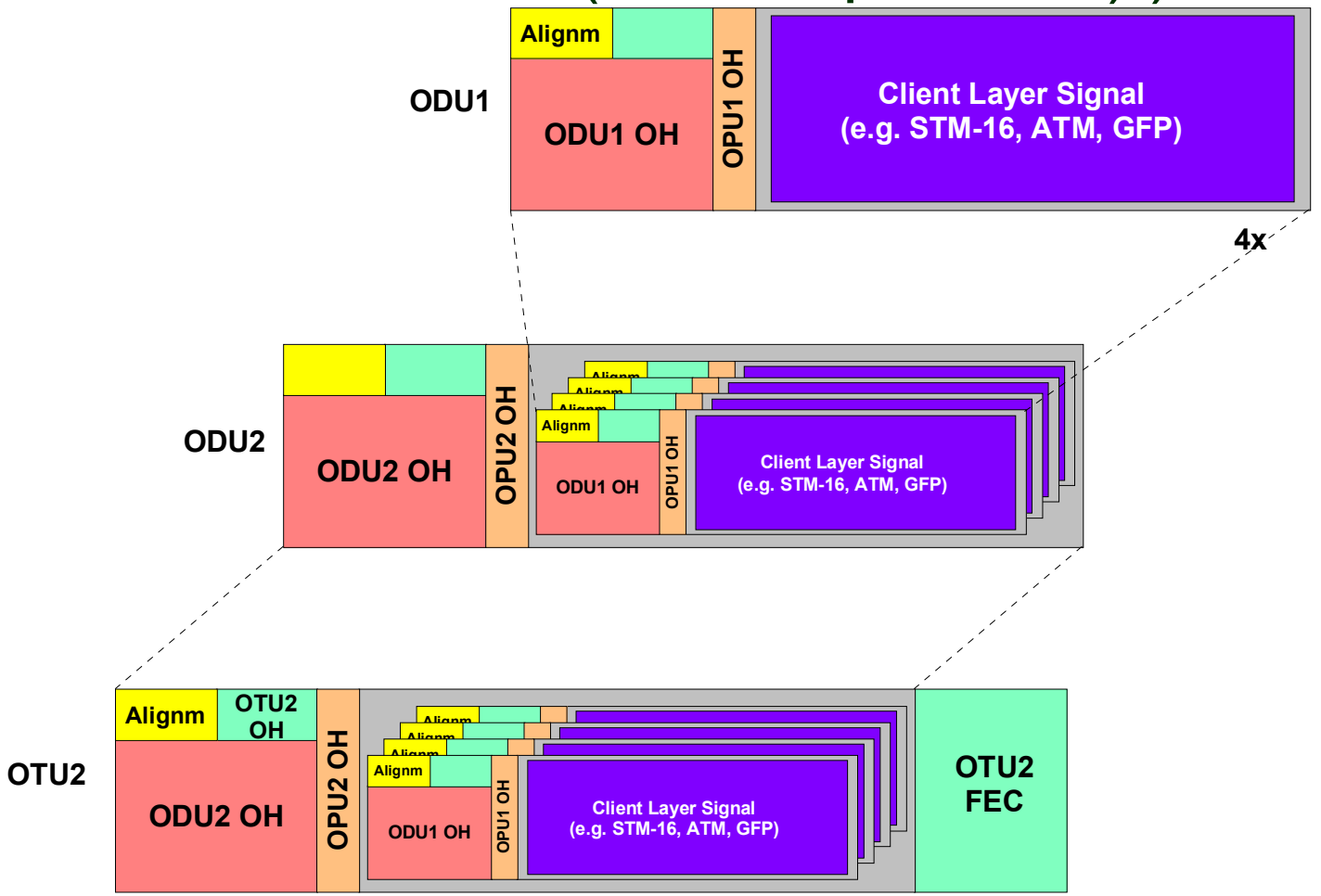
OPU: Optical Channel Payload Unit OH
- PT: Payload Type, e.g.: SDH, ATM, GFP
- vcPT: virtual concatenation PT




Client
Client Payload
OPU
OPU
Client Payload
ODU
ODU
OPU
Client Payload
OTU
FAS
OTU
ODU
OPU
Client Payload
FEC

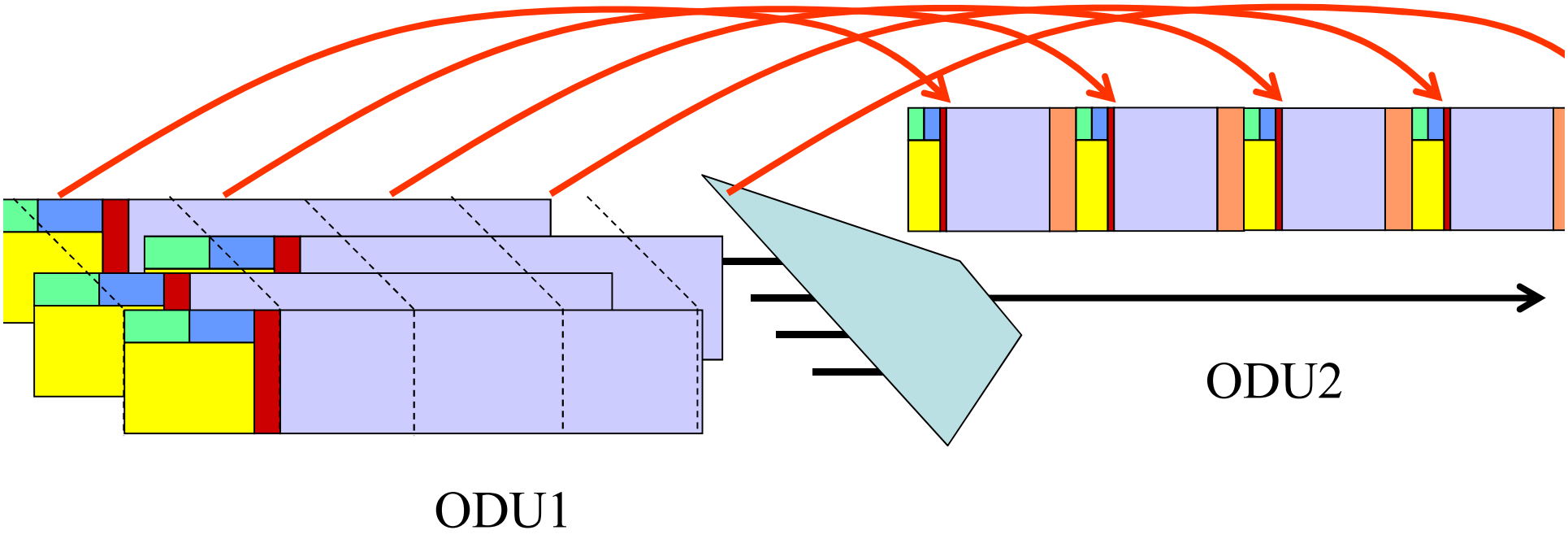
4*ODU1 → ODU2 mux

(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.

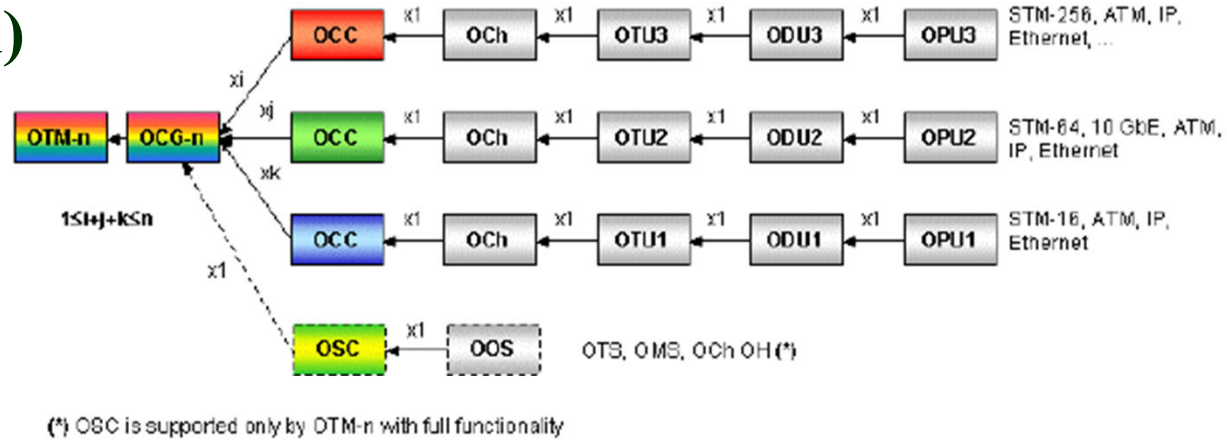
Multiplexing 4 ODU1 signals into an ODU2 (engineer impression)

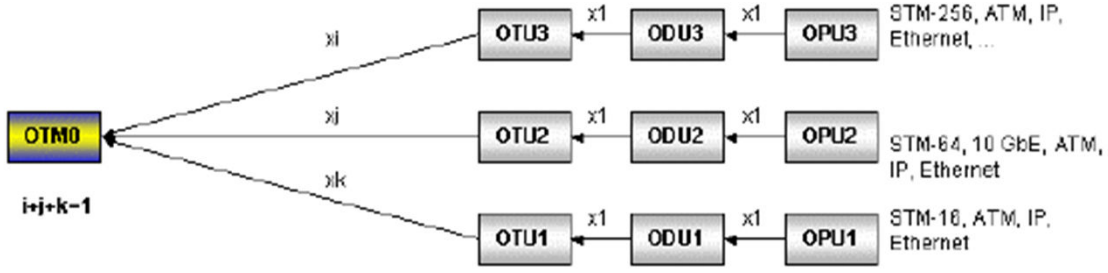


Multiplexing Structure

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)

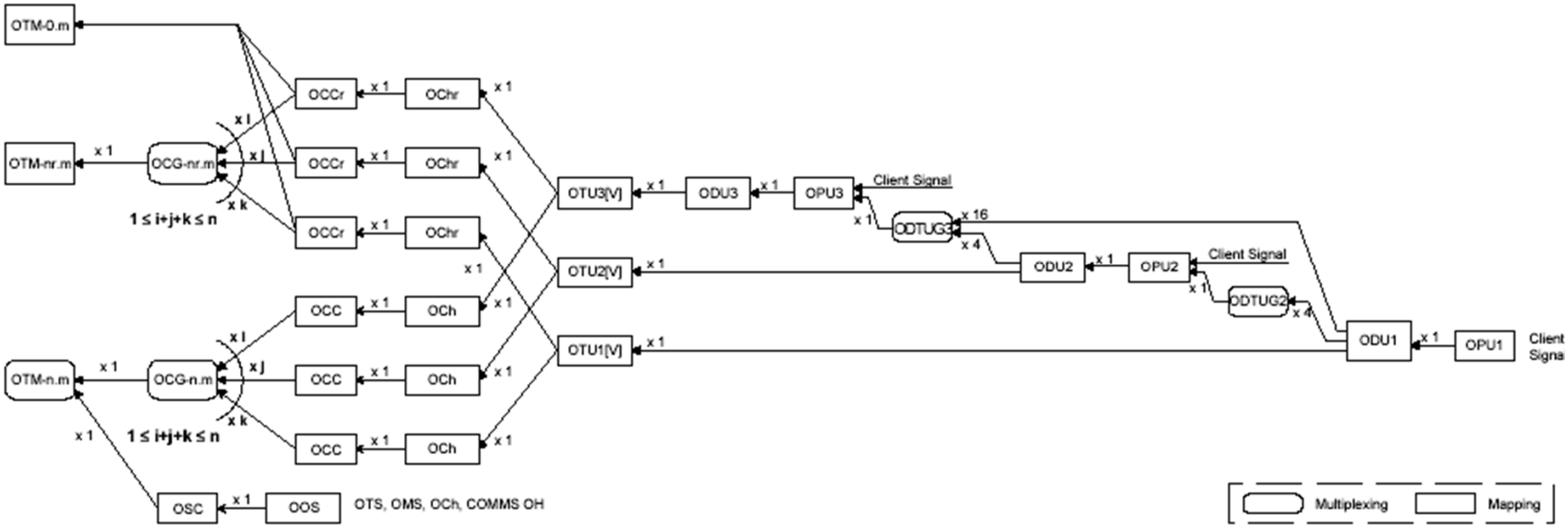
OTM-5.12:
5λ, 2.5 or 10 Gbit/s





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”

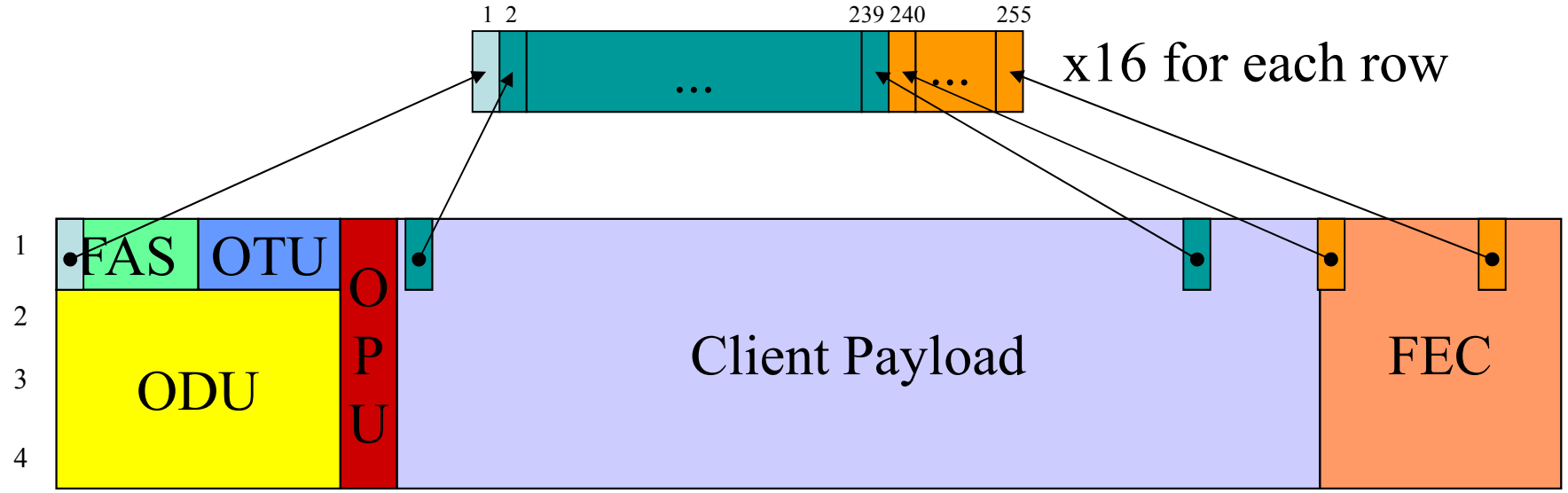
Framing hierarchy	OPU [Gbit/s]	ODU [Gbit/s]	OTU [Gbit/s]	Time [μs]
1	2.488320	239/238 * 2.488320	255/238 * 2.488320	48.971
2	238/237 * 9.953280	239/237 * 9.953280	255/237 * 9.953280	12.191
3	238/236 * 39.813120	239/236 * 39.813120	255/236 * 39.813120	3.035

Tolerance in all cases: ±20ppm

FEC

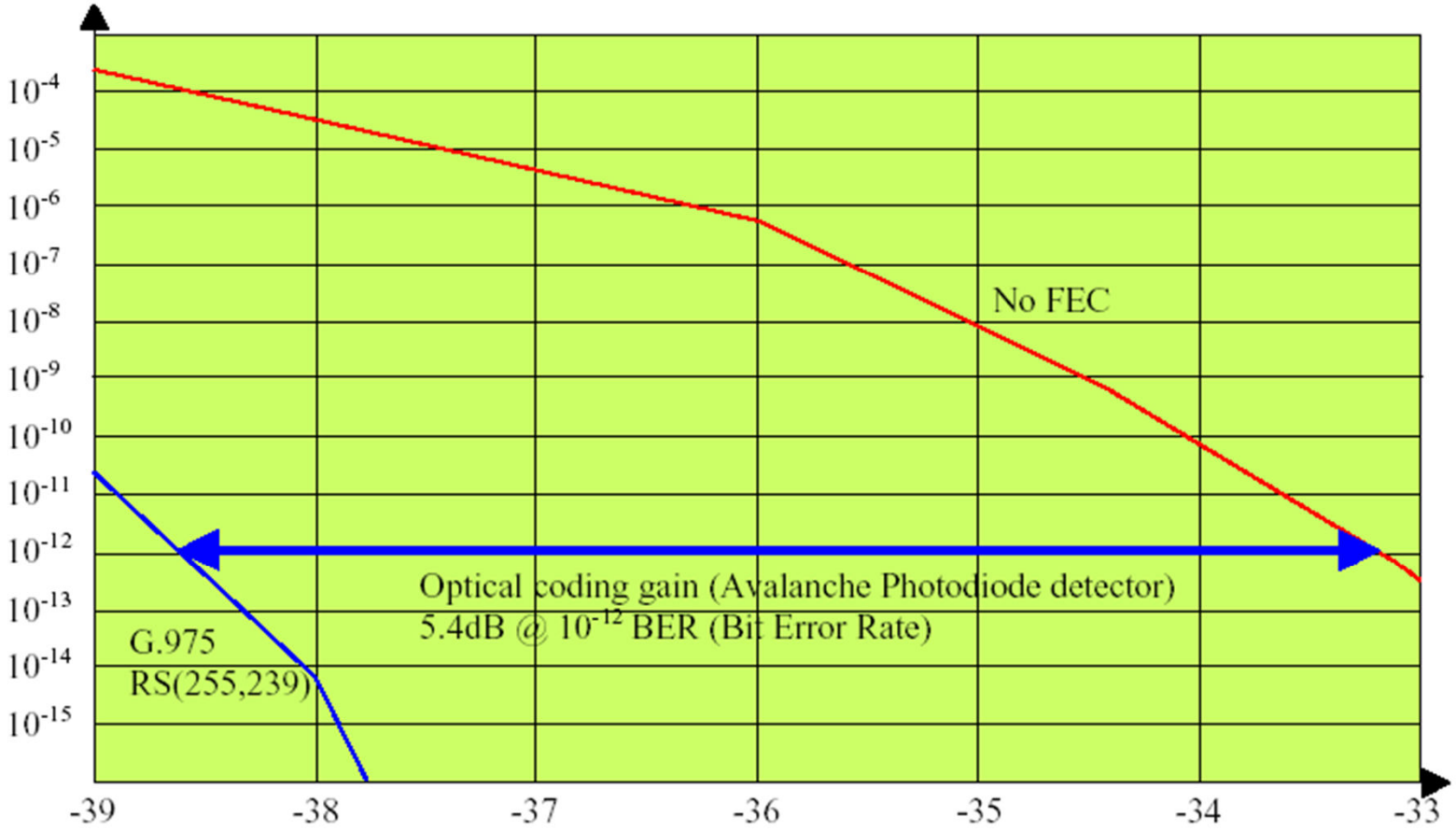
RS (255,239) Reed Solomon code
- Simple
- Significant bit-error correction capability
- Suitable for Block-failures (max 8 bytes)

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 4^{th} 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

Backbone / Transport Networks

Outline:

1.: PCM/PDH (http://www.hte.hu/ob/2.pdf: 2.1.1.1, 2.1.1.2)

2.: SDH/SONET (http://www.hte.hu/ob/2.pdf: 2.1.1.3)

3.: ATM

4.: MPLS

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

6.: OTN

7.: Optical Networks

7. 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?

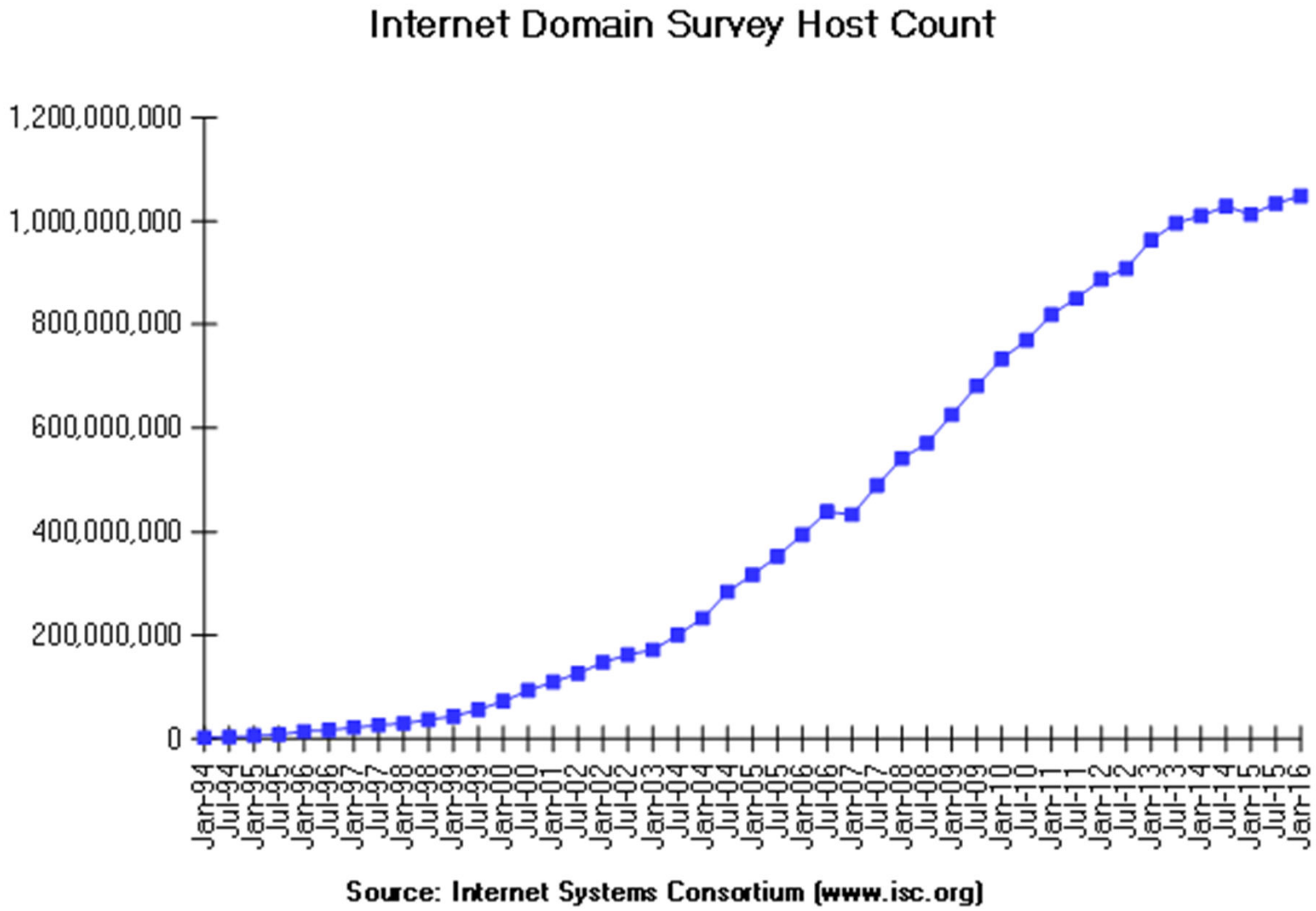
- Not optical transmission links but networks!
- Bandwidth
- Speed (Response time)
- Denser virtual topology (via WDM or fibers)
  - Decreasing the load of IP switches and DXCs ☺
  - More ports ☹
  - Decreasing the delay ☺
  - For IP and Voice

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

www.isc.org

„...counts the number of IP addresses that have been assigned a name”



Telecommunication Networks and Services

BMEVITMA310 in English

Tibor Cinkler (**6.**) May 6, 2016

Thursday 12:00 – 13:30 (I.B.144)

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

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)**

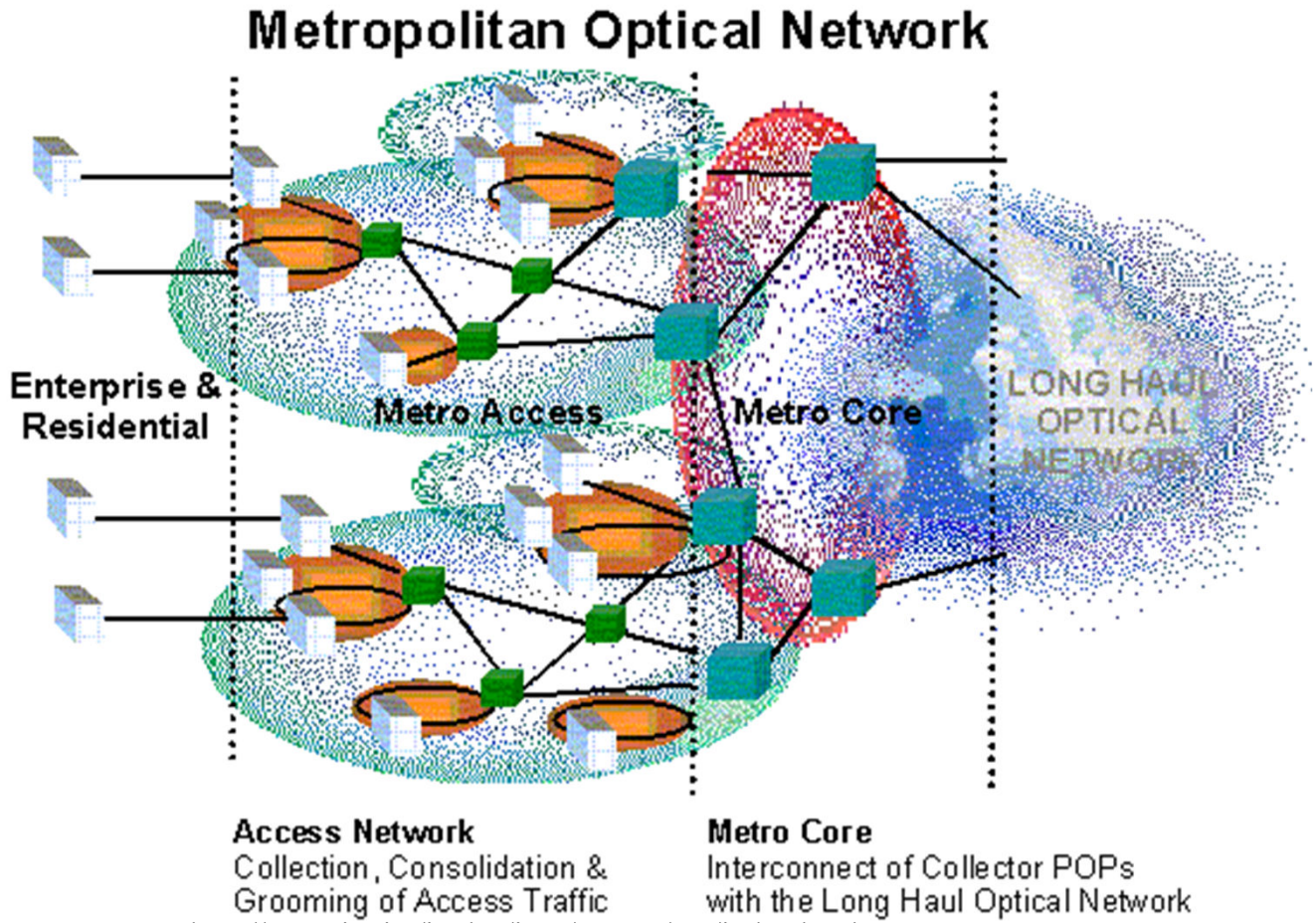
MON-LHON — Positioning

OR:

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

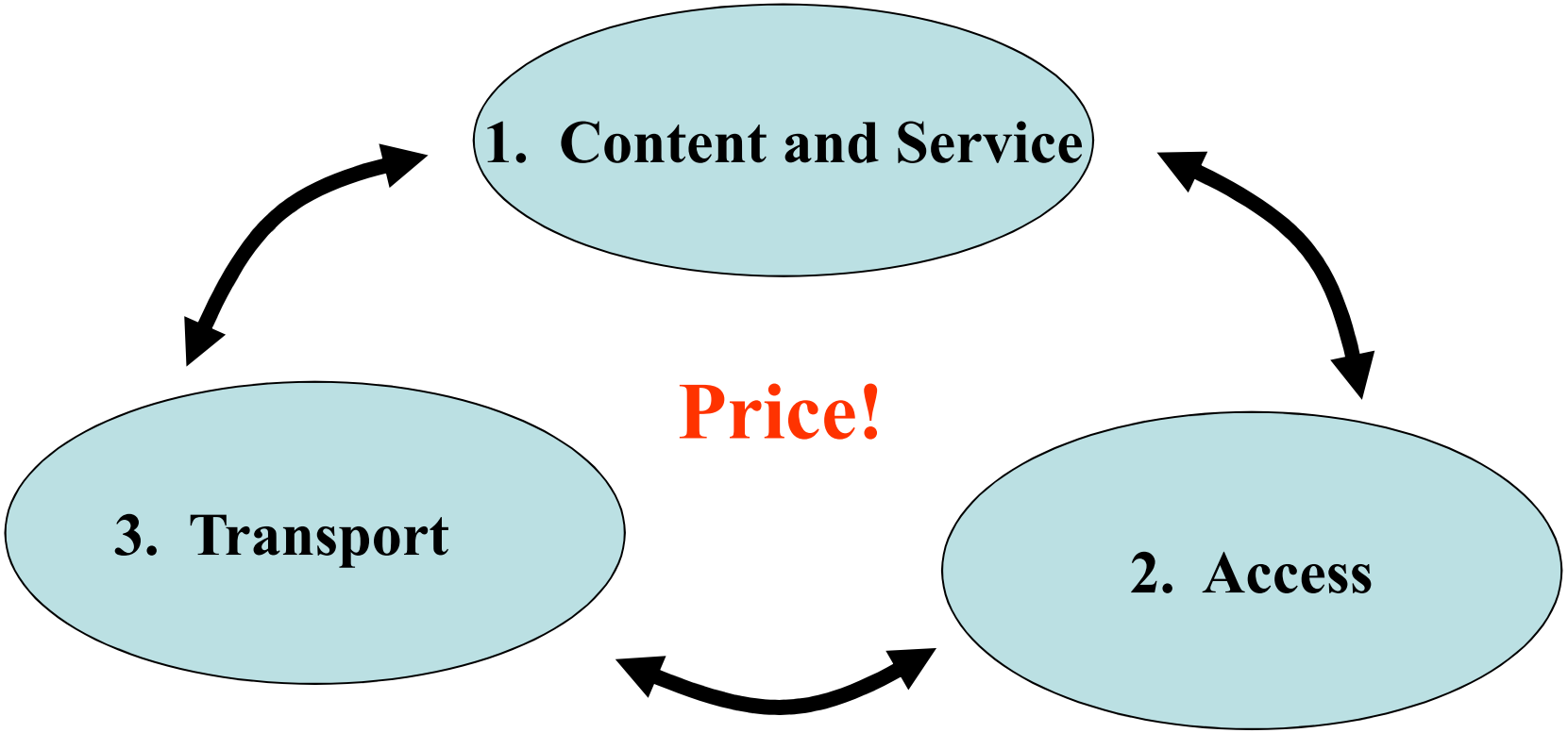
OR:

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



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

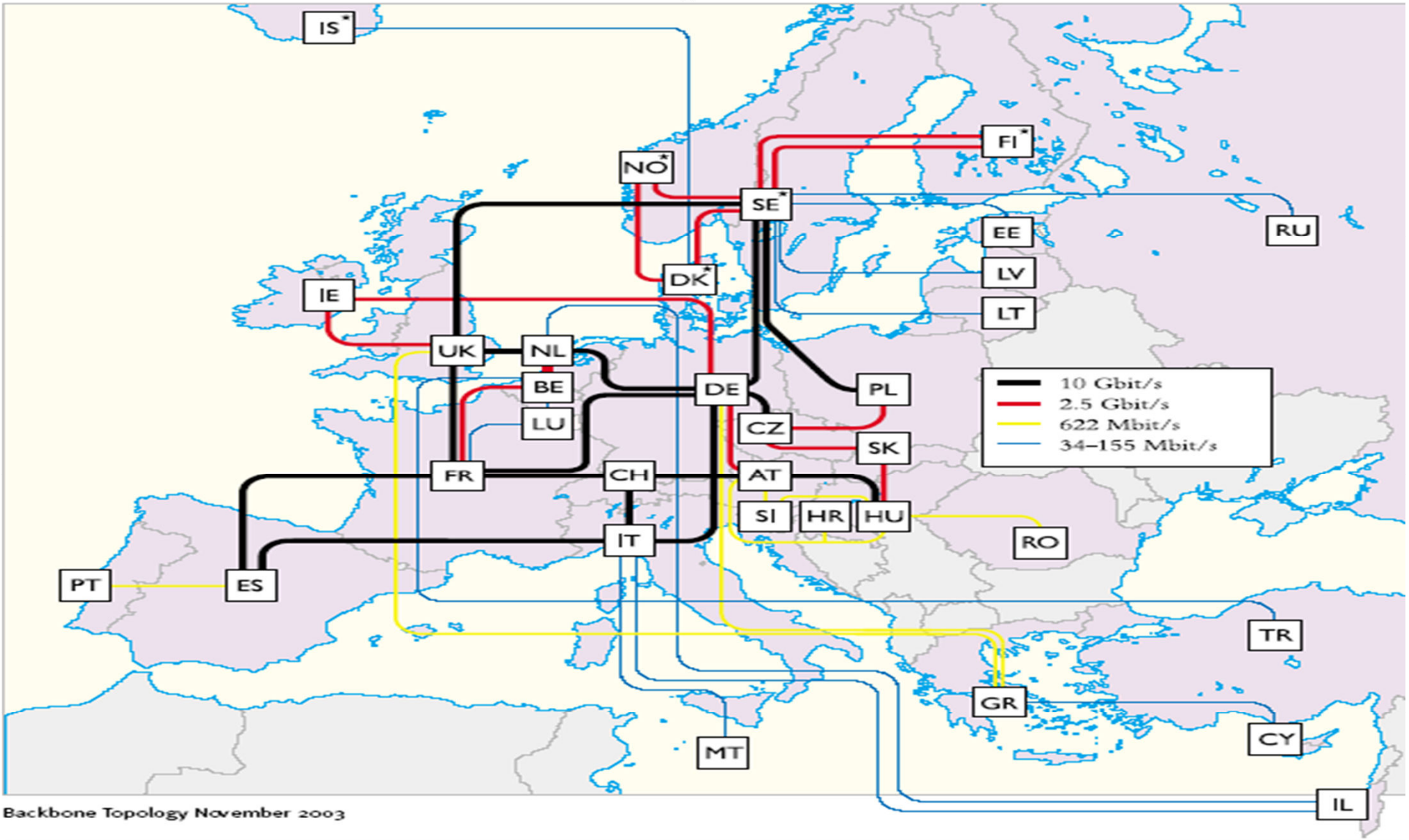
“Circus viciosus”



Network Architectures

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

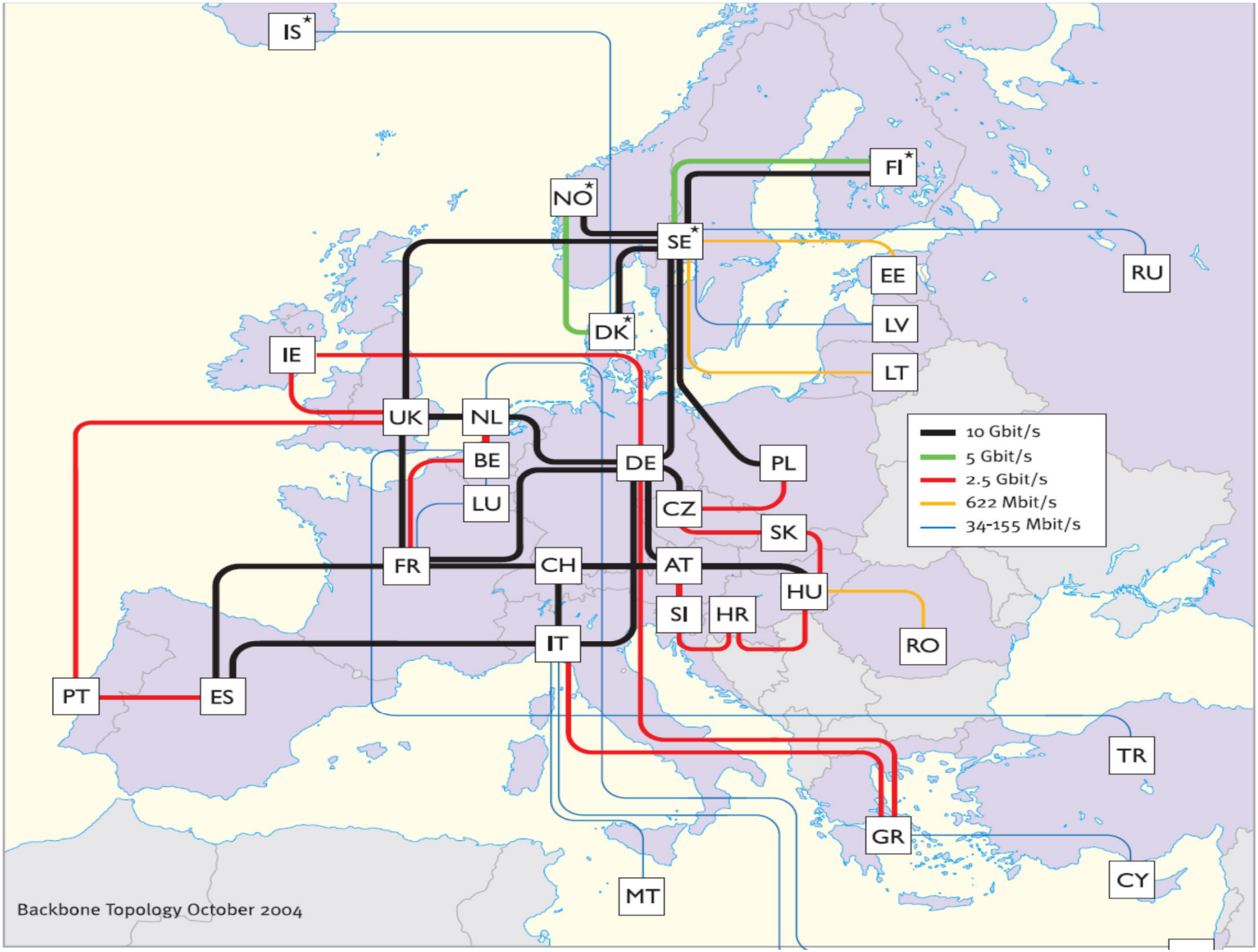
Geant Europan network

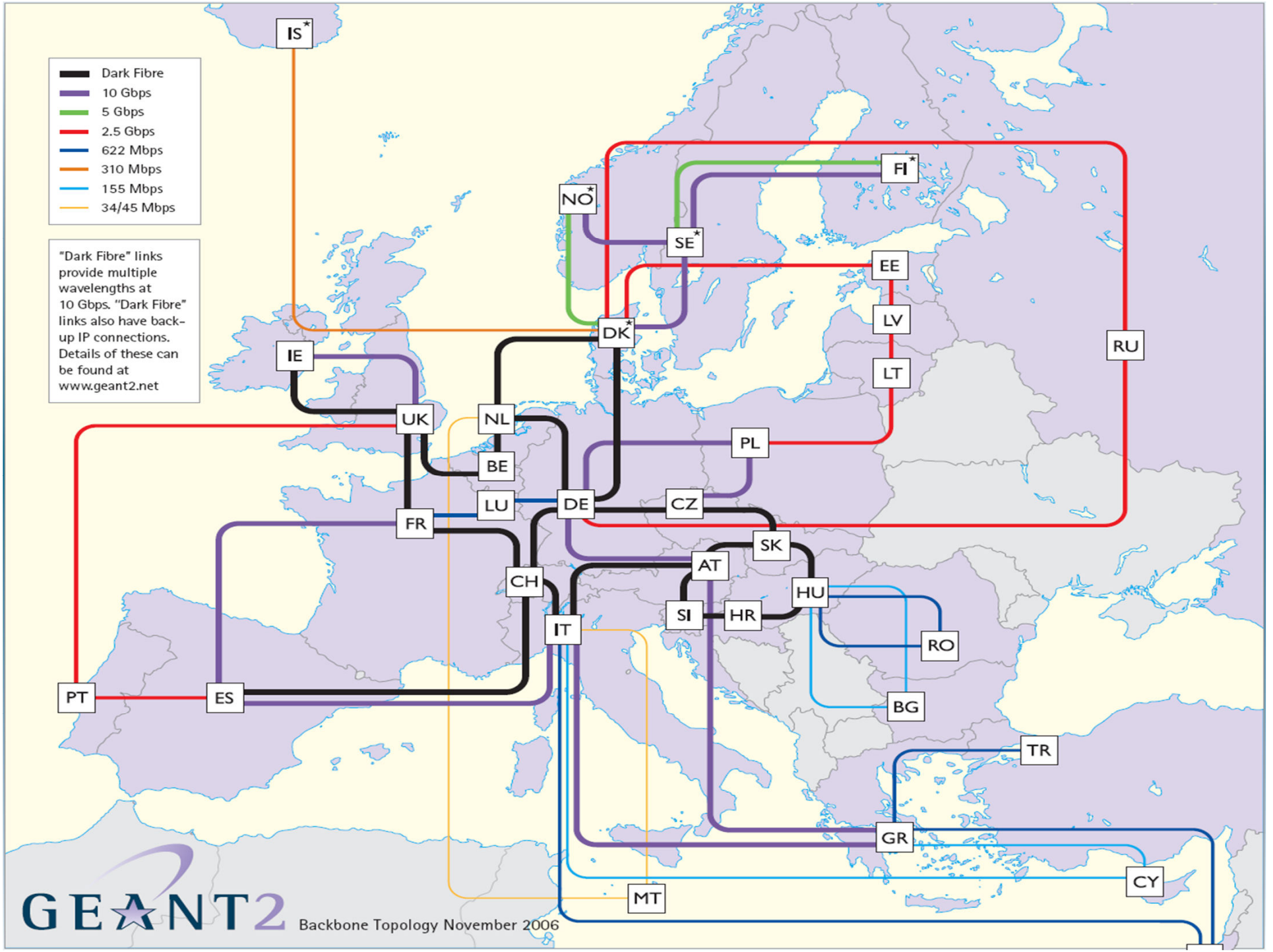


Backbone Topology November 2003

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

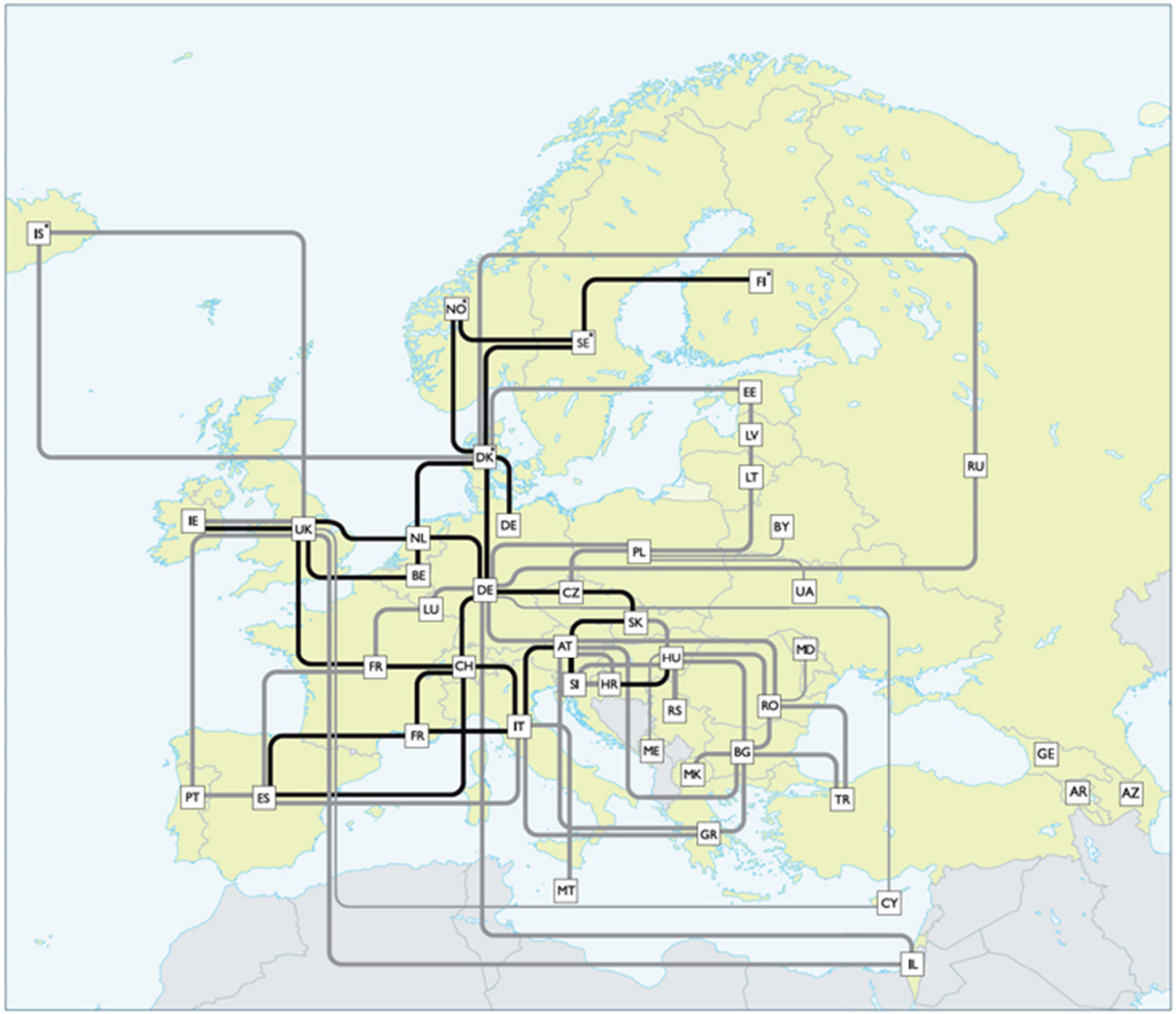
*Connections between these countries are part of NORDUnet (the Nordic regional network)


IS*
NO*
SE*
FI*
RU
EE
LV
LT
DK*
IE
UK
NL
BE
LU
DE
PL
CZ
SK
FR
CH
AT
HU
SI
HR
RO
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
LT
RU
DK*
IE
UK
NL
BE
LU
DE
FR
PL
CZ
SK
AT
CH
HU
SI
HR
IT
RO
BG
PT
ES
TR
GR
CY
MT
GEANT2
Backbone Topology November 2006

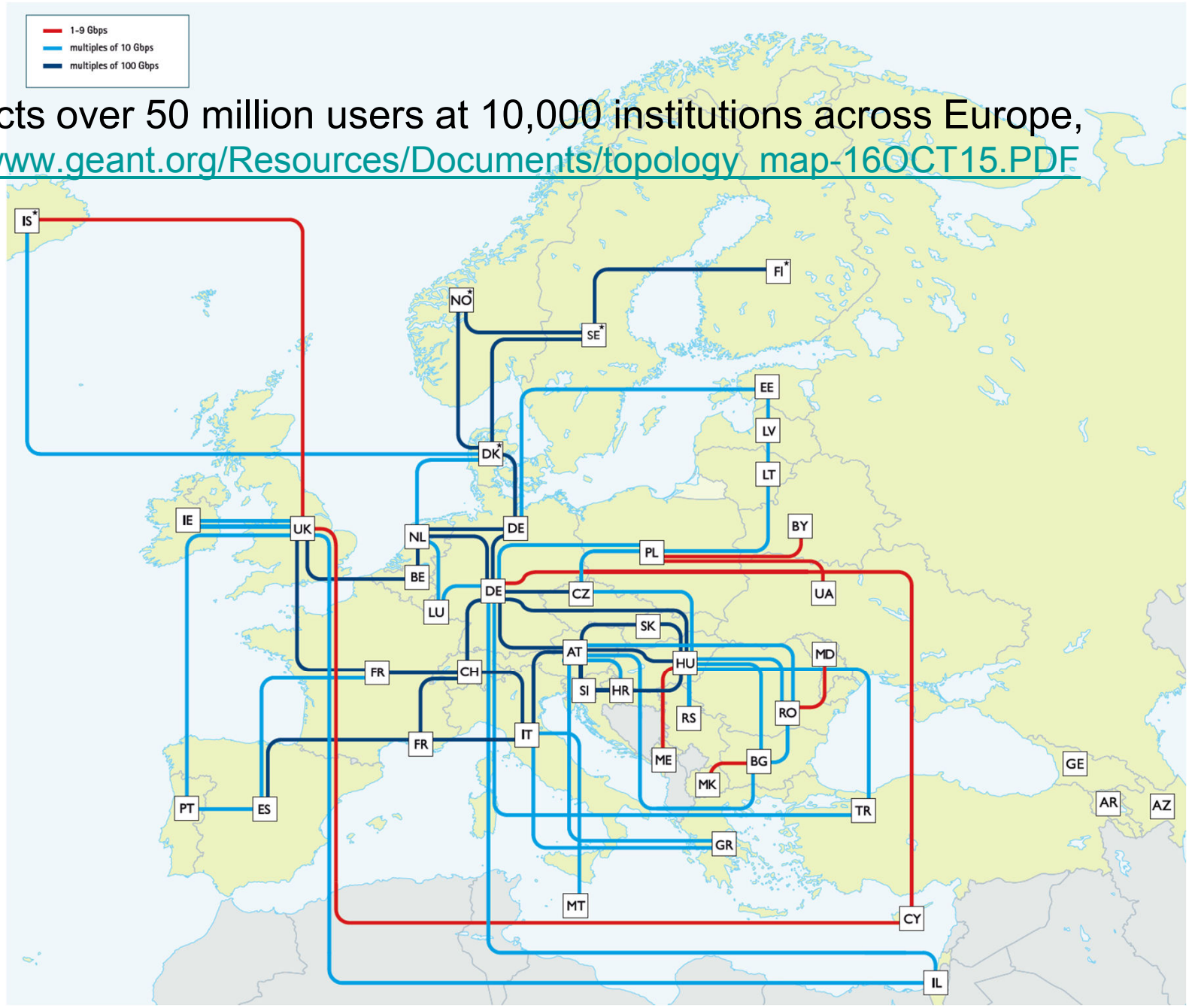
The Pan-European Research and Education Network

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

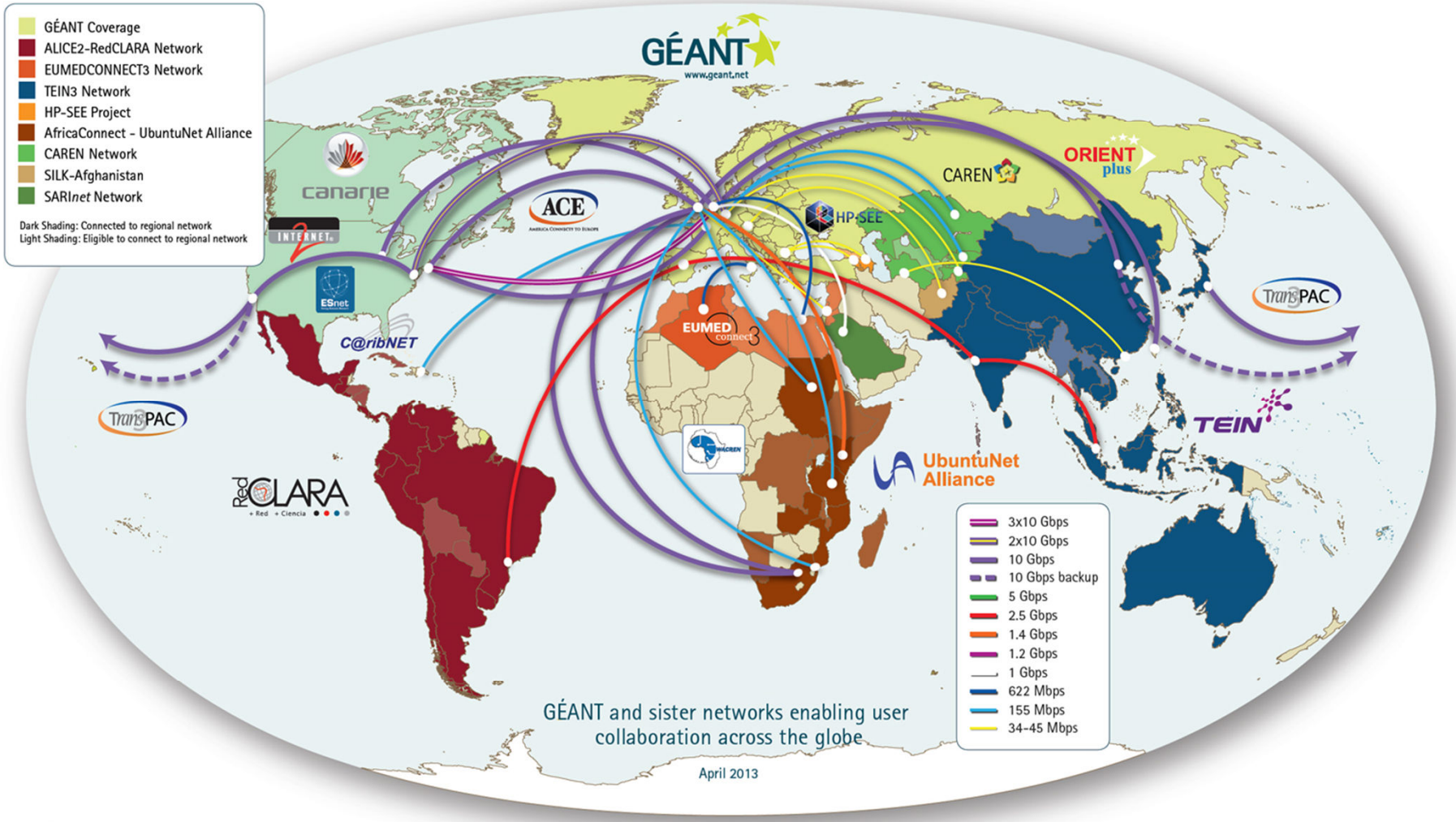


GÉANT connectivity as at September 2013. GÉANT is operated by DANTE on behalf of Europe's NRENs. Black lines indicate dark fibre.

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



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 RtD Framework Programme.
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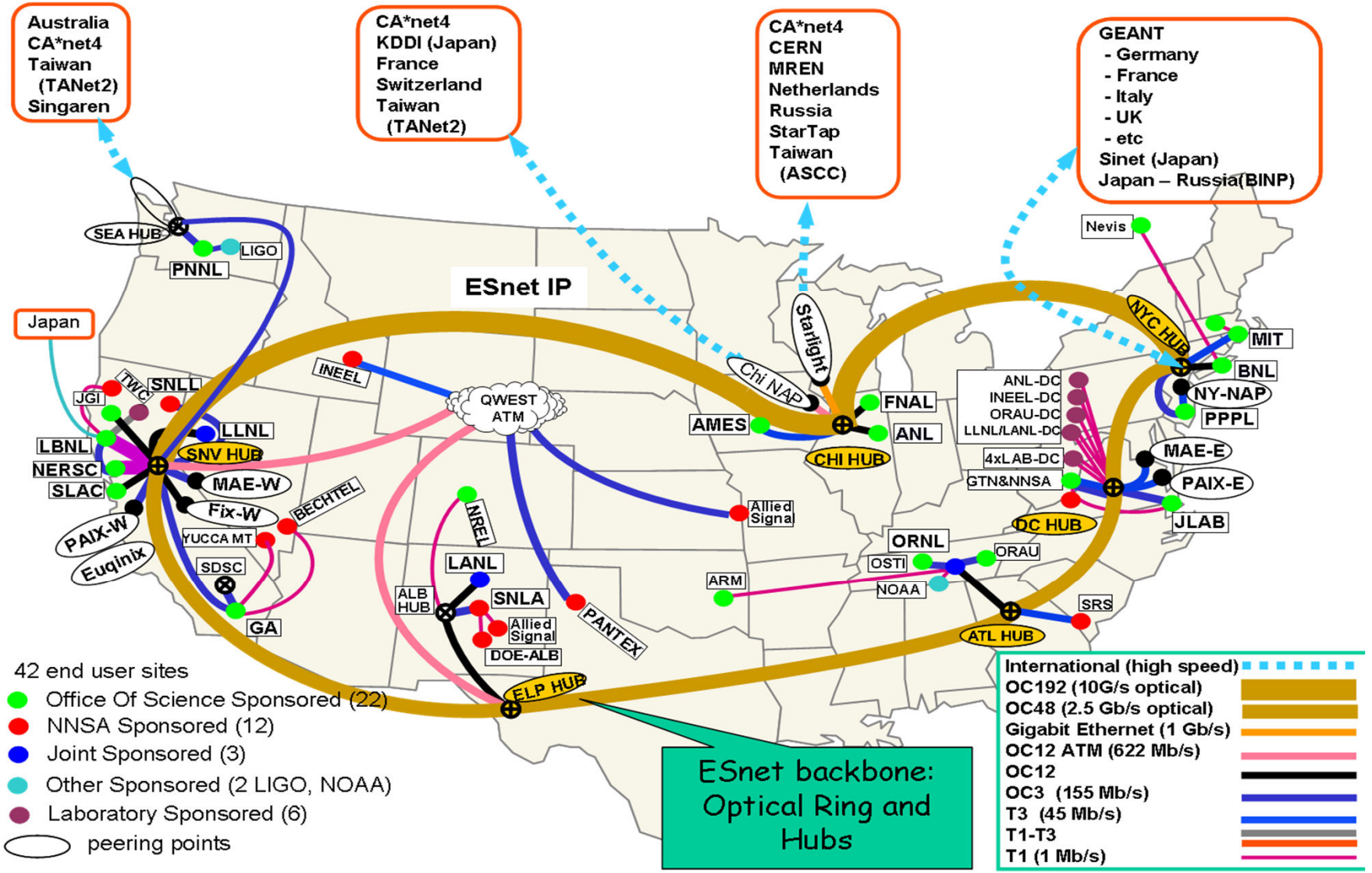
SEVENTH FRAMEWORK PROGRAMME

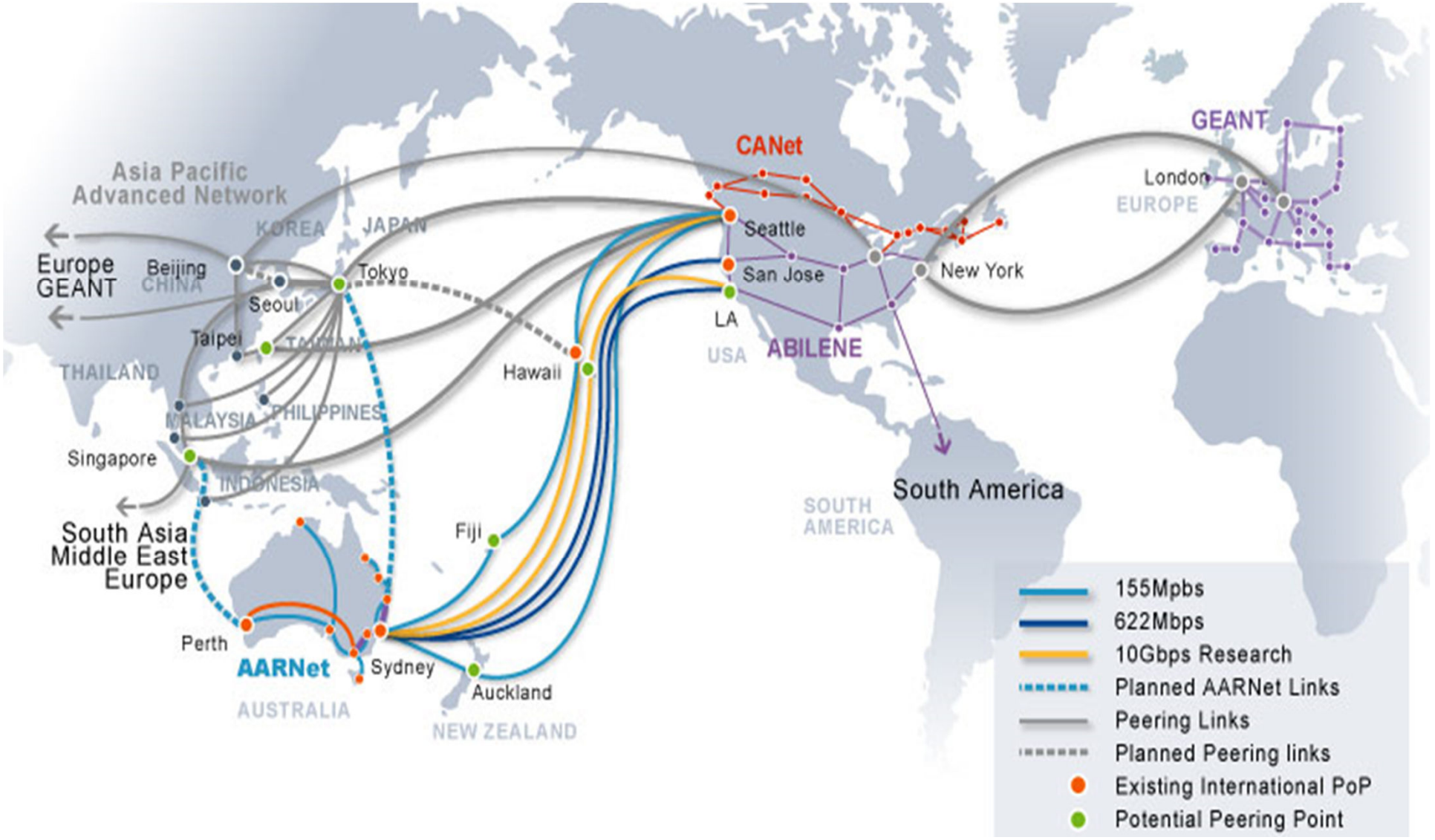
Co-funded by the European Union

ESnet (2003)



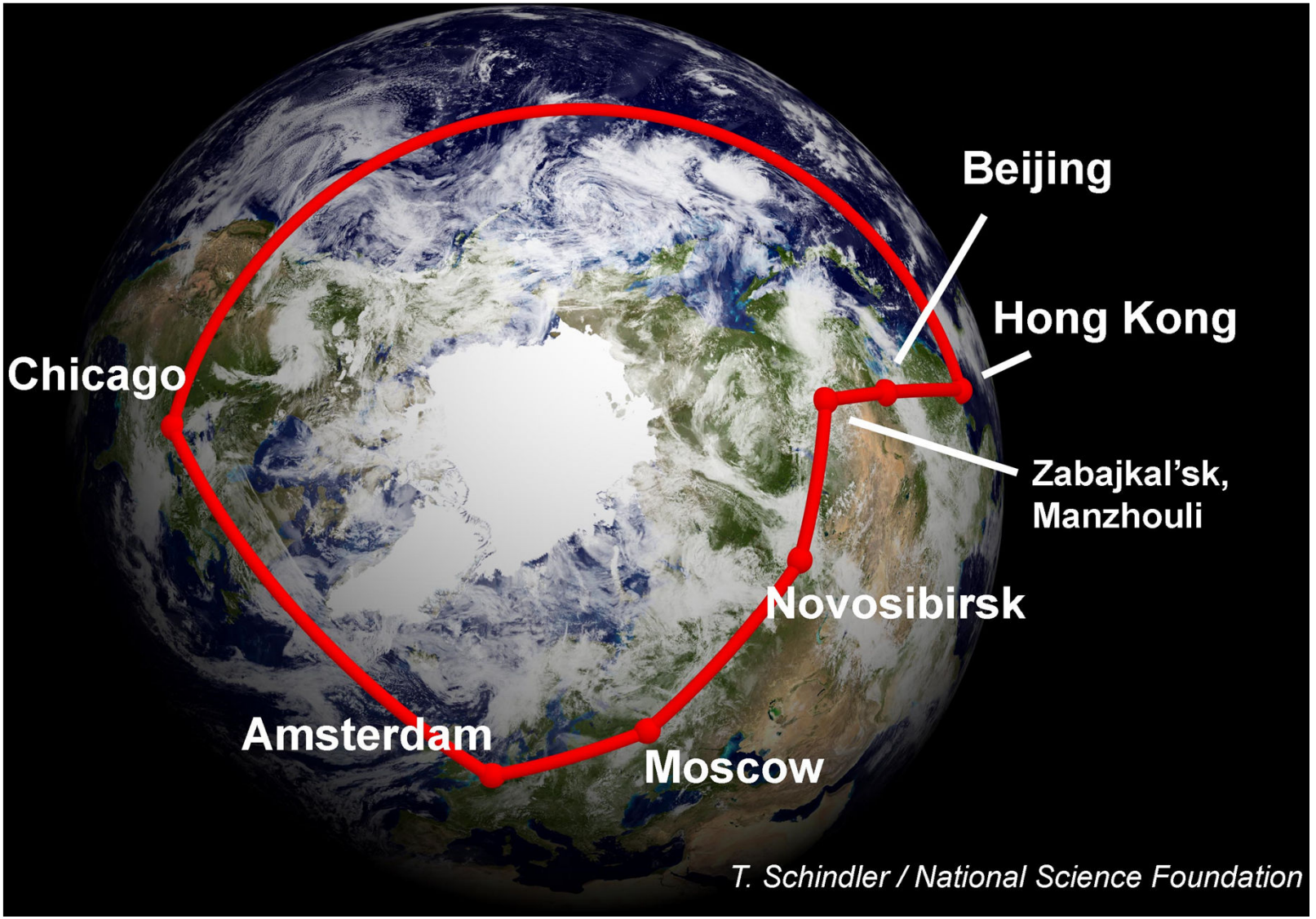
Source: H.B.Newman, GNEW2004

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



GLORIAD: Global Optical Ring

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

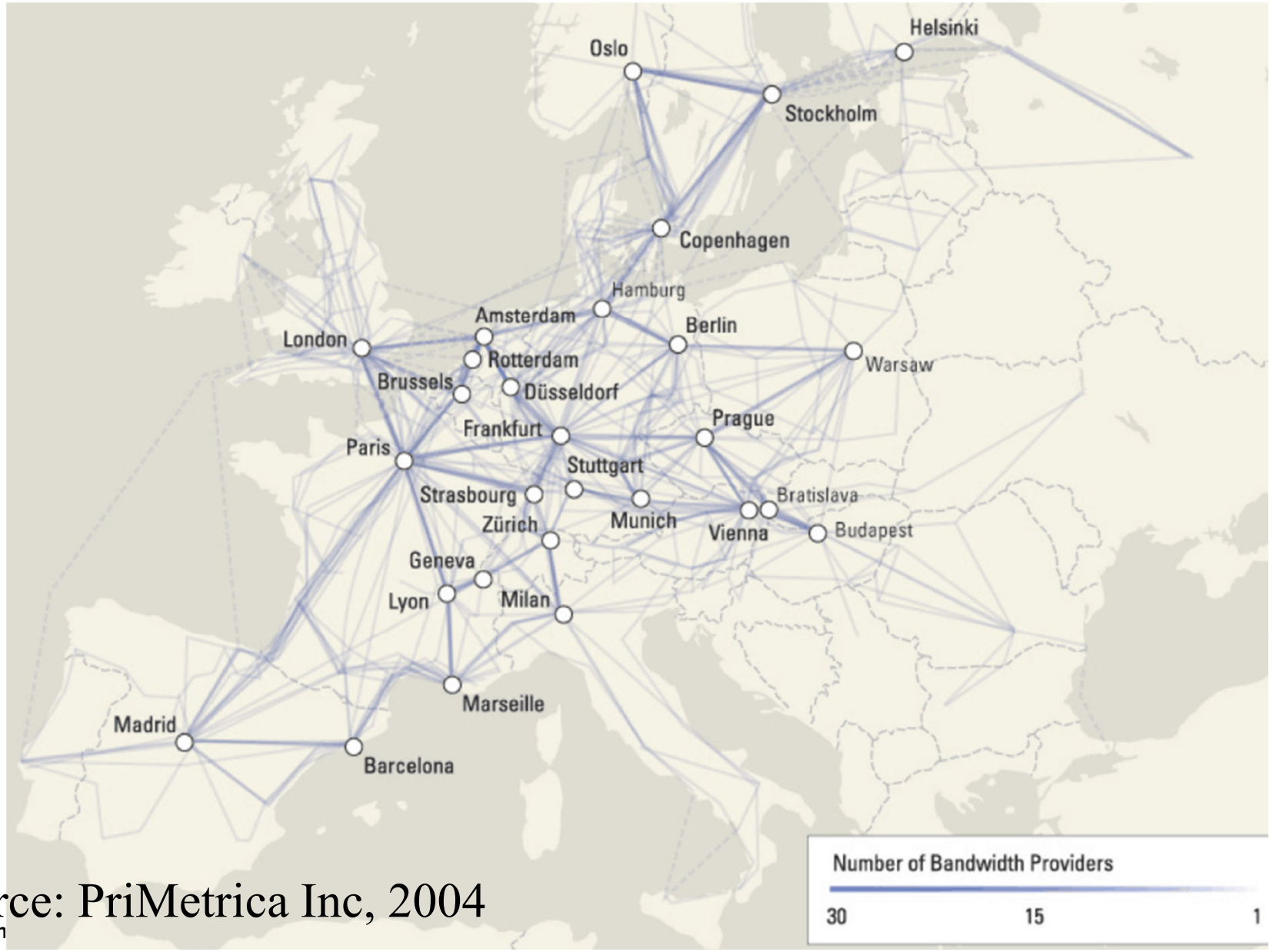


Optical cable systems of Americas

- 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

submarine-cable-map-201x

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

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

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

3 Generations

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

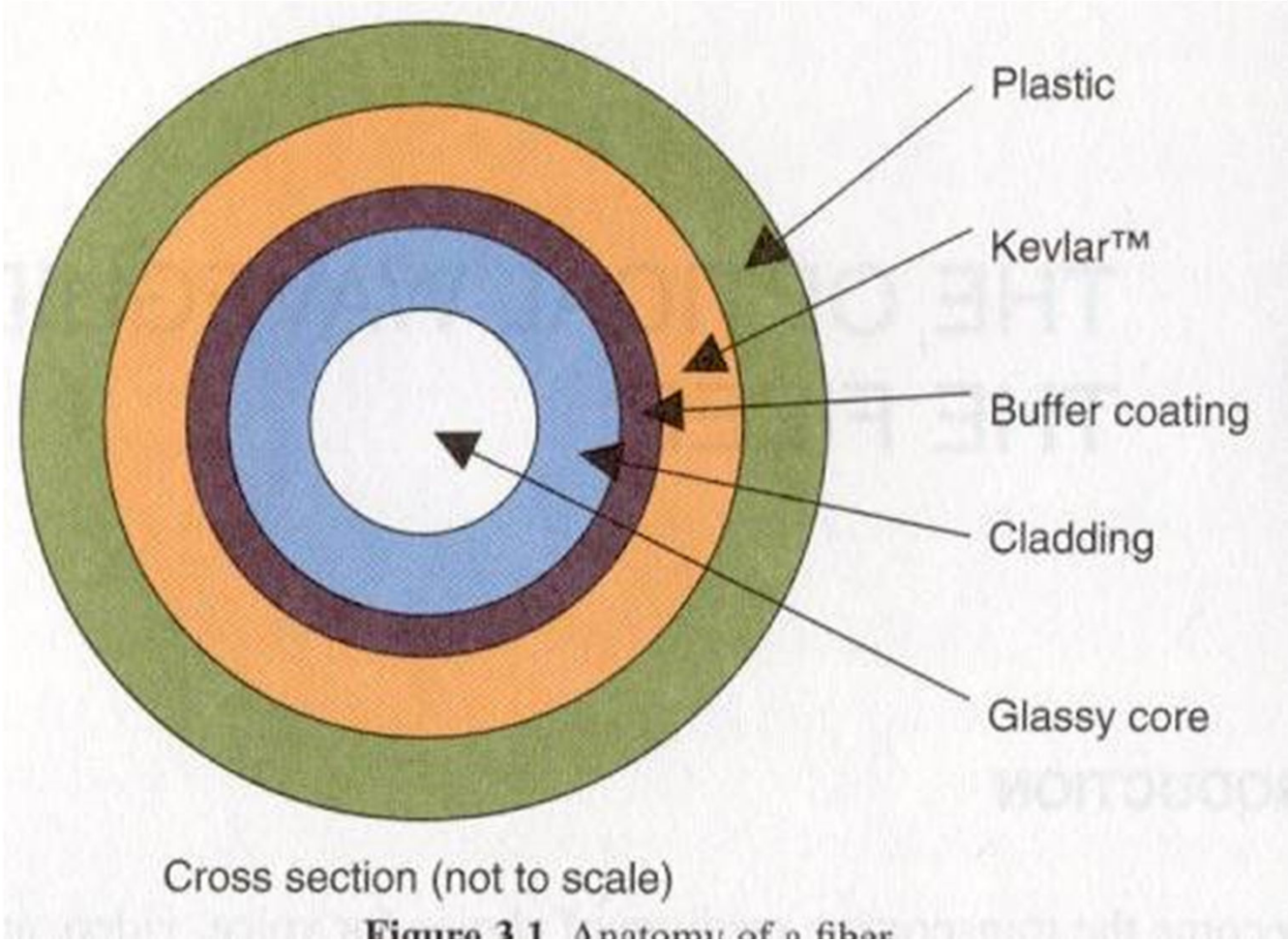
Multiplexing Solutions

- Space (OSDM)
- Wavelength (WDM (CWDM & DWDM))
- Time (OTDM)
- Code (OCDM)
- OOFDM
- NDWDM

Optical Technologies

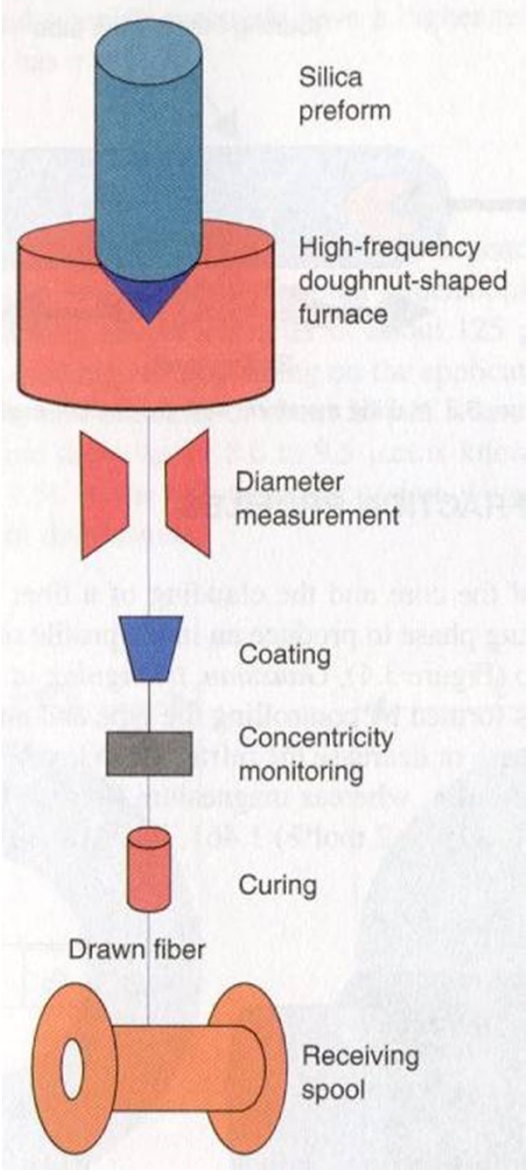
- Fibers
- AWG Arrayed Waveguide Grating
- Transmission Impairments, transmitters, receivers, filters
- Optical Amplifiers

Fiber Anatomy



Source: Shivkumar Kalyanaraman

Fiber Manufacturing



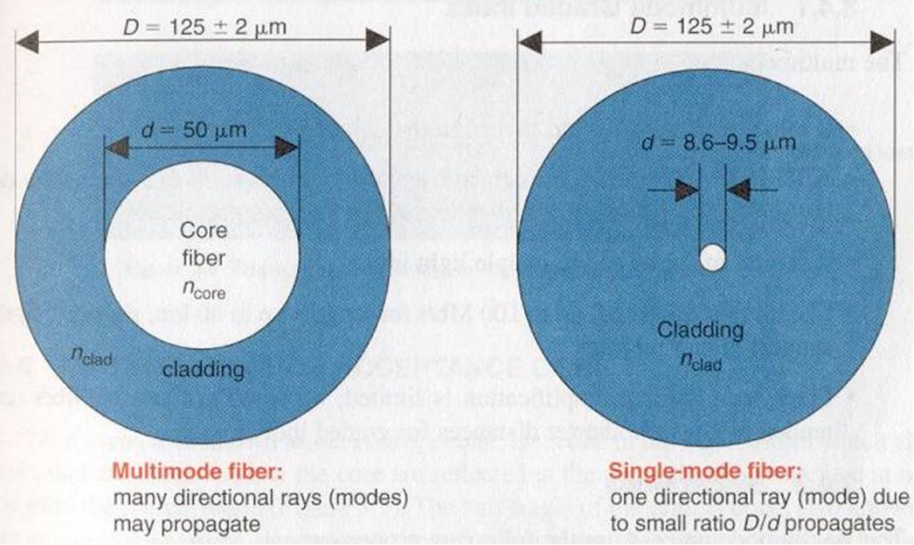
- dopping
  - Graded index
  - (Step Index)

- Multiple cables per duct
- ~1000 fibers per cable
- Multi-core fibers?
- 160 λ per fiber/core
- 2.5Gbps or 10 Gbps per λ

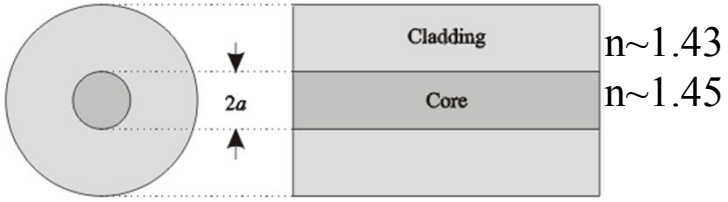
Source: Shivkumar Kalyanaraman

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

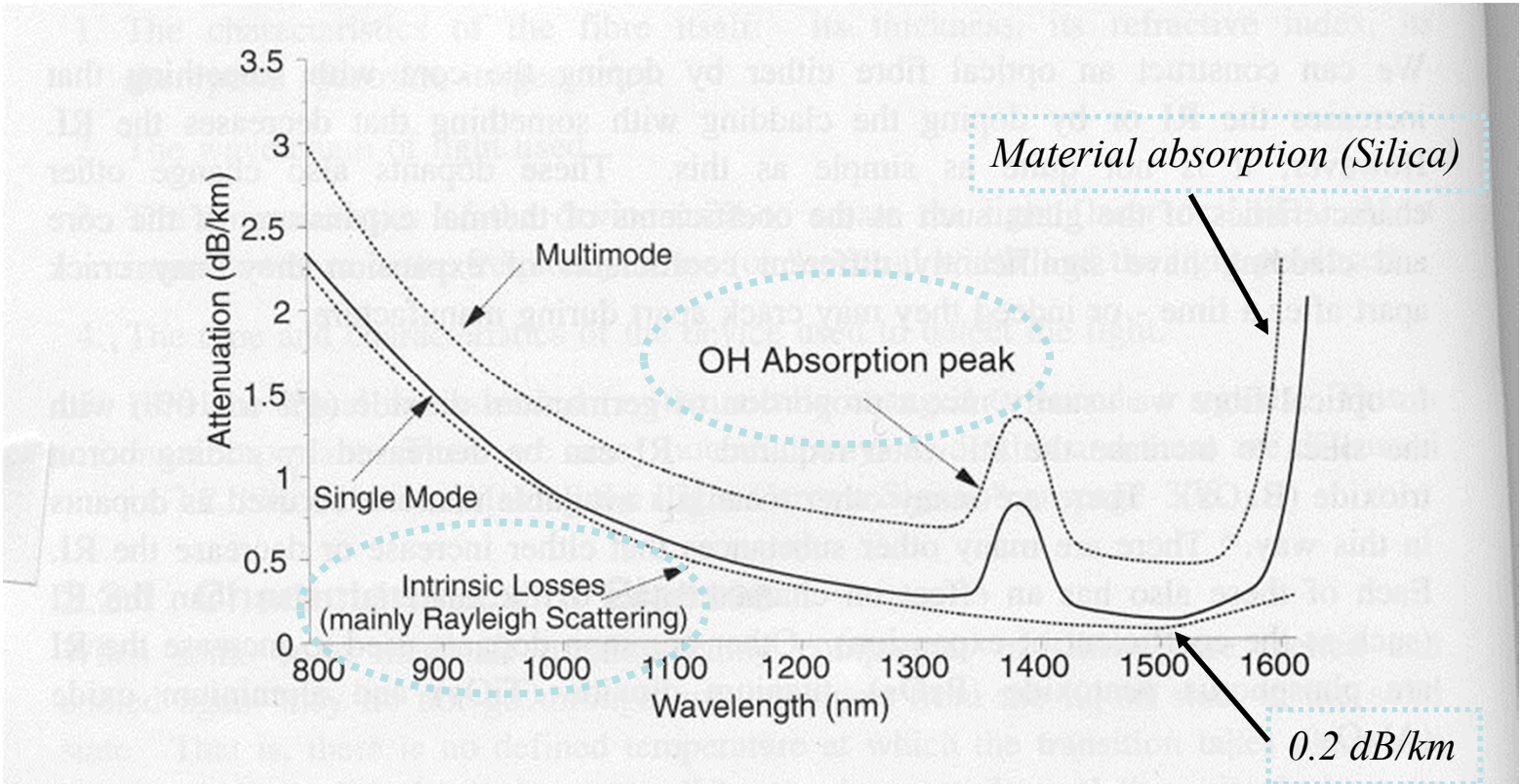


Figure 13. *Typical Fibre Infrared Absorption Spectrum. The lower curve shows the characteristics of a single-mode fibre made from a glass containing about 4% of germanium dioxide (GeO_2) dopant in the core. The upper curve is for modern graded index multimode fibre. Attenuation in multimode fibre is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

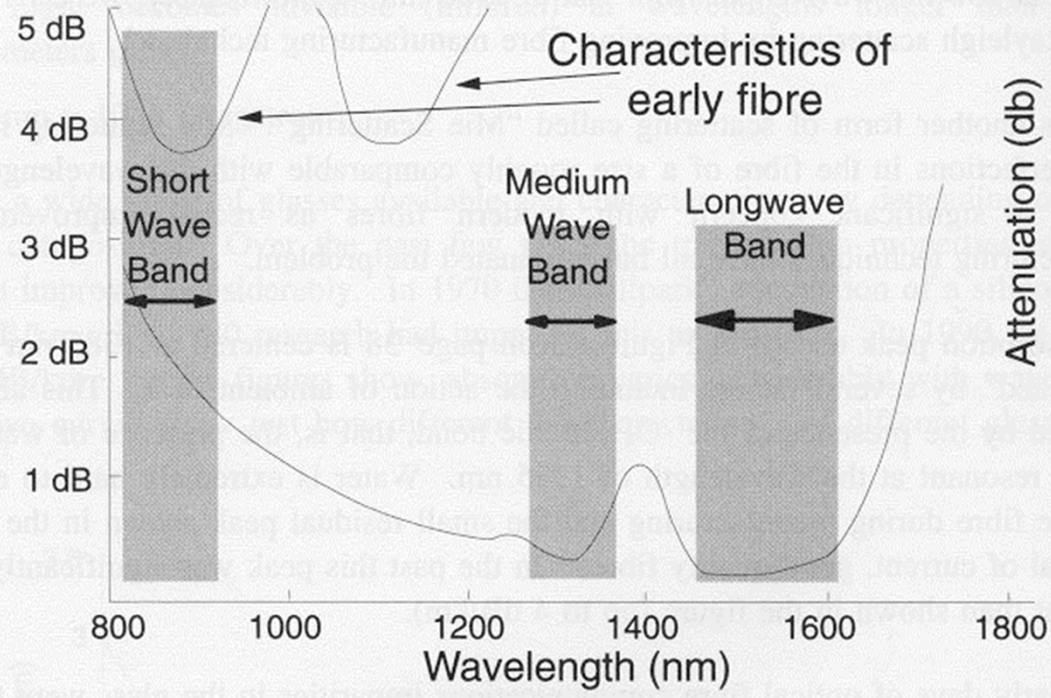


Figure 14. *Transmission Windows. The upper curve shows the absorption characteristics of fibre in the 1970s. The lower one is for modern fibre.*

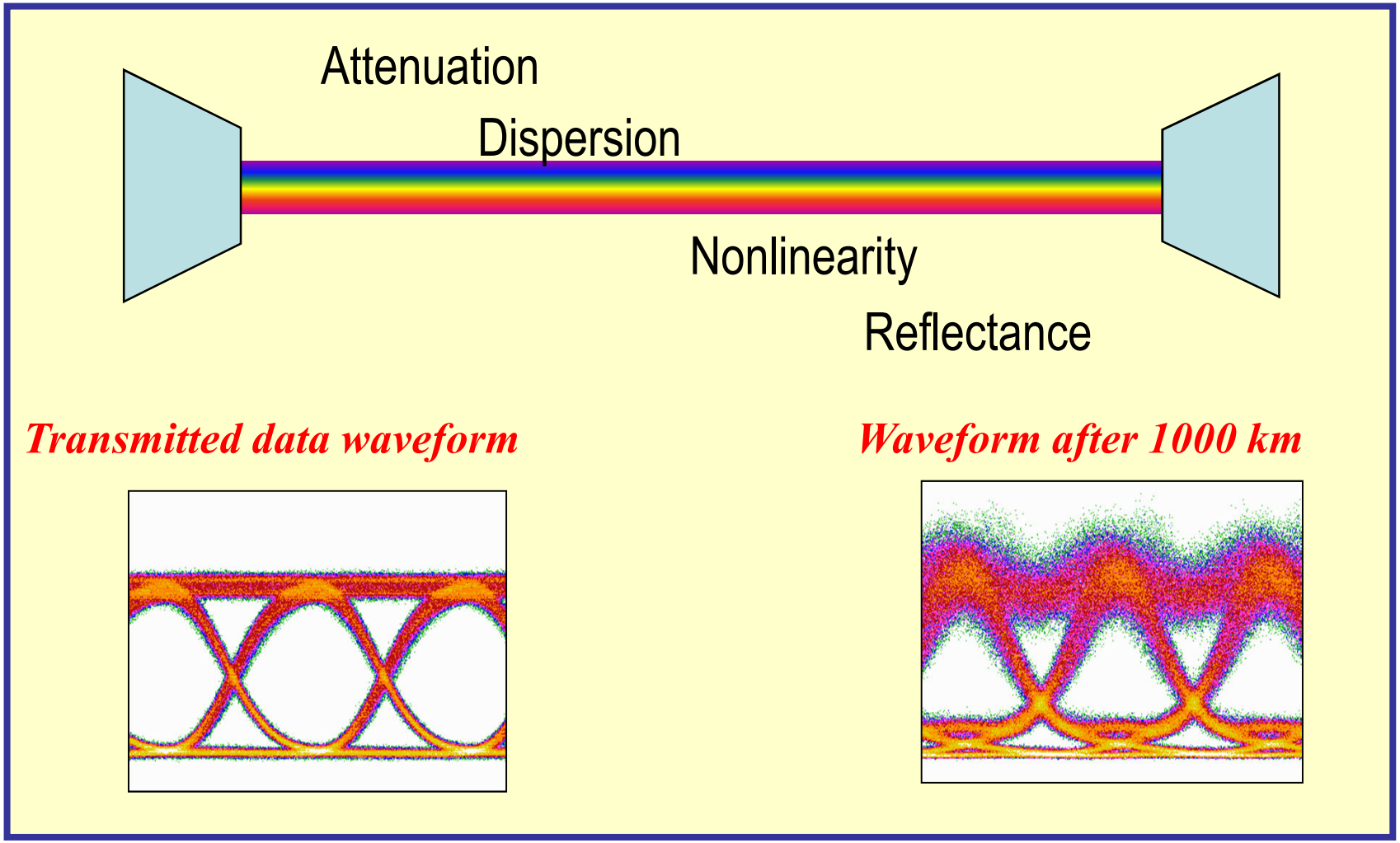
Lucent's new AllWave Fiber (1998) eliminates absorption peaks due to watervapor in the 1400nm area!

Forrás: Shivkumar Kalyanaraman

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

Optical Transmission Impairments



Forrás: Shivkumar Kalyanaraman

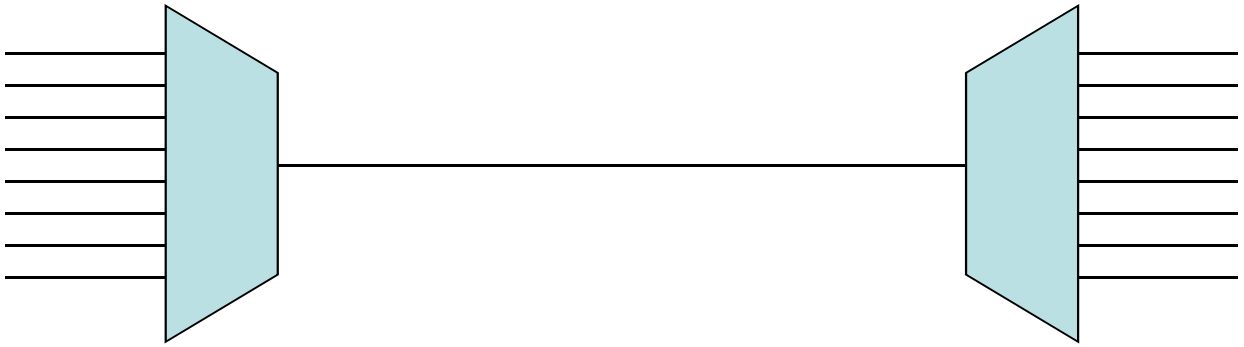
Wavelength MUX/DEMUX

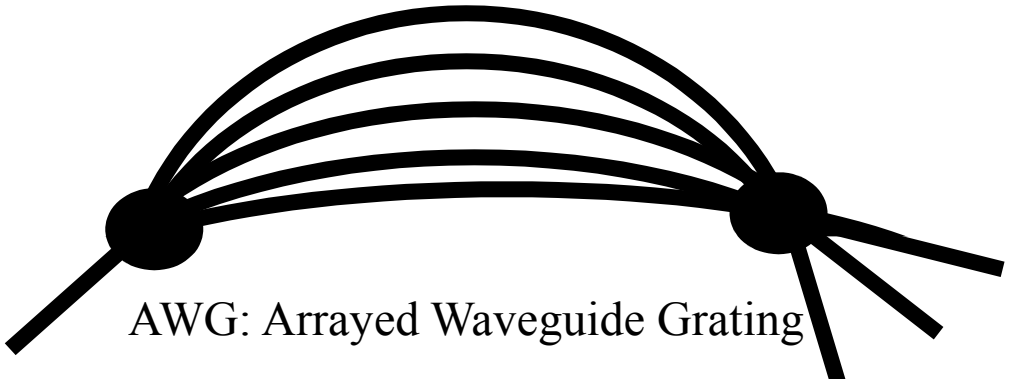
Point-to-point WDM link ...

DWDM (Denser – Wider – Denser)

CWDM (Coarse)

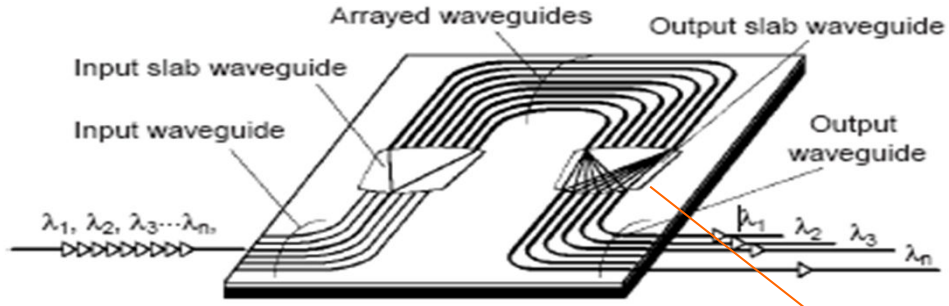
(WDM: Wavelength Division Multiplexing)





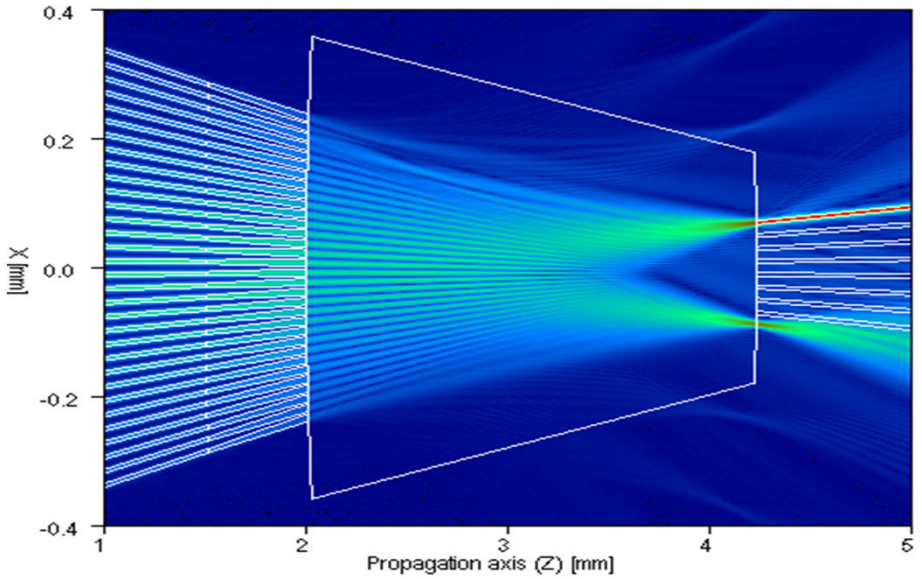
AWG: Arrayed Waveguide Grating

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