Telecommunication Networks and Services

BMEVITMA310 in English

Tibor Cinkler (**5.**) December 1, 2015

Tuesday 12:15 – 13:45 (I.L.105)

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 (1./2)

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?

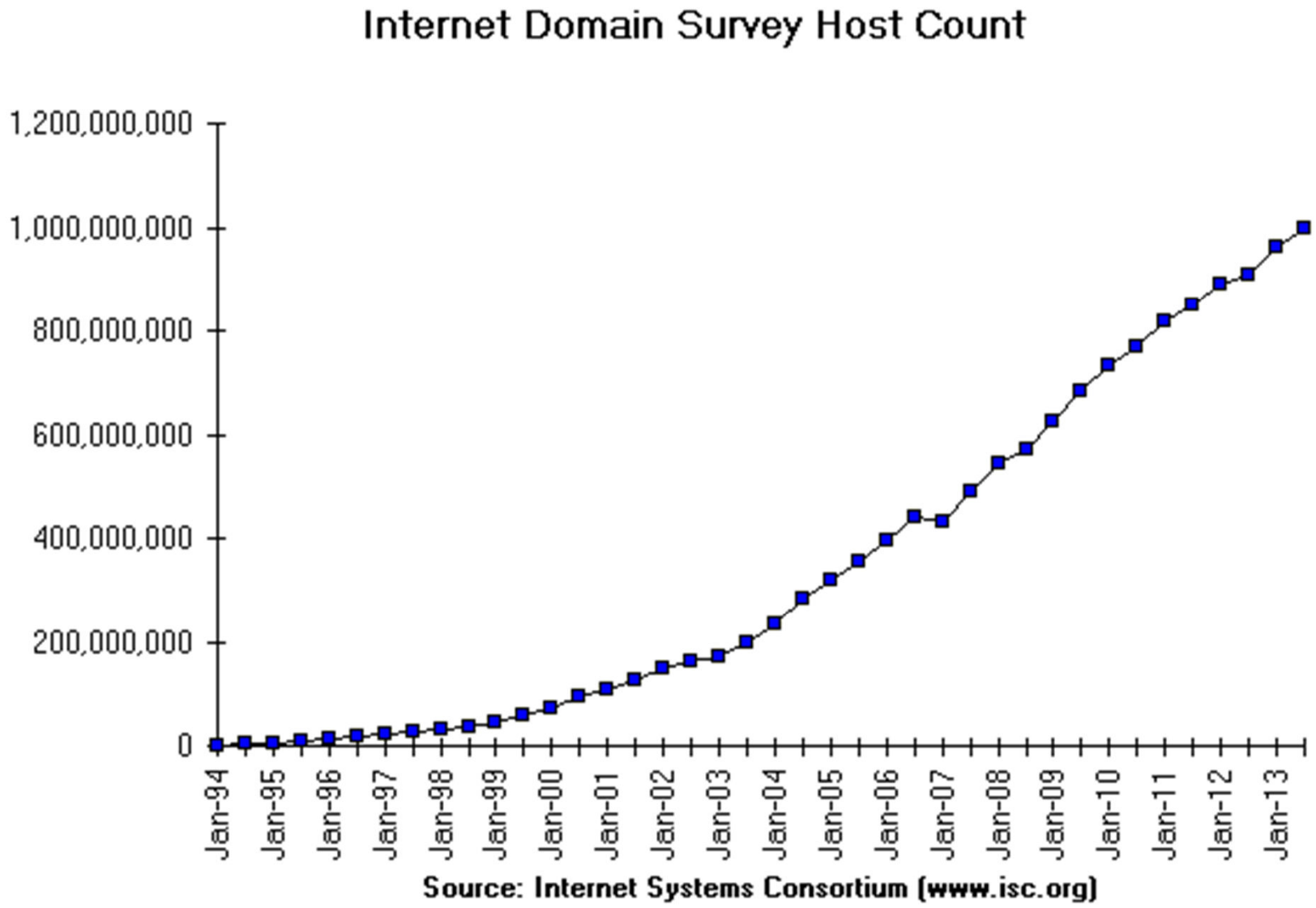
- Not optical transmission links but networks!
- Bandwidth
- Speed (Response time)
- Denser virtual topology (via WDM or fibers)
  - Decreasing the load of IP switches and DXCs ☺
  - More ports ☹
  - Decreasing the delay ☺
  - For IP and Voice

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

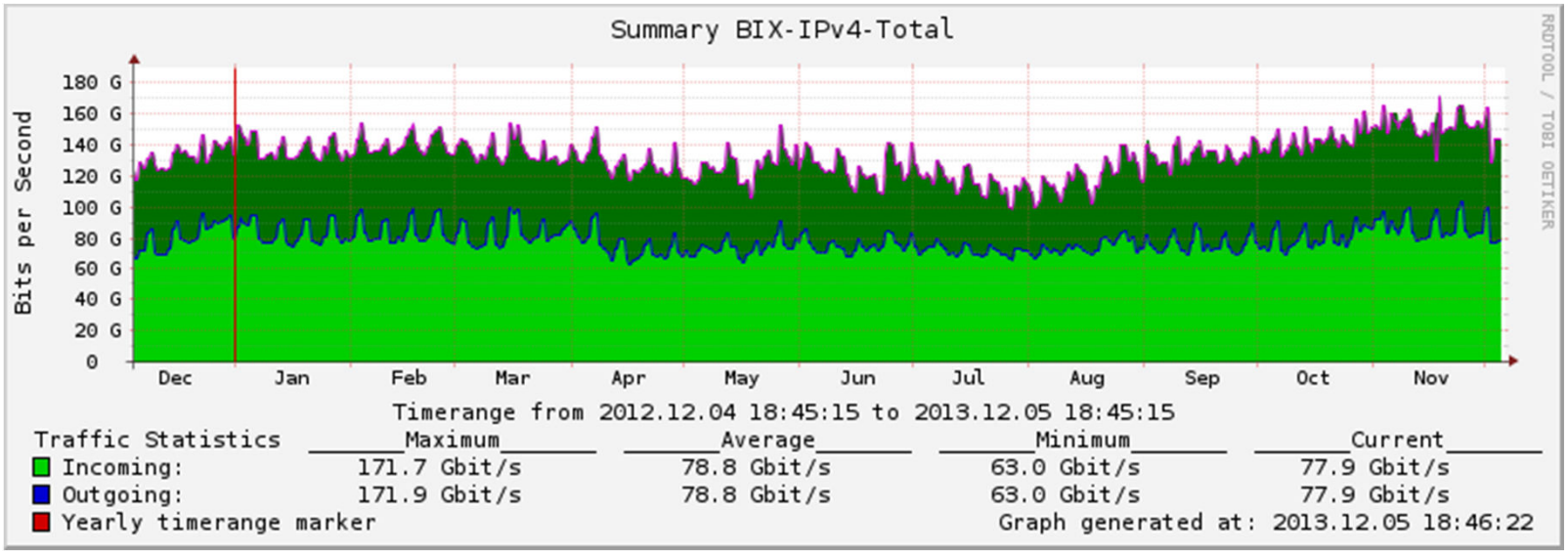
www.isc.org

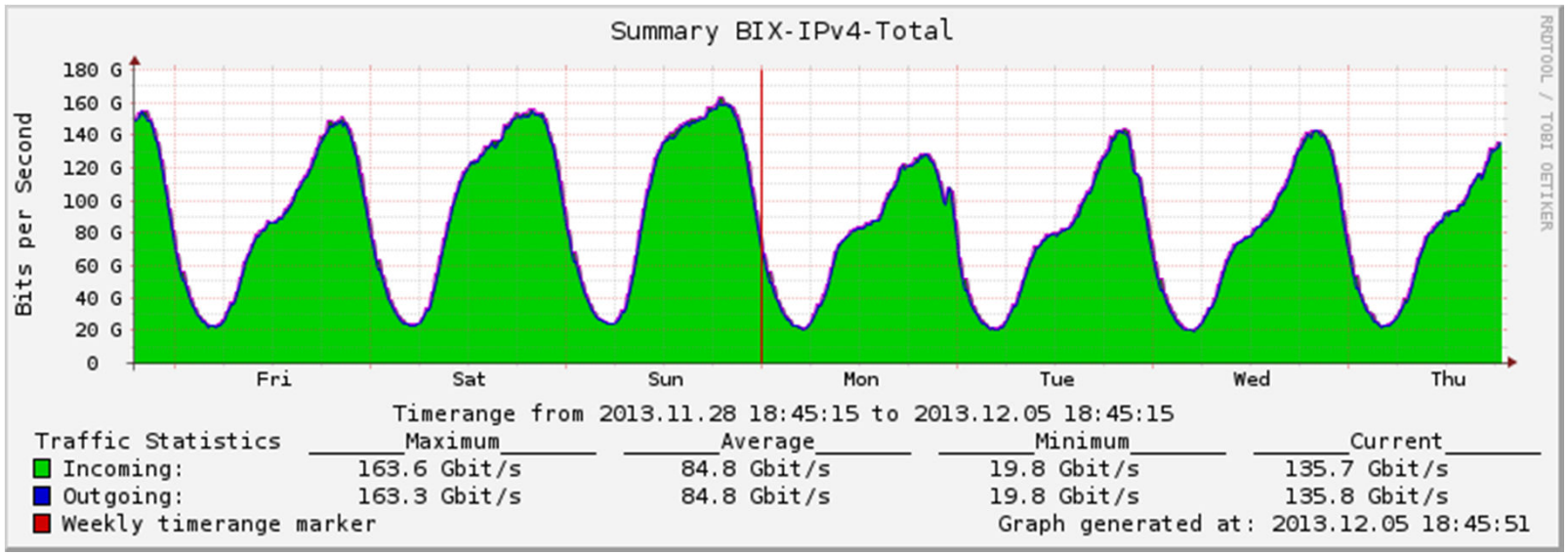
„...counts the number of IP addresses that have been assigned a name”



www.bix.hu: IPv4

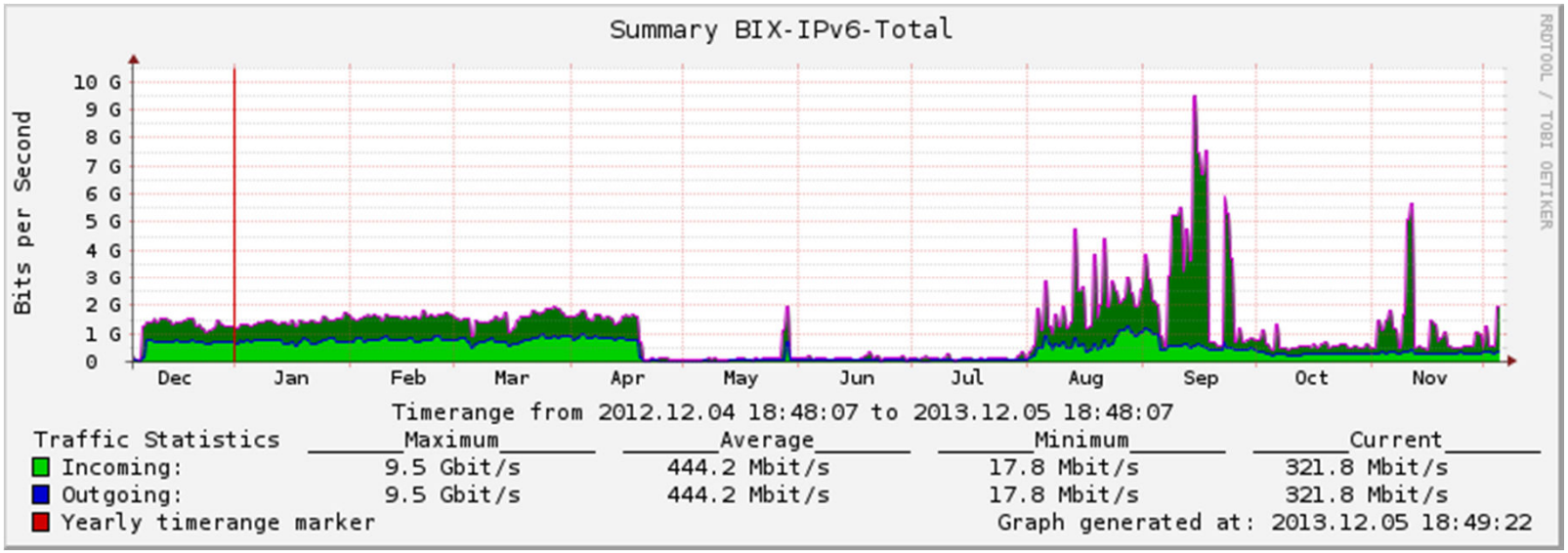
Yearly Graph (1 day averages)
Weekly Graph (30 minute averages)
Source: http://www.bix.hu/

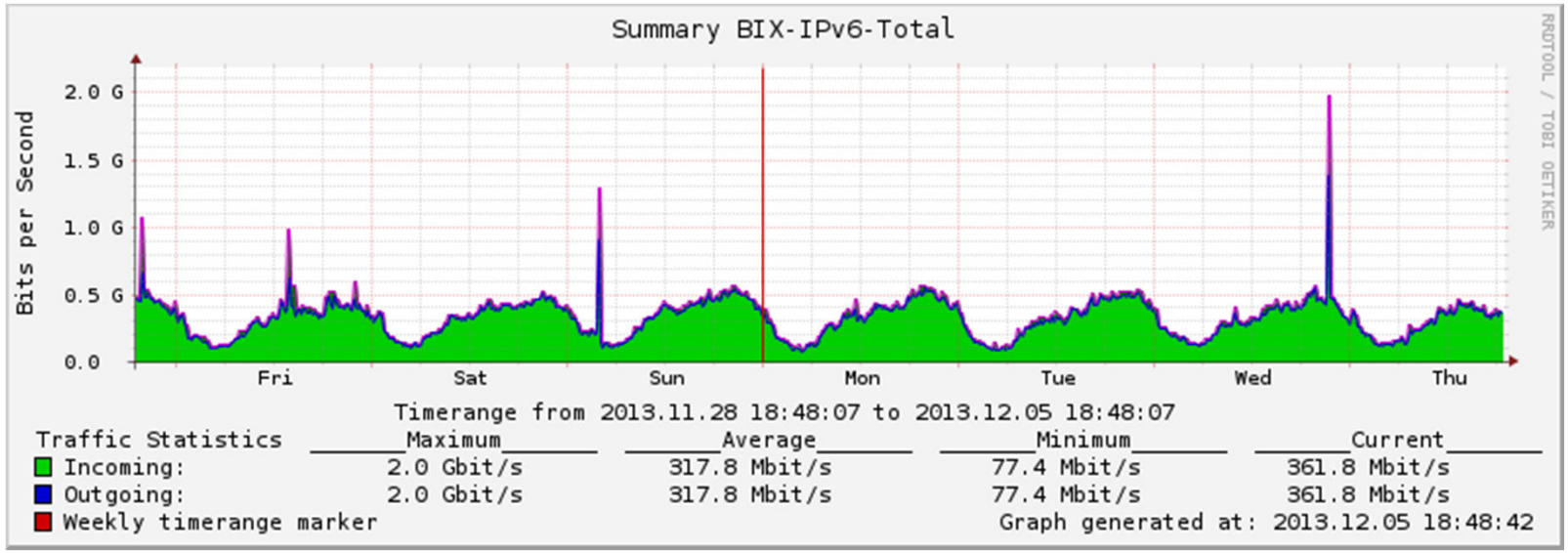




www.bix.hu: IPv6

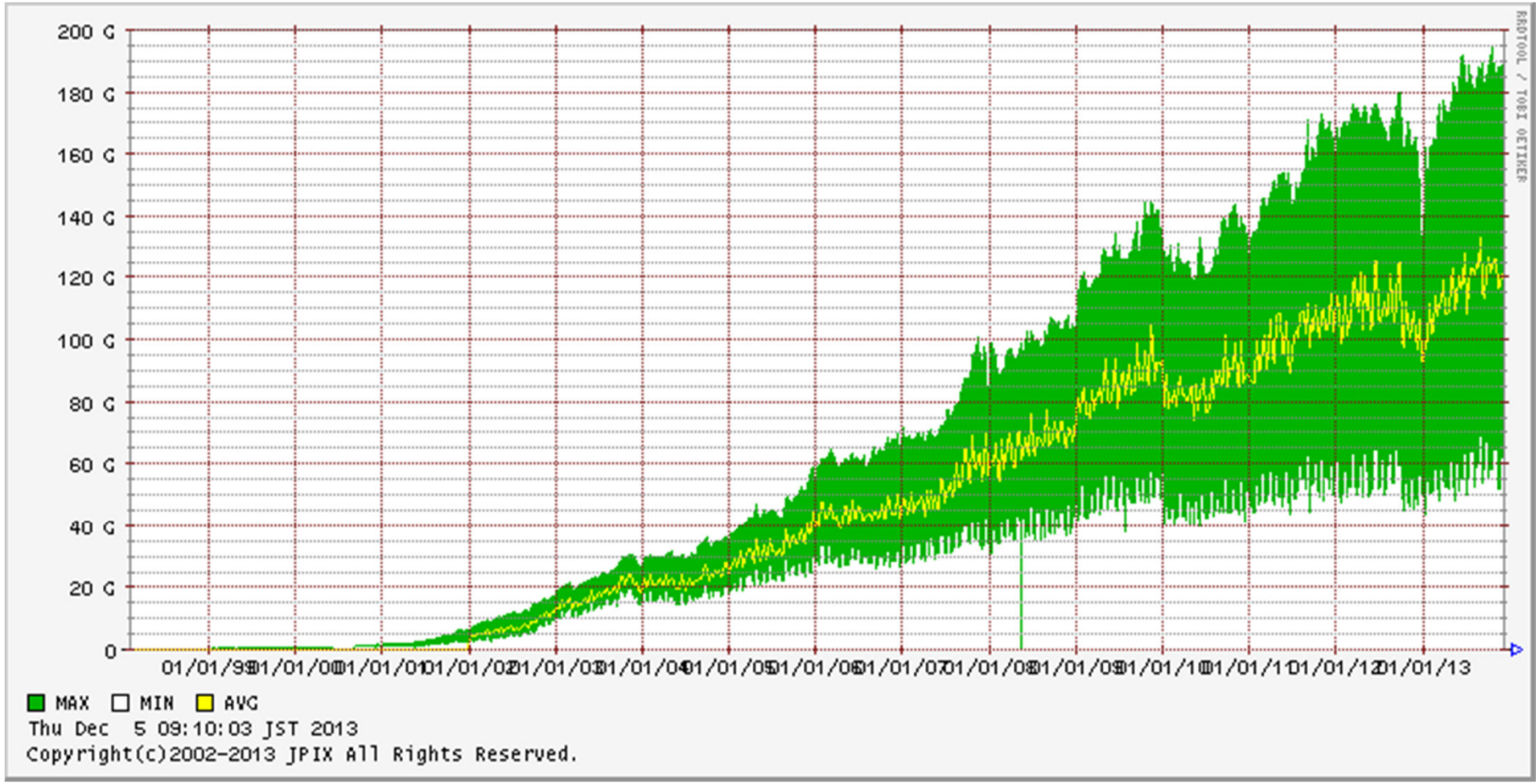
Yearly Graph (1 day averages)
Weakly Graph (30 minute averages)
Forrás: http://www.bix.hu/





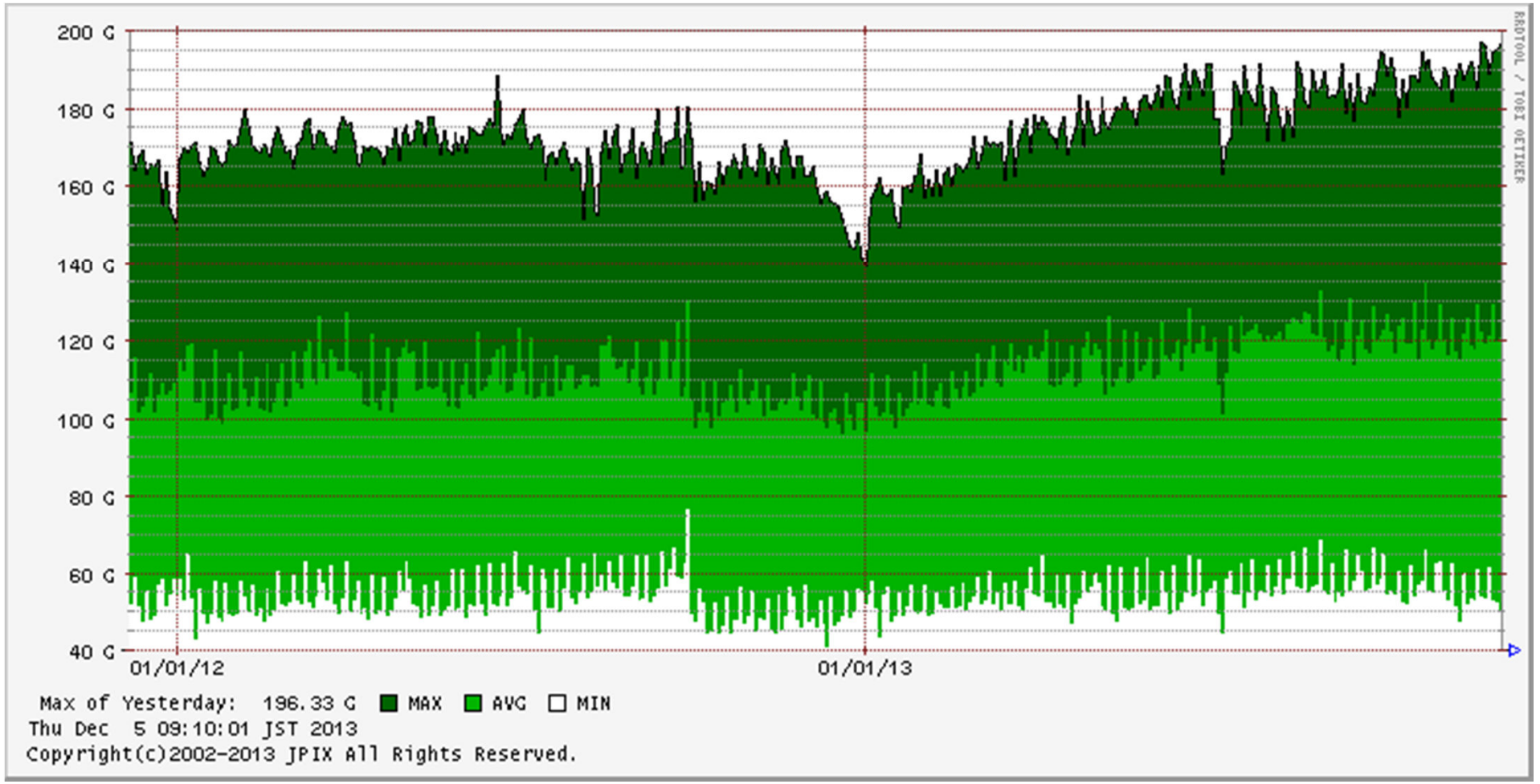
www.jpix.ad.jp

http://www.jpix.ad.jp/graphs/TOTAL.In.minmax256_e.gif



www.jpix.ad.jp

http://www.jpix.ad.jp/graphs/TOTAL.In.minmax256A_e.gif



Bandwidth-hungry applications

video excghange, HDTV, 3D.

- **video, higher resolutions, 3D stb**
- **free point view TV (on demand)**
- **„4K”: 8Mpixel per frame solutions, 8k**
- **Gaming (e.g., after life)**
- **YouTube**
- **Grid/Cloud computing**

- **Phone browsers (Opera, Mozilla...)**
- **iPhone, iTunes, Android, ...**
- **Compressed video 600 Mbit/s – “raw" multiple 10 Gbit/s**

Bandwidth-hungry Applications

- **Peer-to-Peer**
- **GRIDs**
- **SAN, oSAN**
- **Audio and Video Broadcast, IPTV**
- **VoD (video)**
- **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)**

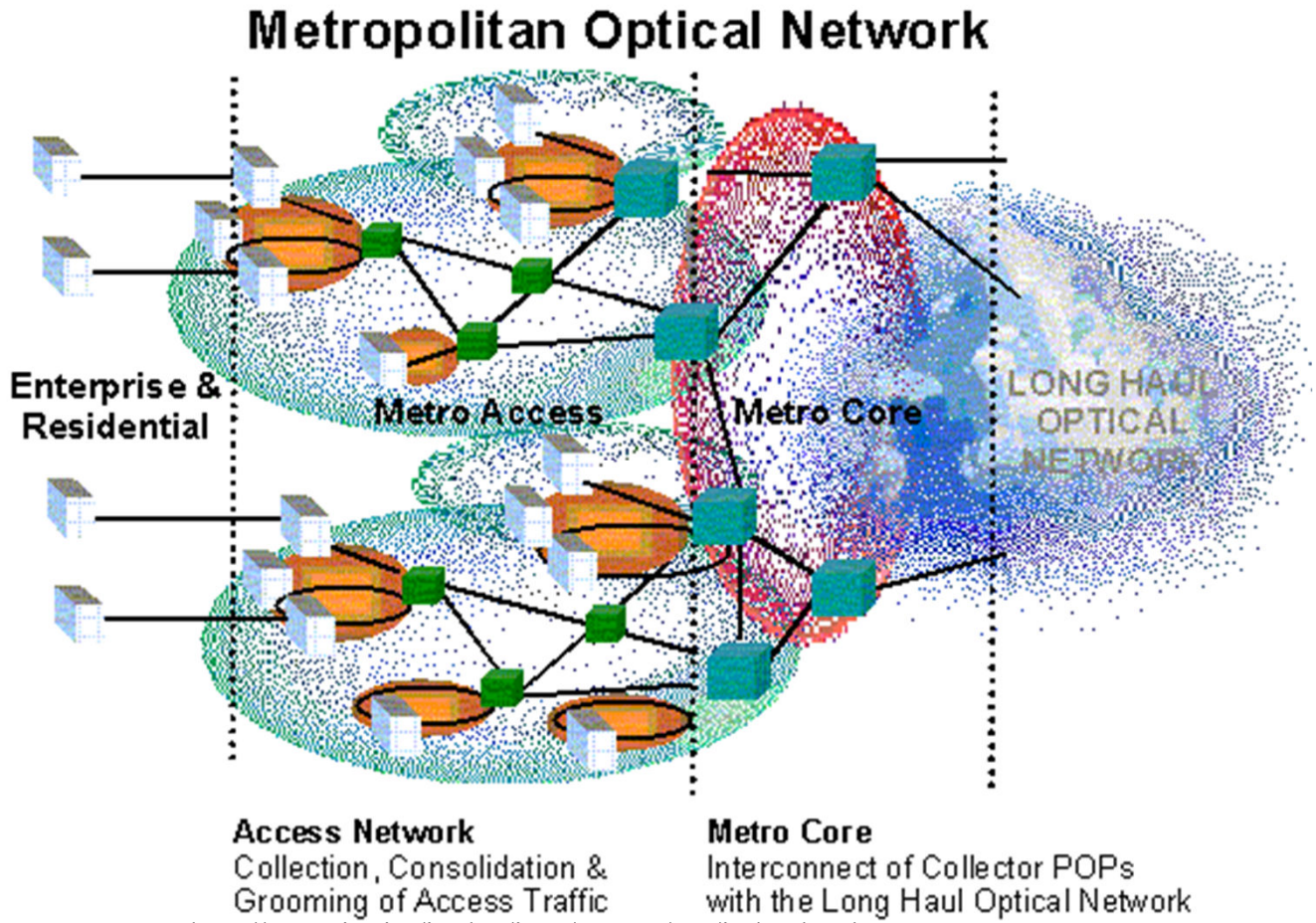
MON-LHON — Positioning

OR:

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

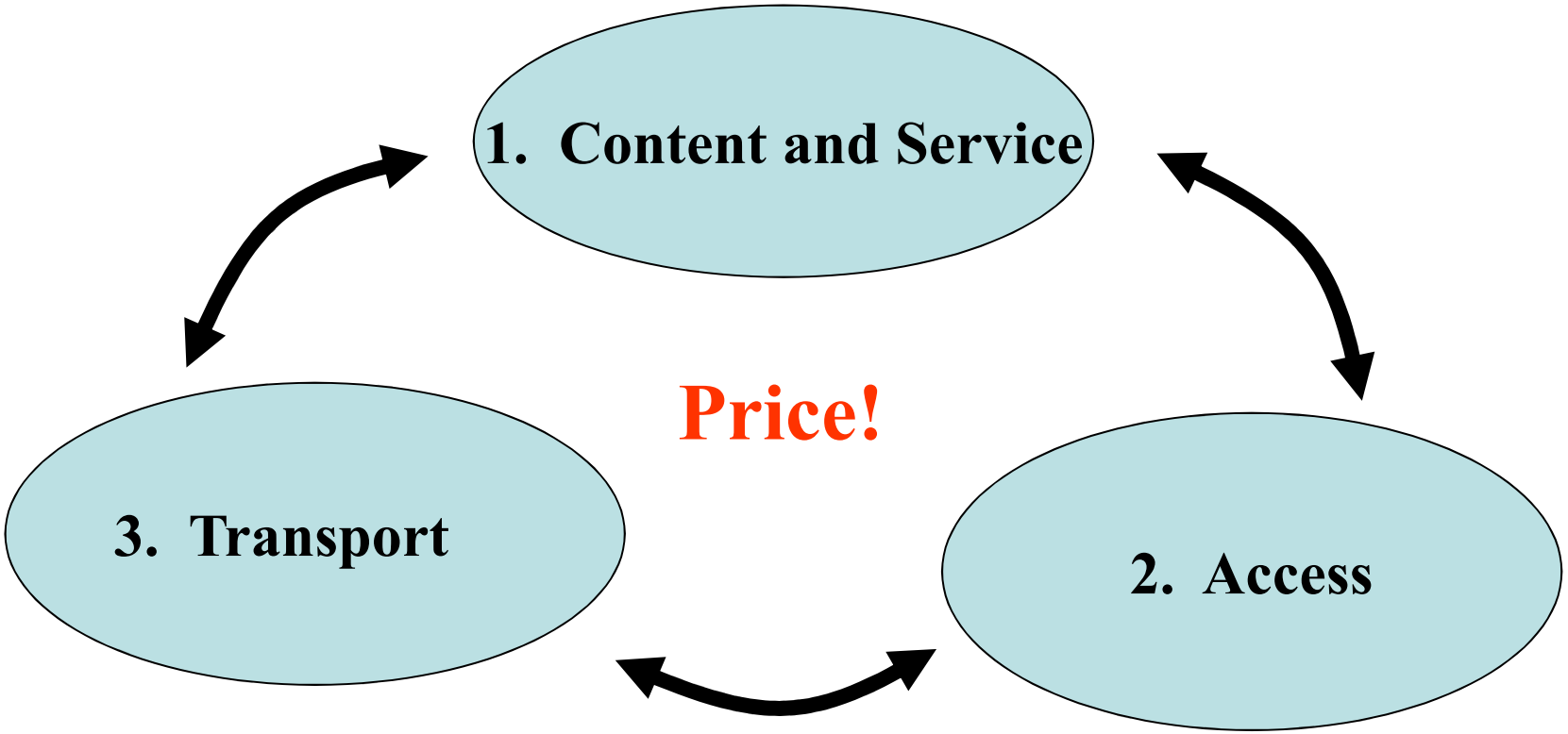
OR:

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



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

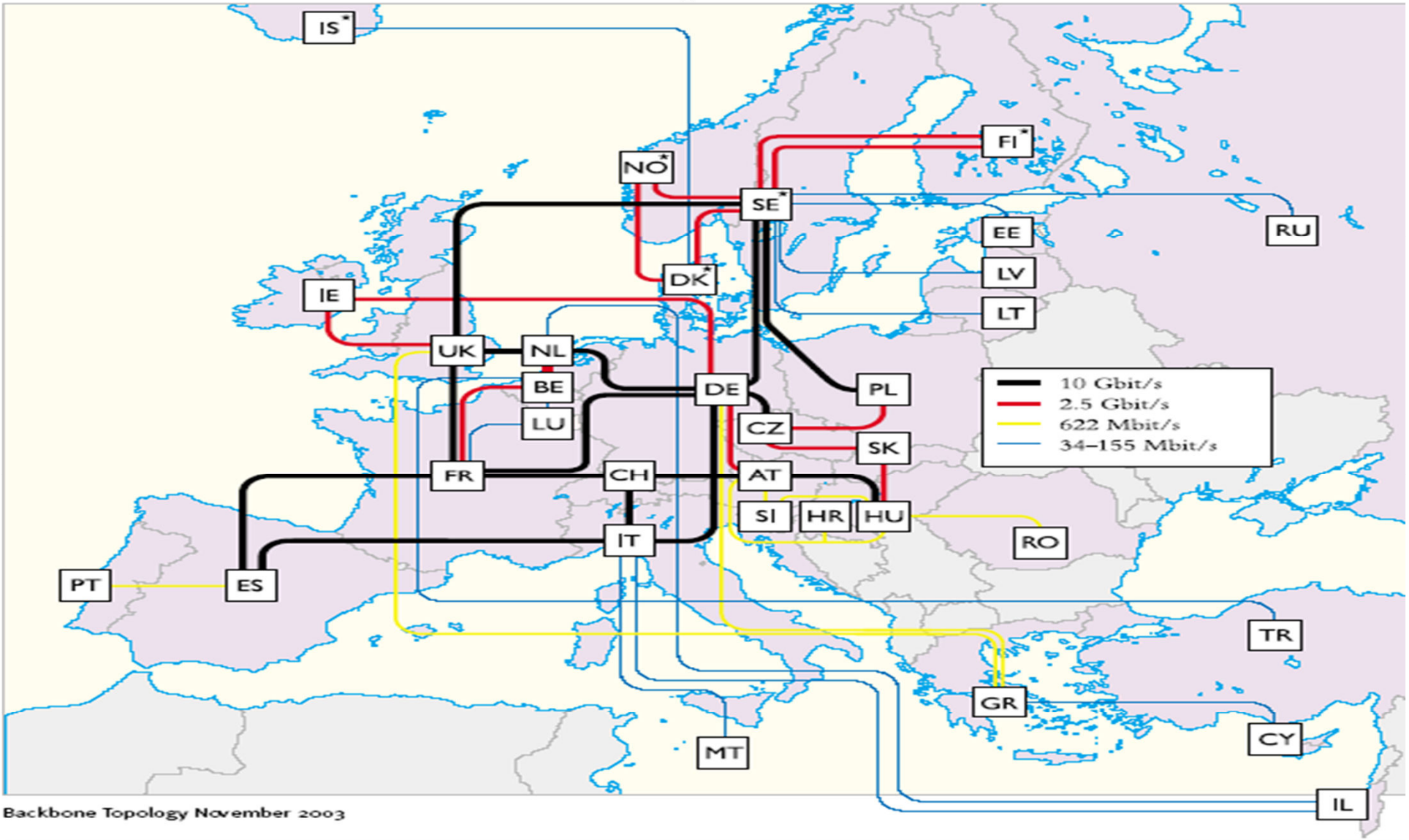
“Circus viciosus”



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

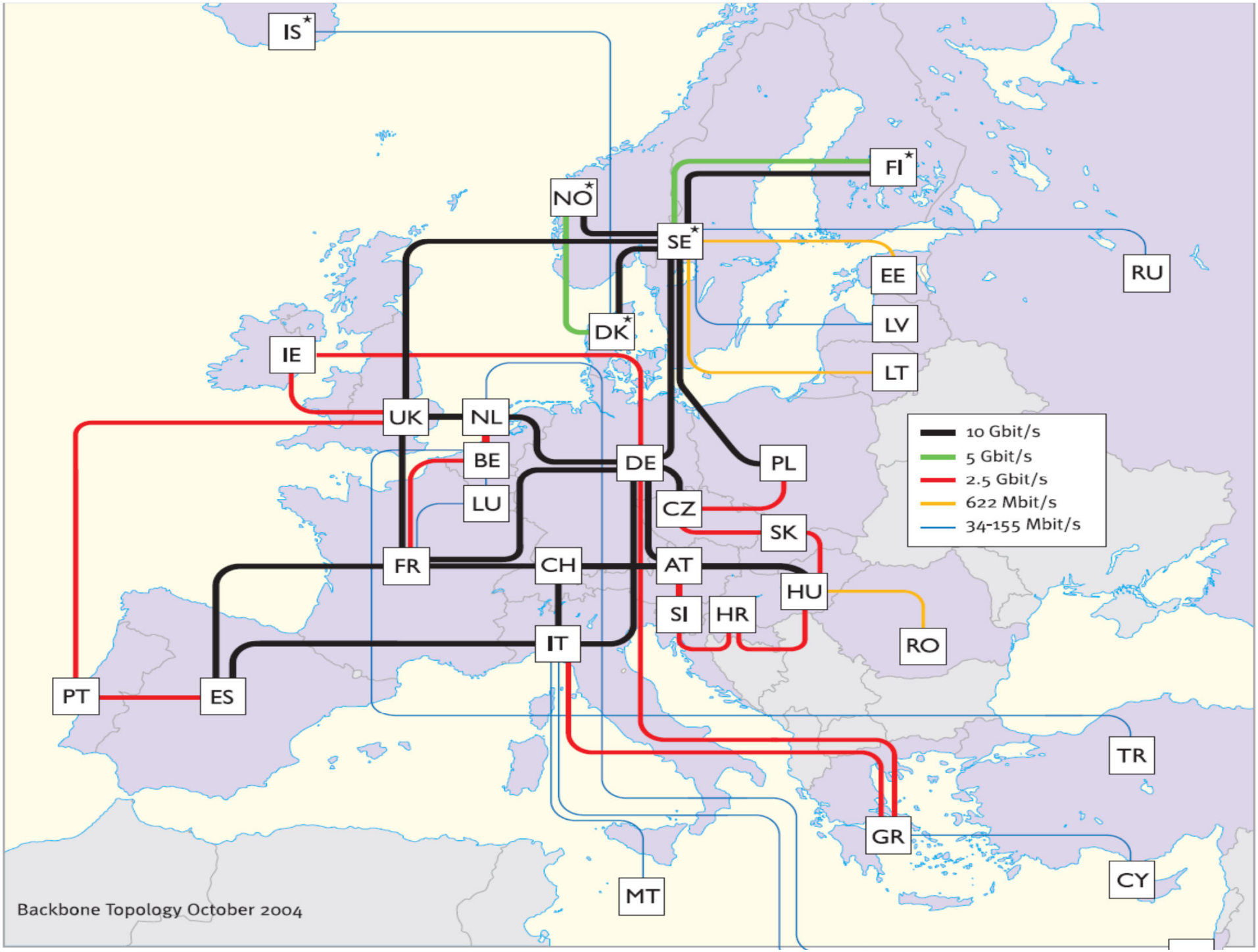
Geant Europan network

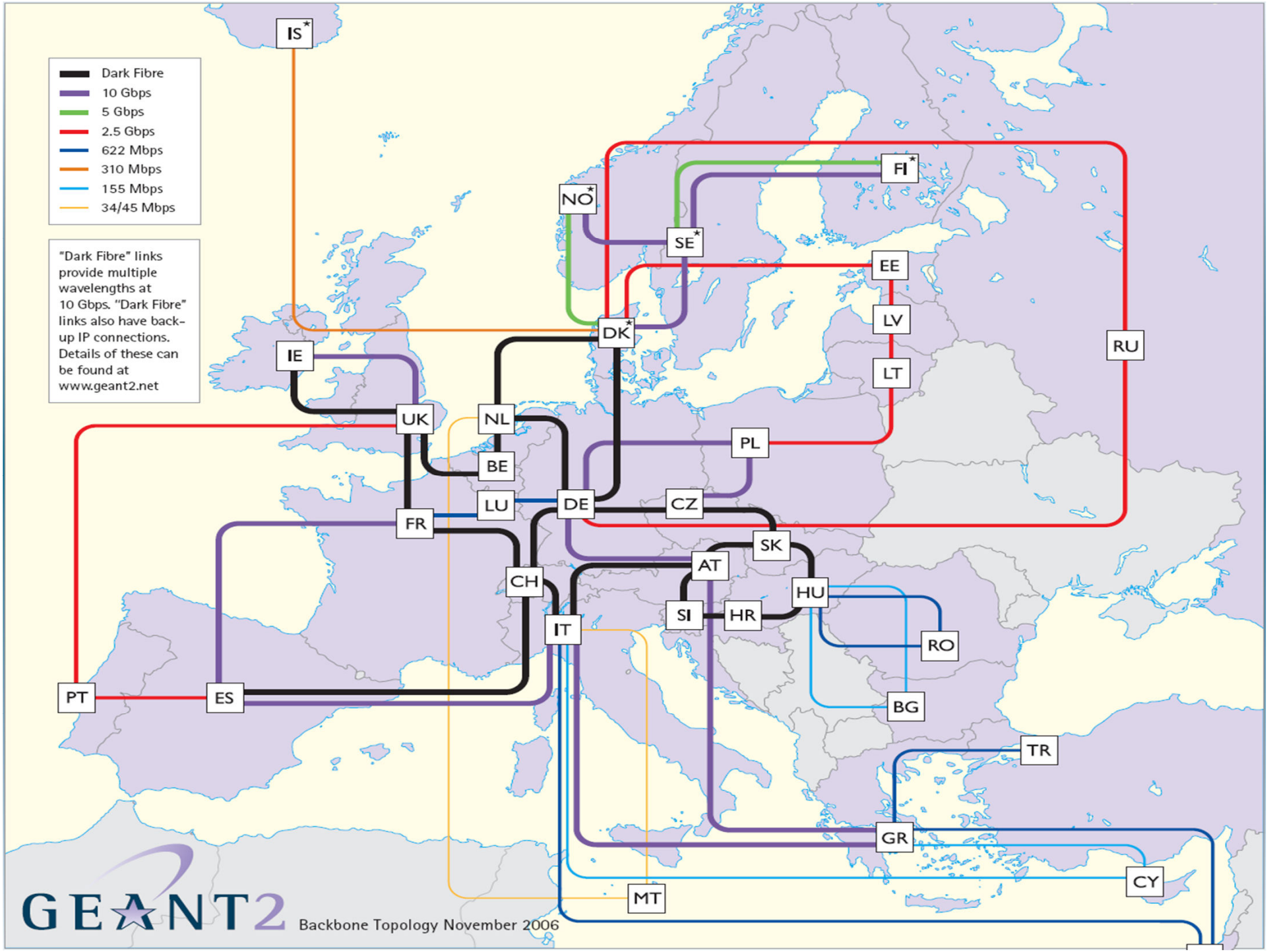


Backbone Topology November 2003

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

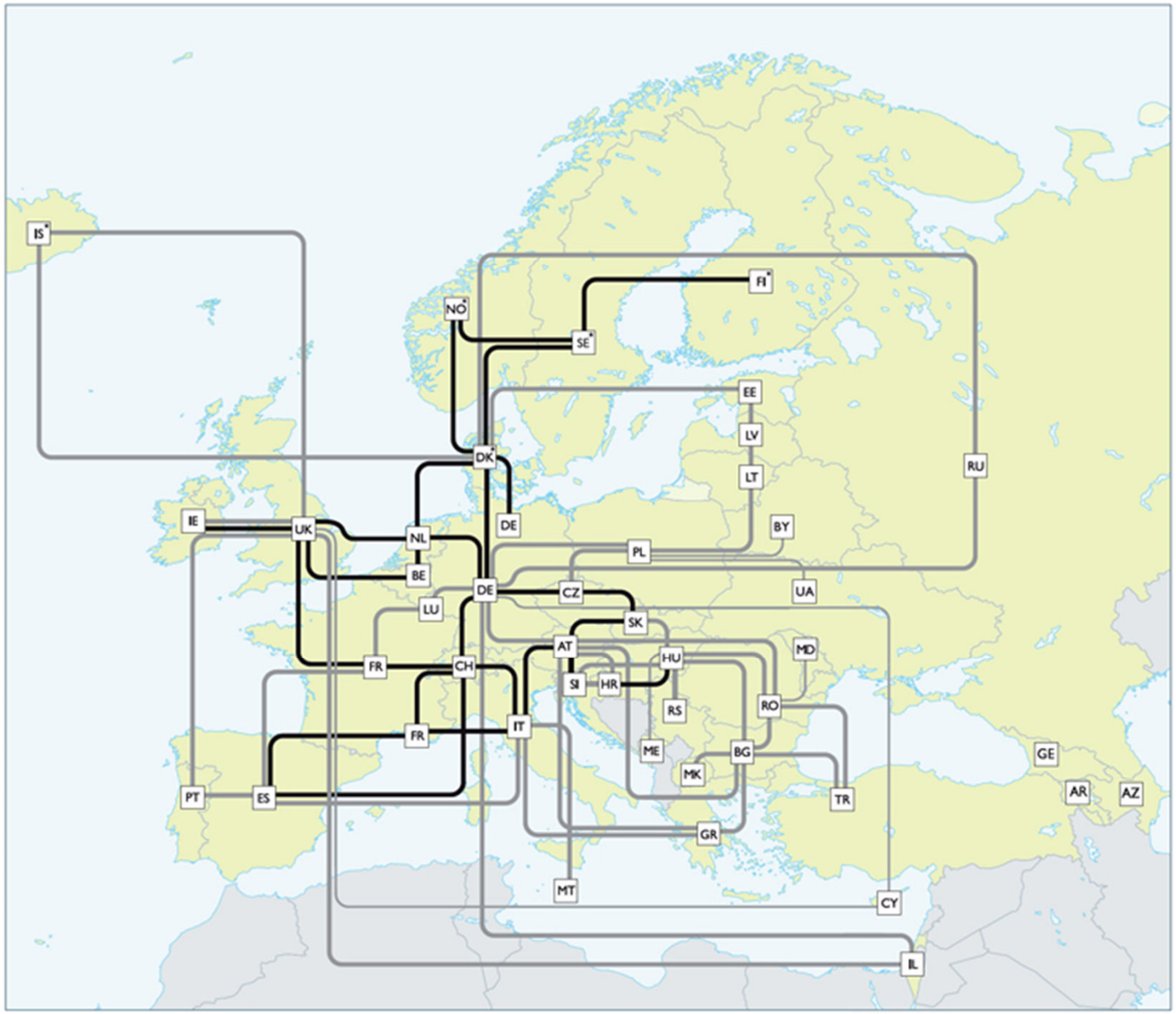
*Connections between these countries are part of NORDUnet (the Nordic regional network)


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

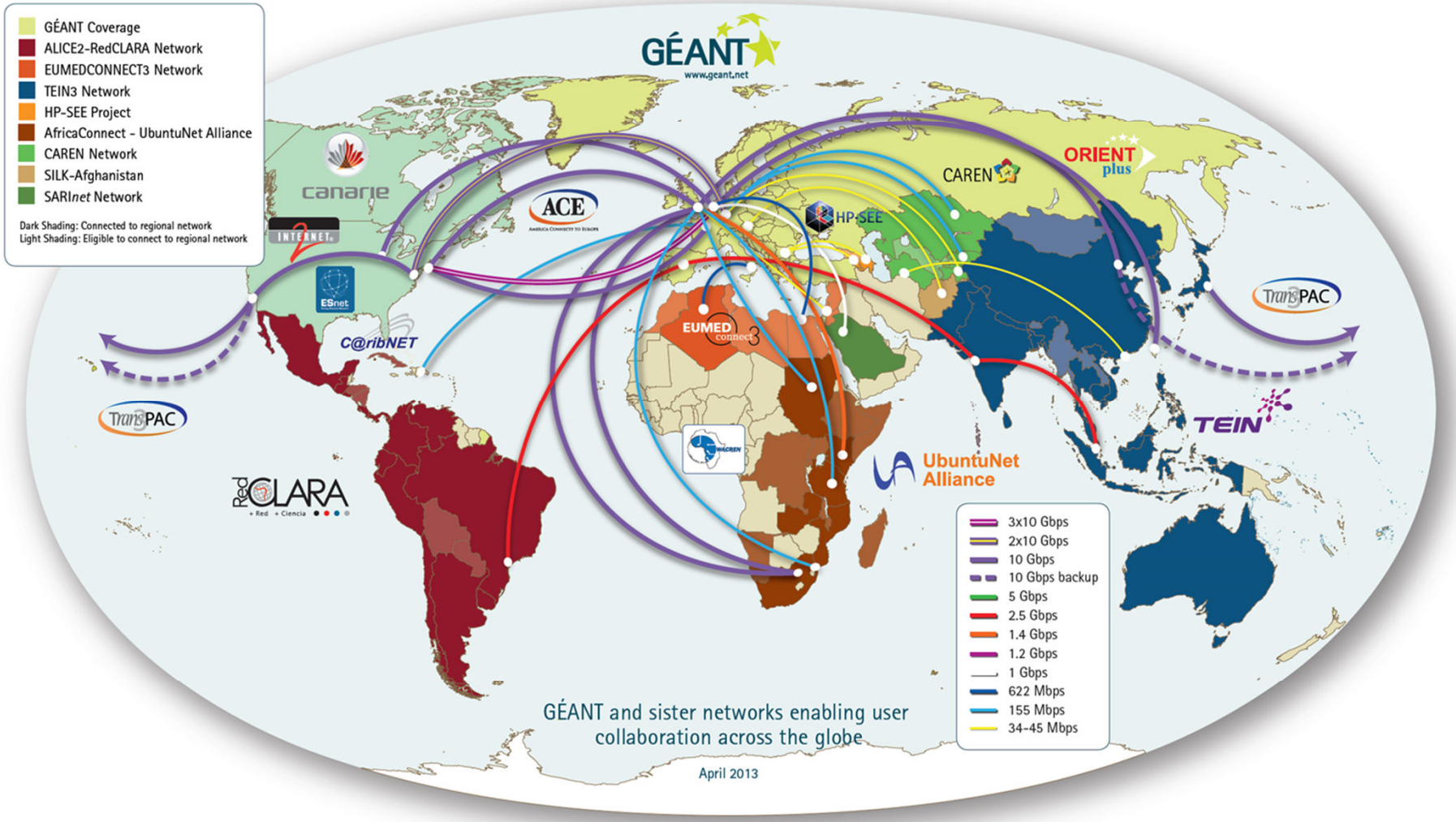
The Pan-European Research and Education Network

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.

GÉANT At the Heart of Global Research Networking



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

connect • communicate • collaborate

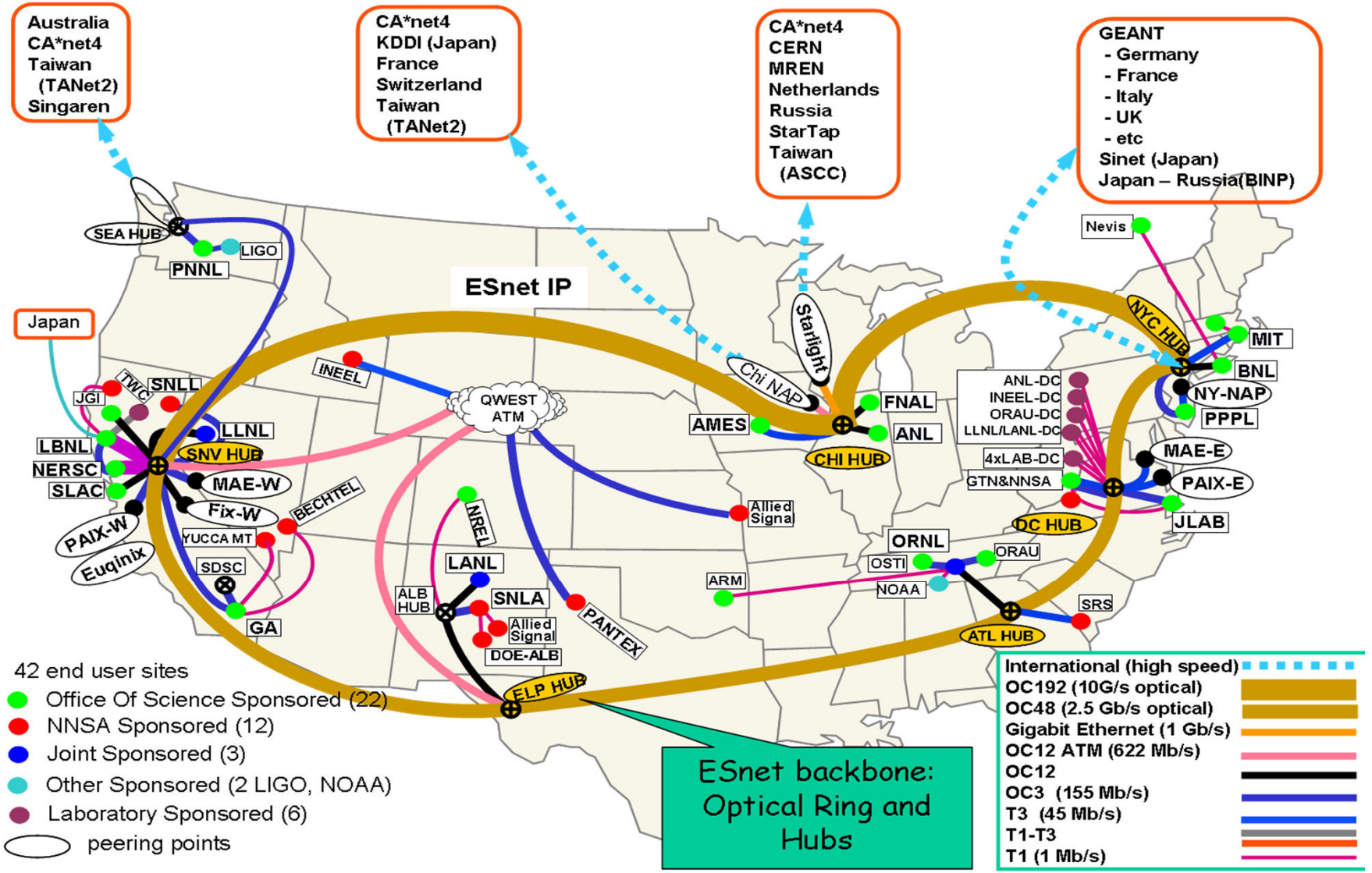
GÉANT is co-funded by the European Union within its 7th RtD Framework Programme.

This document has been produced with the financial assistance of the European Union. The contents of this document are the sole responsibility of DANTE and can under no circumstances be regarded as reflecting the position of the European Union.

SEVENTH FRAMEWORK PROGRAMME

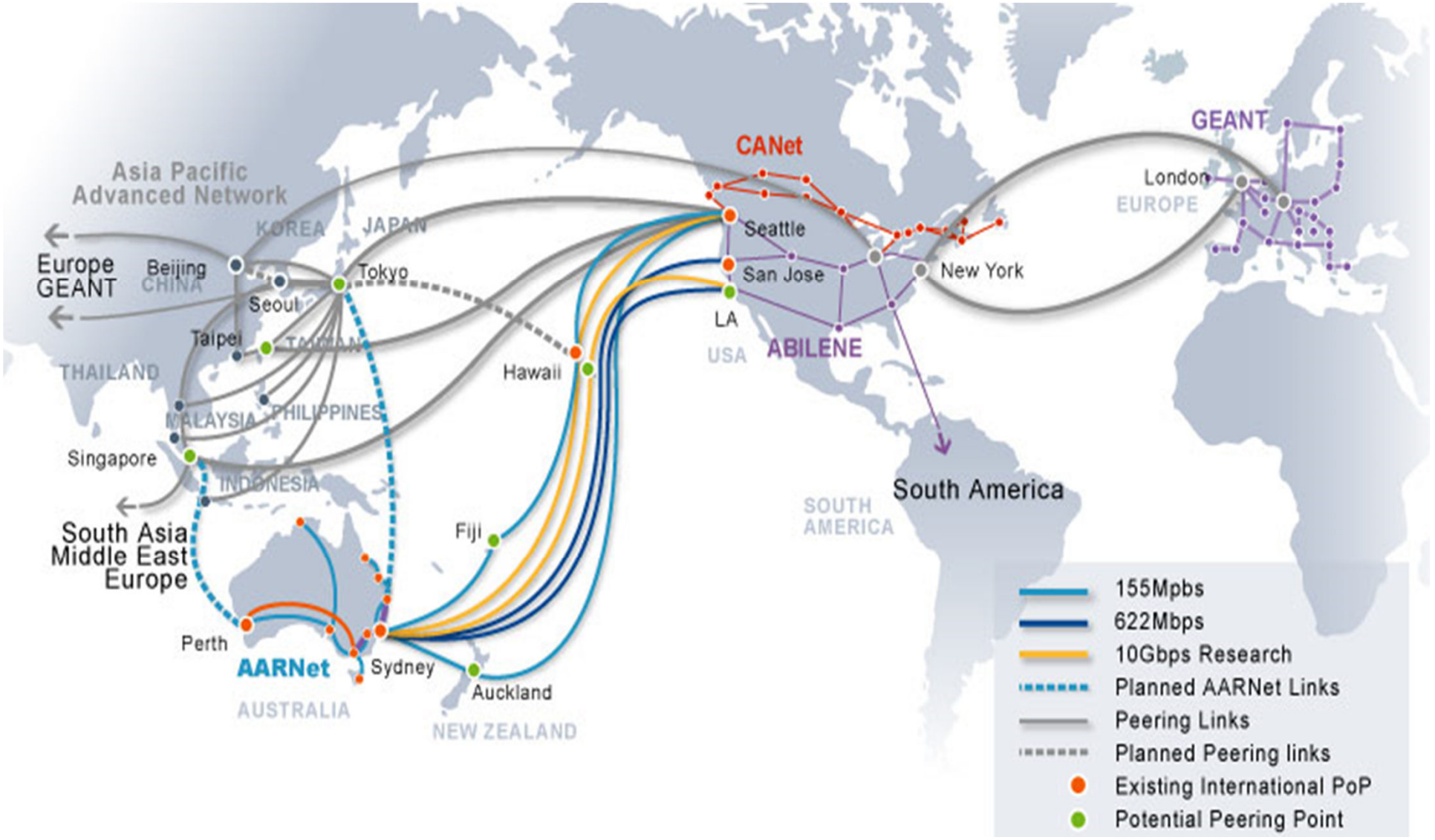
Co-funded by the European Union

ESnet (2003)



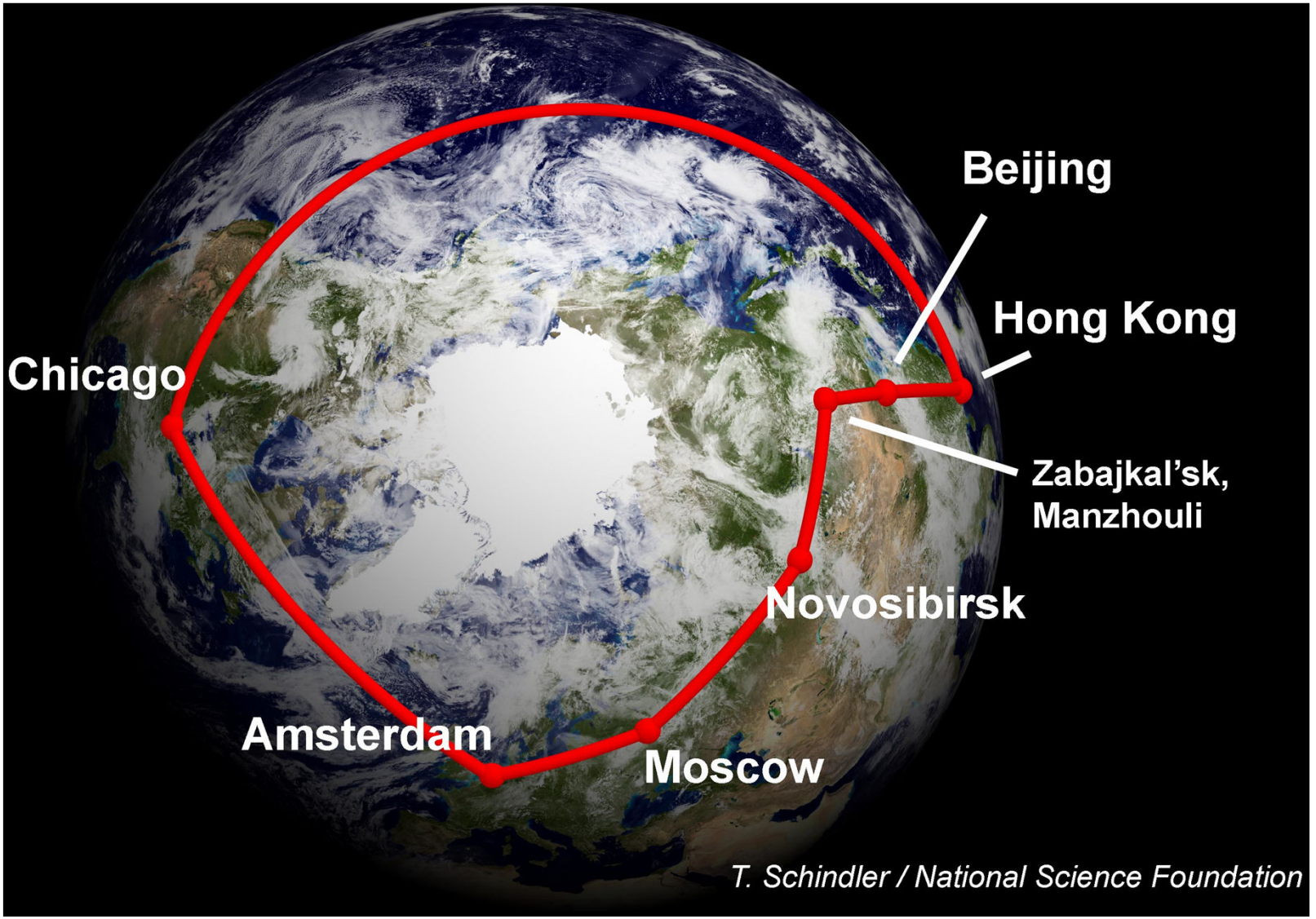
Source: H.B.Newman, GNEW2004

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



GLORIAD: Global Optical Ring

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

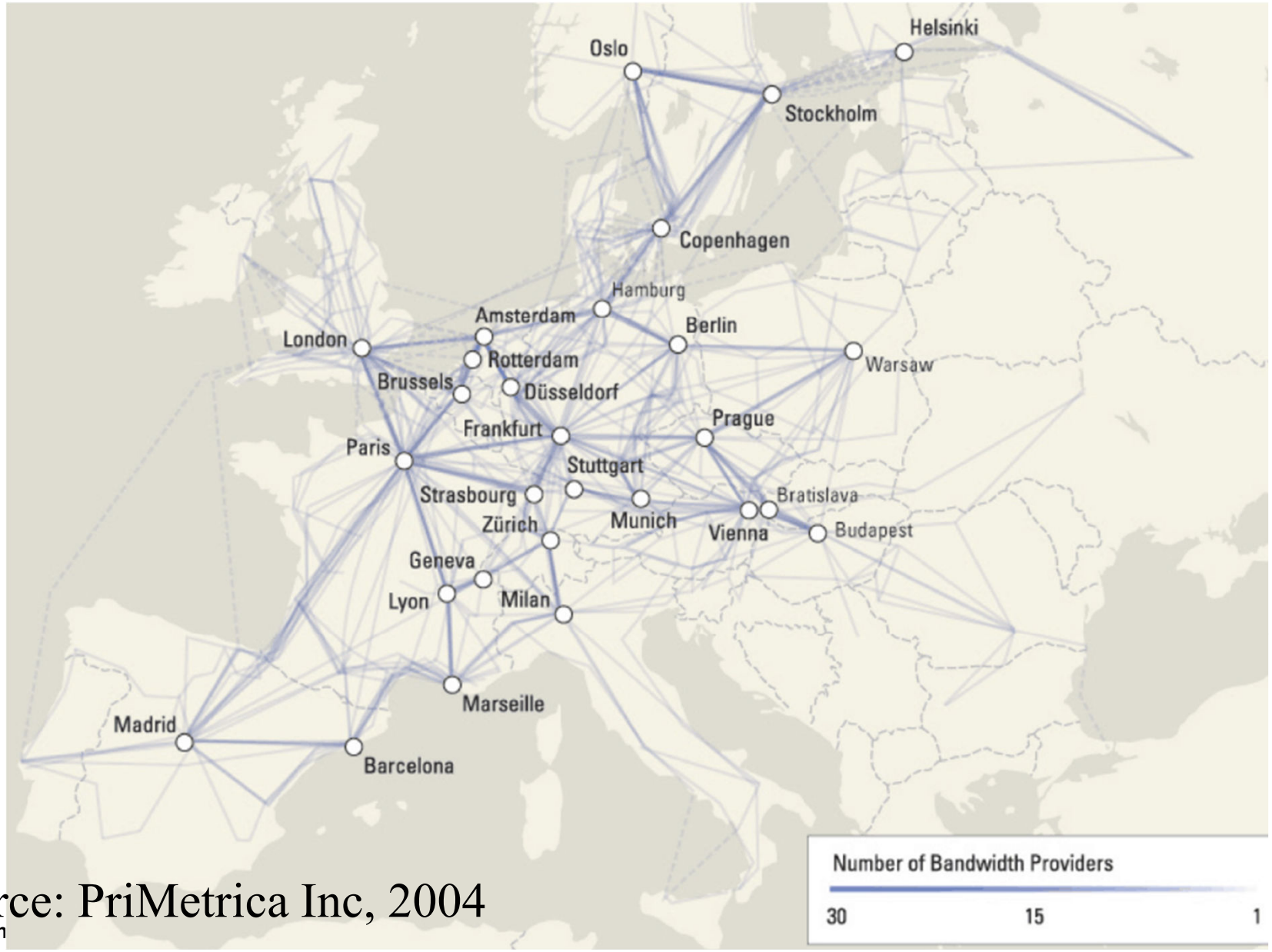


Optical cable systems of Americas

- 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

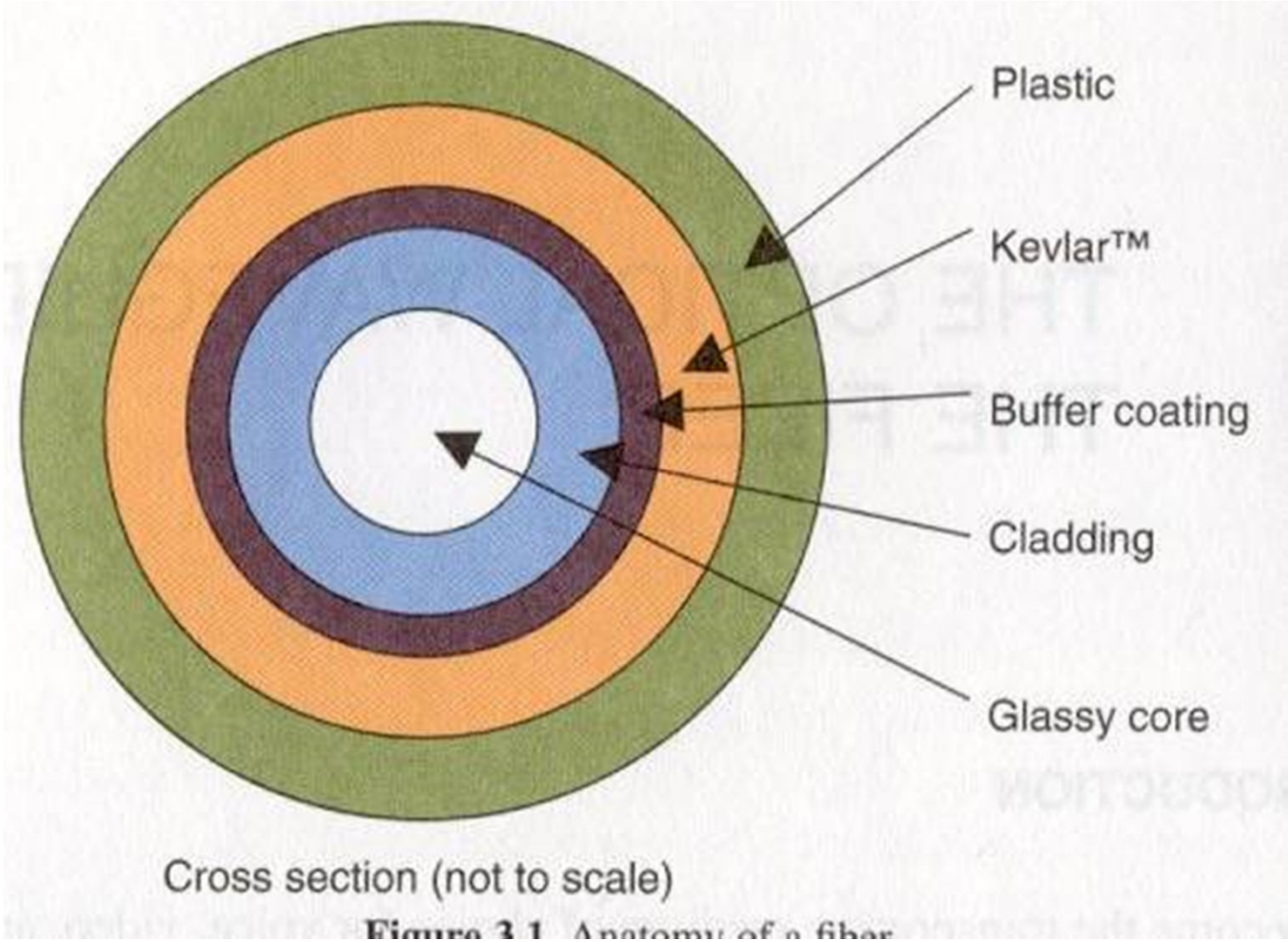
Multiplexing Solutions

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

Optical Technologies

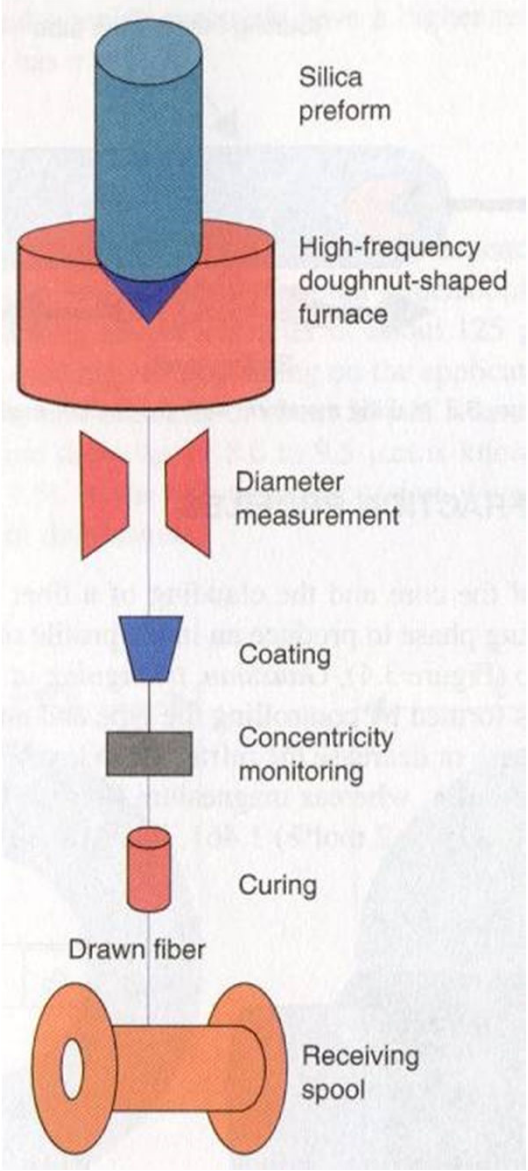
- Fibers
- AWG Arrayed Waveguide Grating
- Transmission Impairments, transmitters, receivers, filters
- Optical Amplifiers

Fiber Anatomy



Source: Shivkumar Kalyanaraman

Fiber Manufacturing



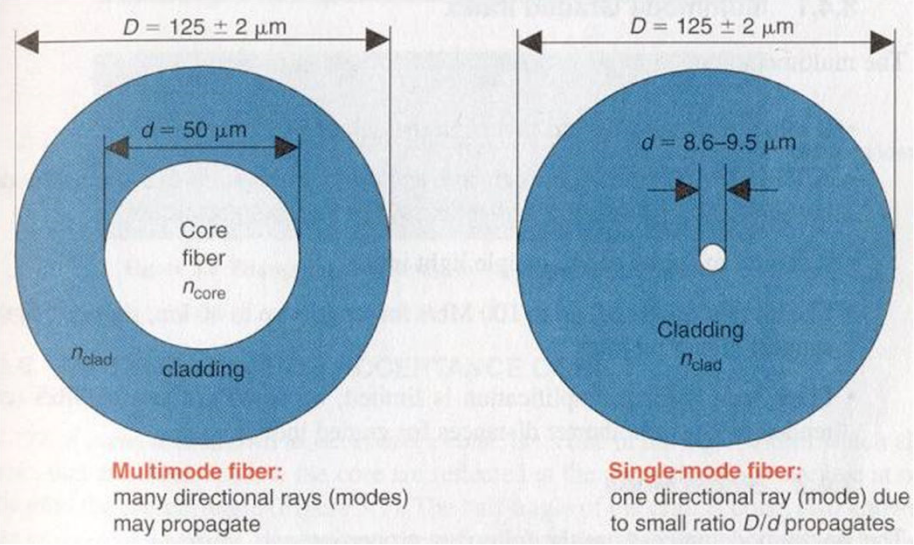
- dopping
  - Graded index
  - (Step Index)

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

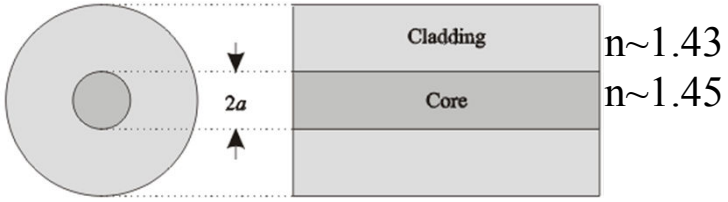
Source: Shivkumar Kalyanaraman

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

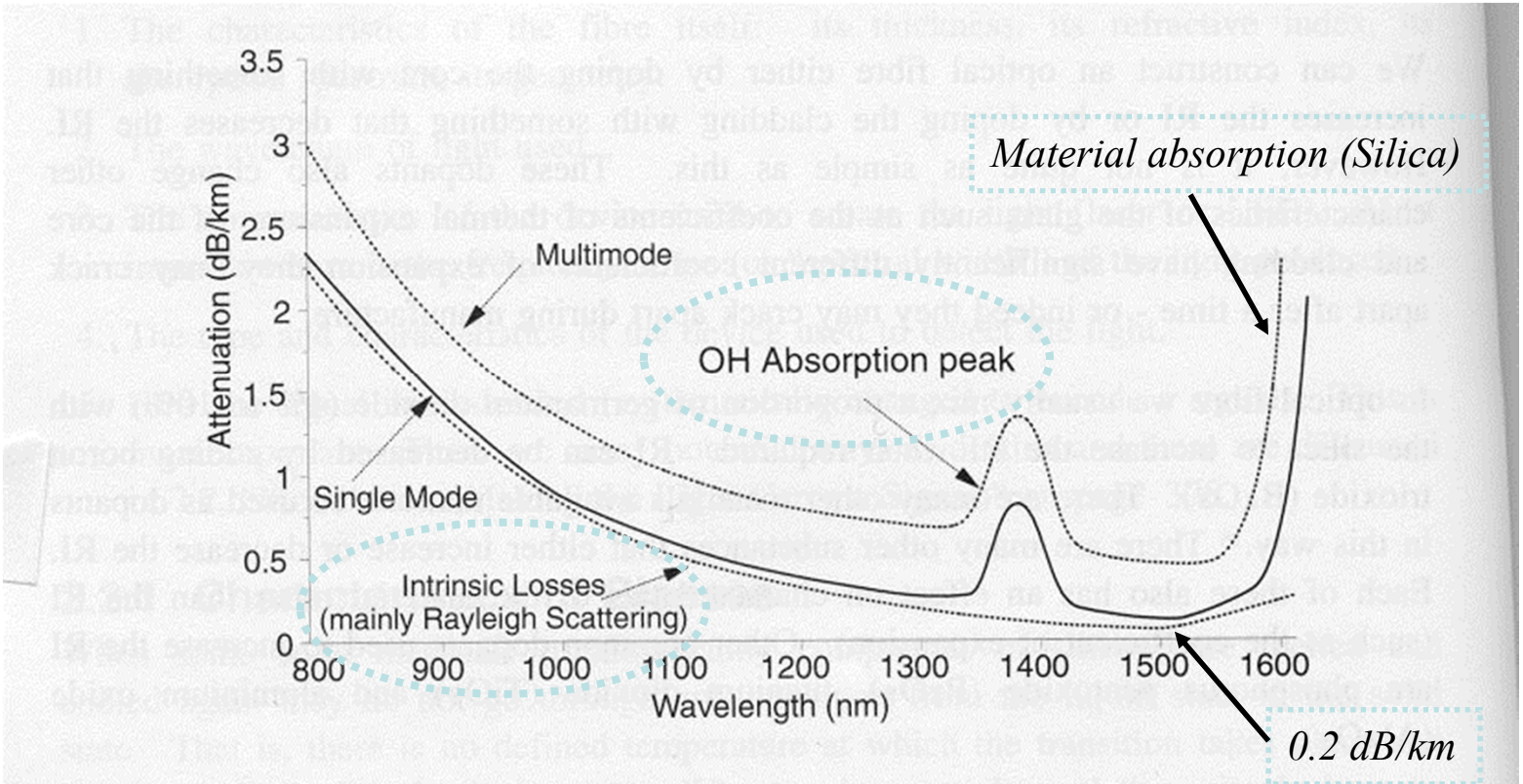


Figure 13. *Typical Fibre Infrared Absorption Spectrum. The lower curve shows the characteristics of a single-mode fibre made from a glass containing about 4% of germanium dioxide (GeO_2) dopant in the core. The upper curve is for modern graded index multimode fibre. Attenuation in multimode fibre is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

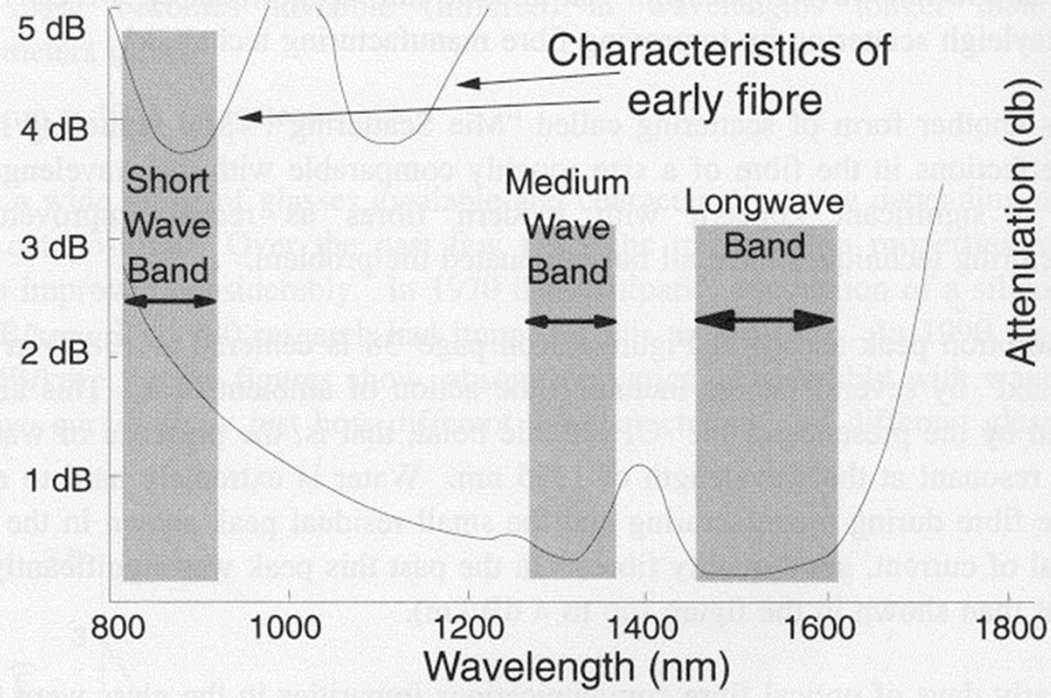


Figure 14. *Transmission Windows. The upper curve shows the absorption characteristics of fibre in the 1970s. The lower one is for modern fibre.*

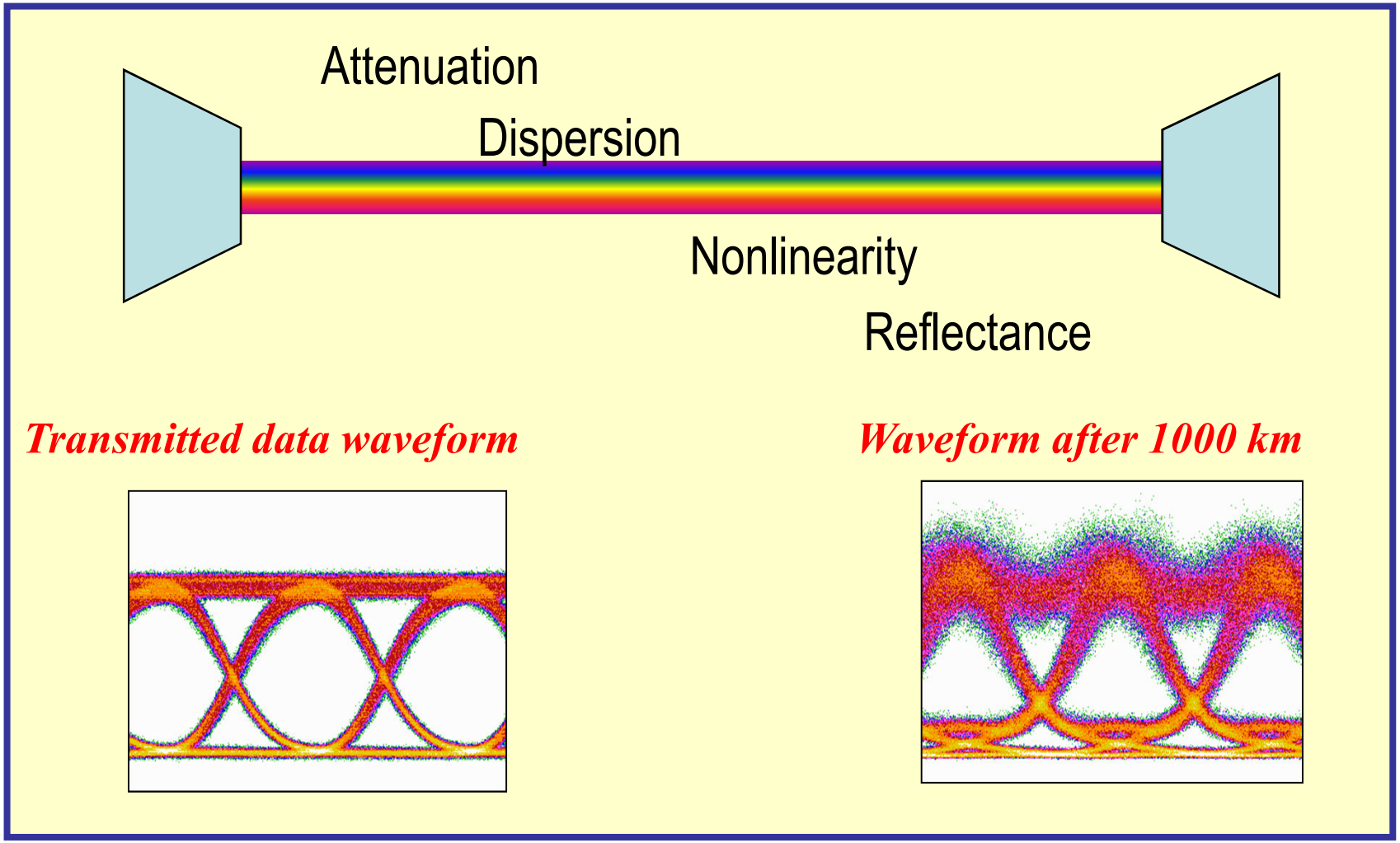
Lucent's new AllWave Fiber (1998) eliminates absorption peaks due to watervapor in the 1400nm area!

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

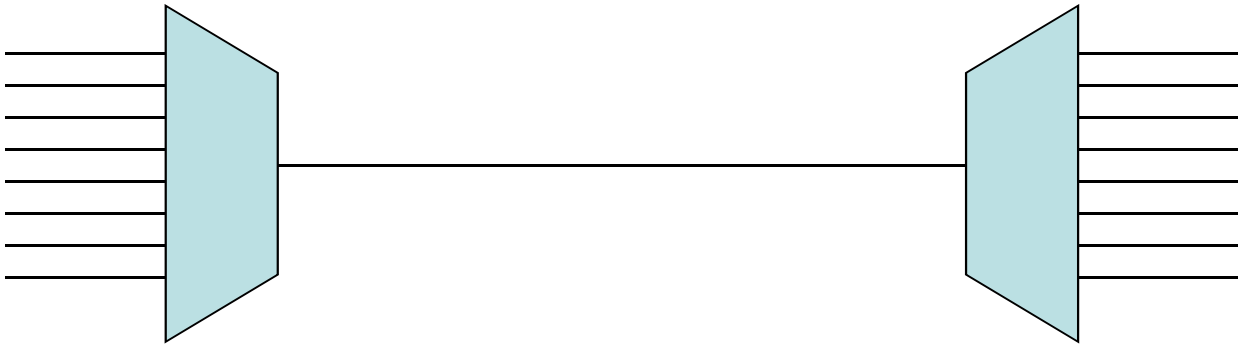
Wavelength MUX/DEMUX

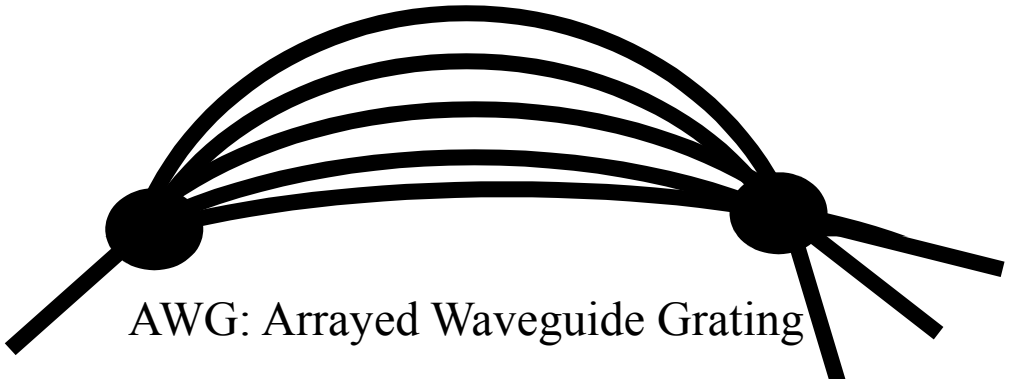
Point-to-point WDM link ...

DWDM (Denser – Wider – Denser)

CWDM (Coarse)

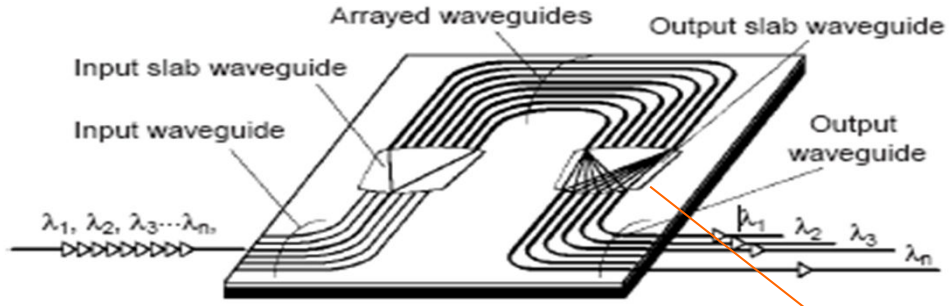
(WDM: Wavelength Division Multiplexing)





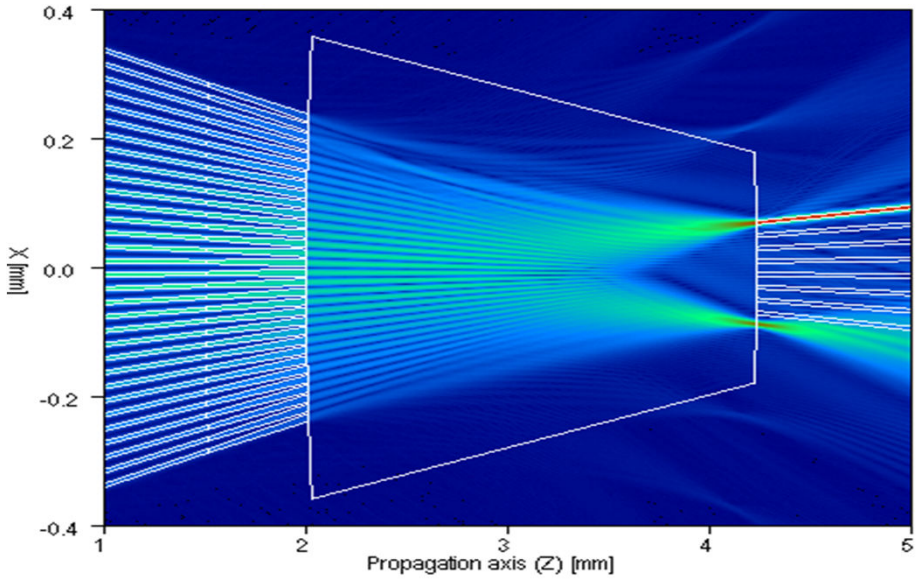
AWG: Arrayed Waveguide Grating

Arrayed waveguide grating



- **AWG**

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



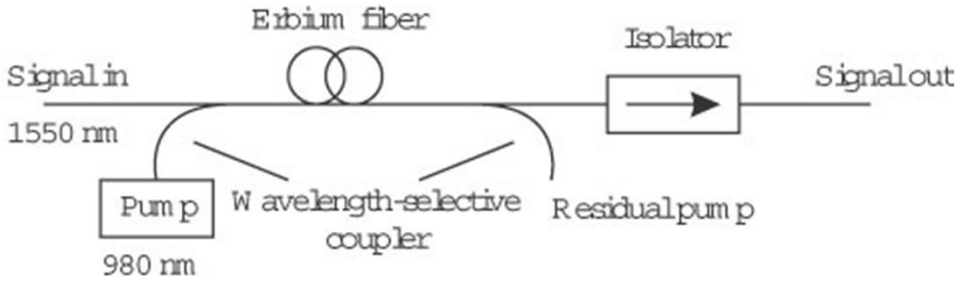
Source: Robotiker, Andrea Bianco Redondo Networks 2008, Budapest

C2V animation

Idaig jutottunk 2015.12.01.

All-Optical 3R?

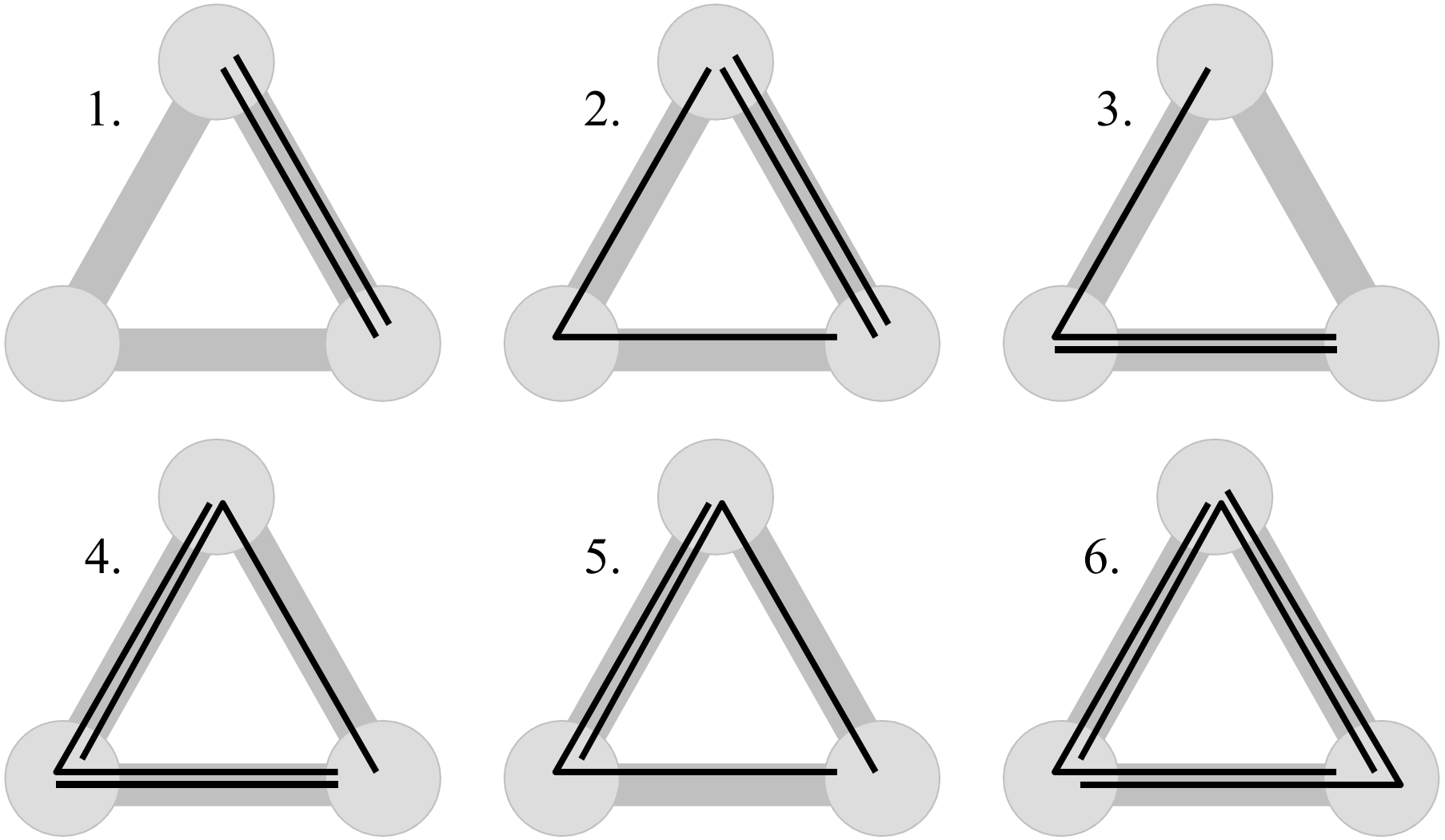
- 3R: Re-Amplification, Re-Shaping, Re-Timing
  - all optically?
- SOA: Semiconductor Optical Amplifier
- EDFA: Erbium Dopped Fiber Amplifier (Er^{3+} or smilar elements)
- Ramman Amplifier



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

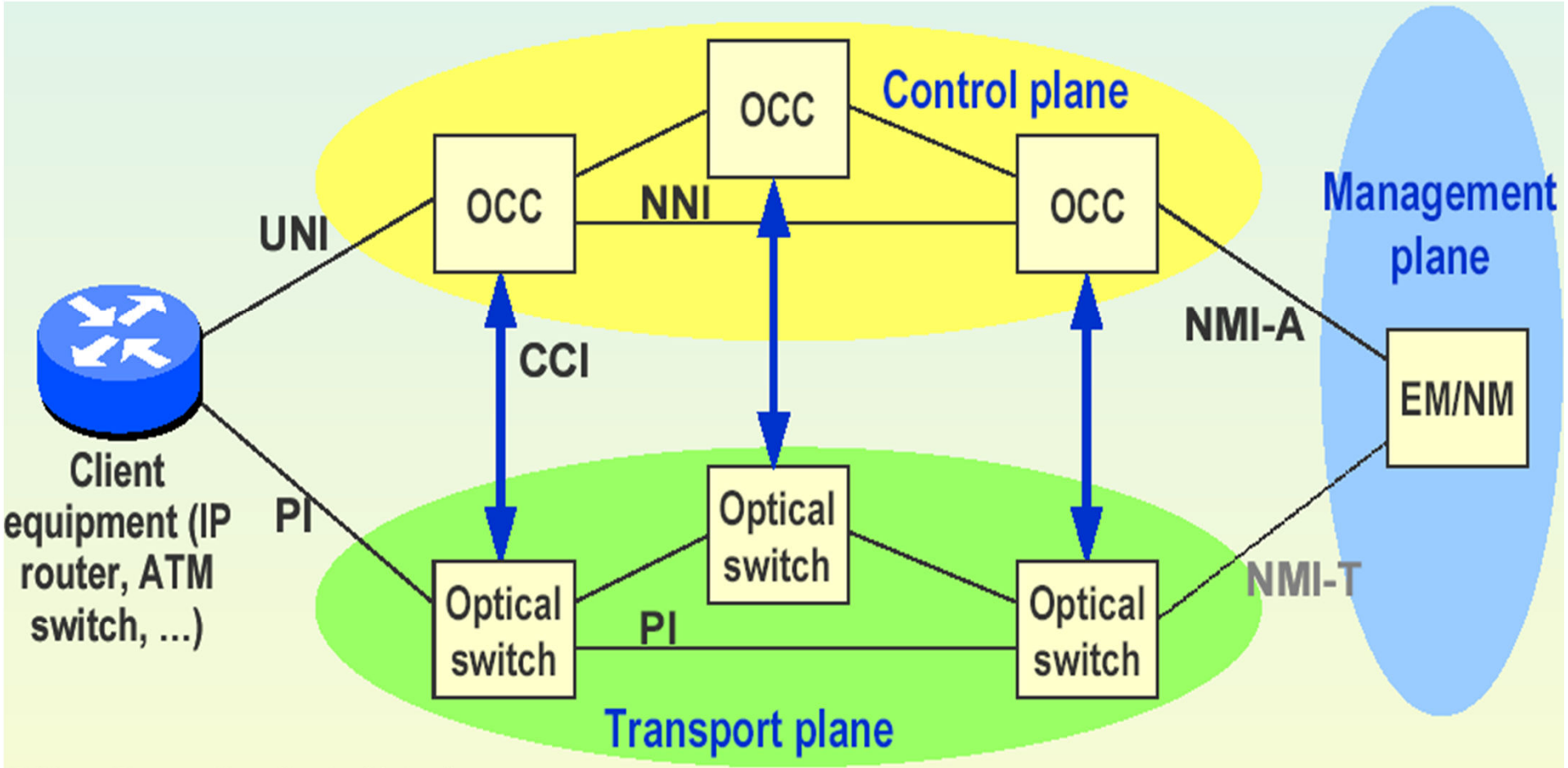
A Negative Example for Dynamic Networks



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


Control plane
OCC
OCC
OCC
NNI
UNI
CCI
Management plane
NMI-A
EM/NM
Client equipment (IP router, ATM switch, ...)
PI
Optical switch
Optical switch
Optical switch
PI
NMI-T
Transport plane
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

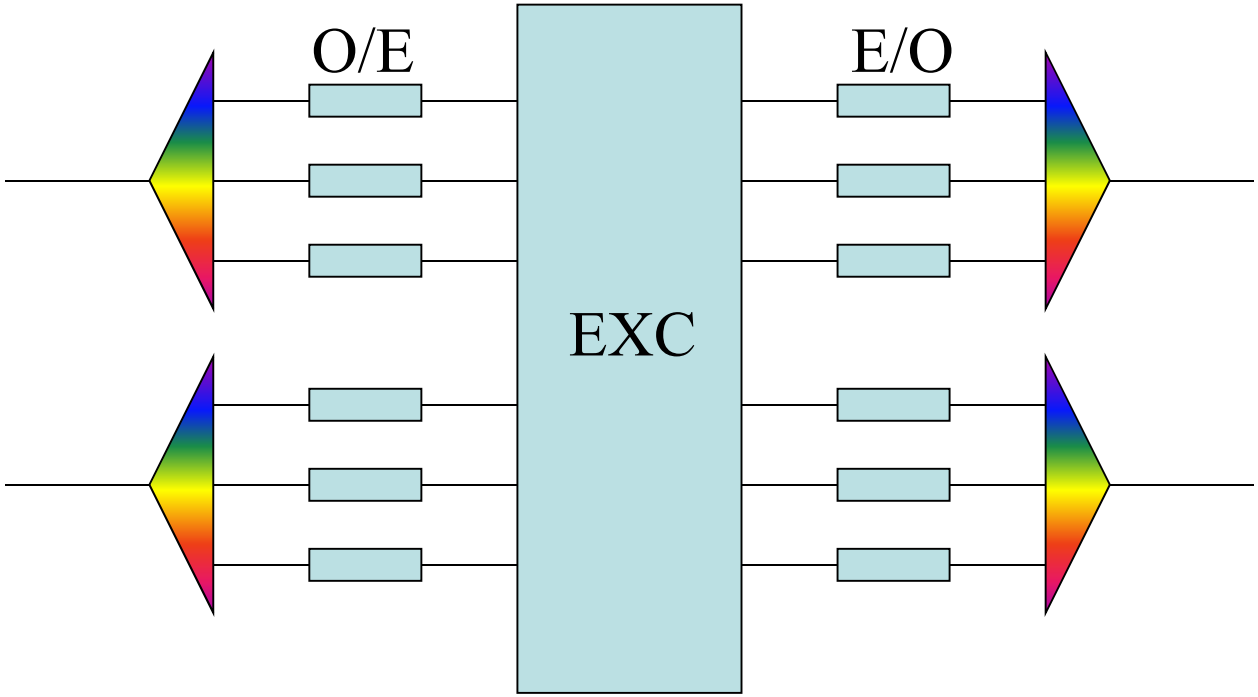
Switching vs. Cross-Connecting

- 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:

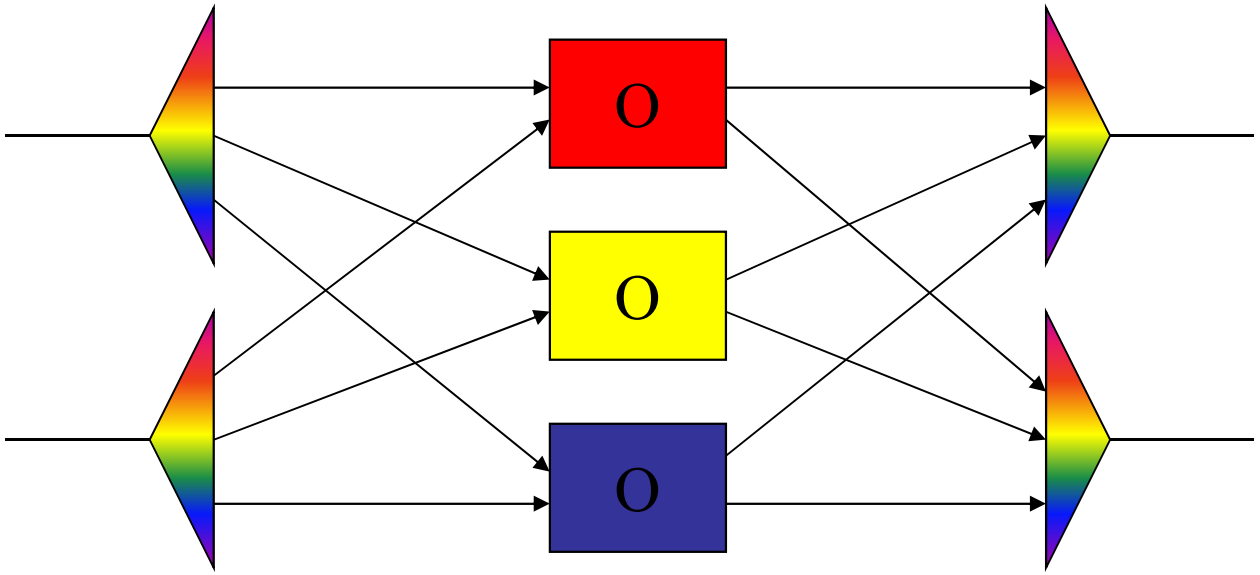
- Permanent
- Soft – Permanent
- Switched

Electro - Optical Cross Connect (EOXC)



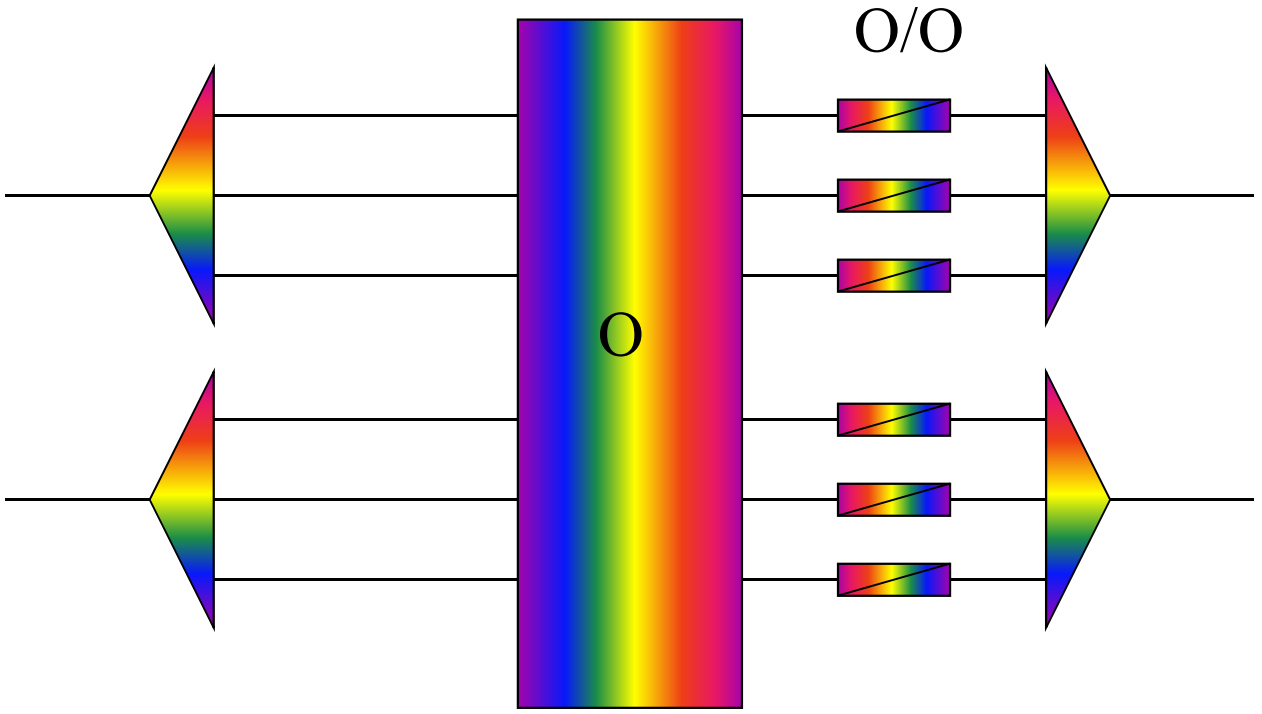
- Full Wavelength Conversion Capability (Property)
- Expensive Transponders
- Cheap, fast electronic core (space switching: EXC)
- Not transparent

Optical Cross Connect (OXC)
No λ conversion capability



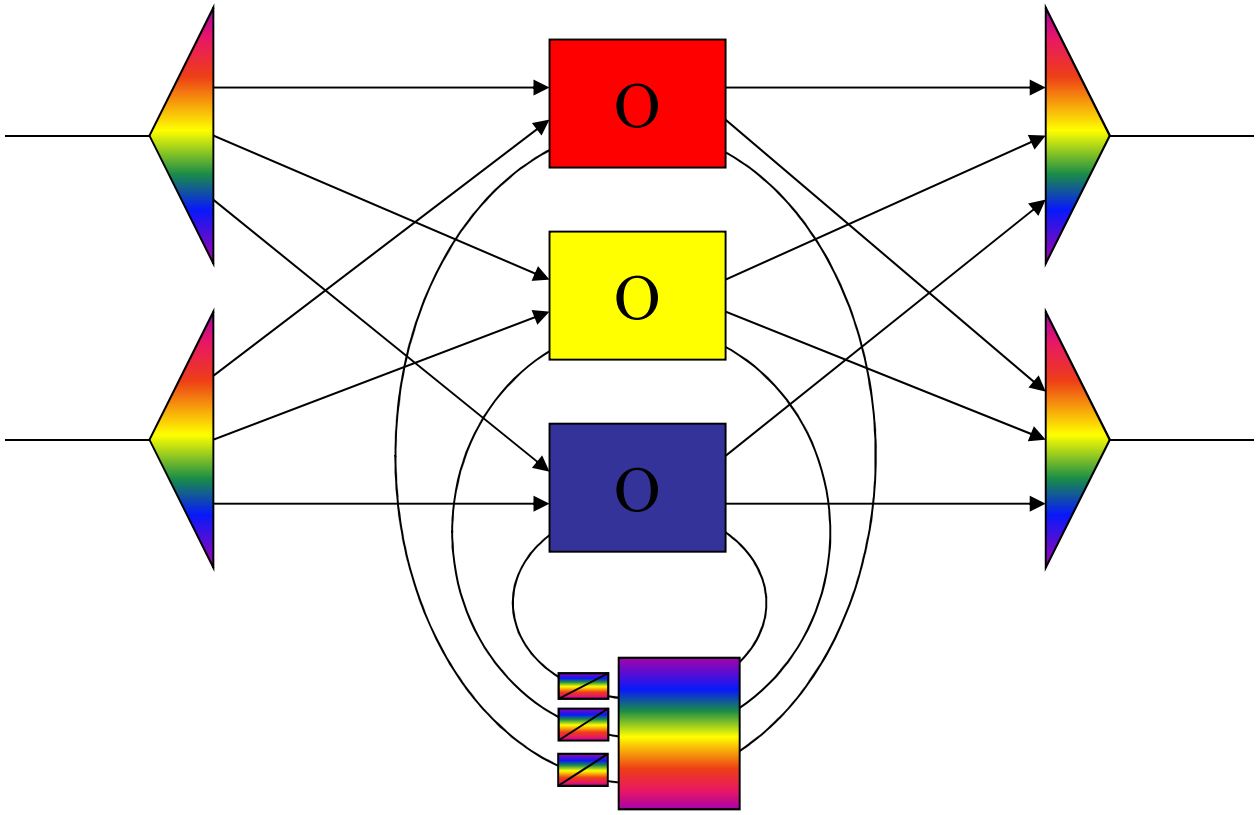
- All-Optical (optical core: 3 x 2x2 = 12)
- No λ conversion capability
- Transparent, but complex routing!

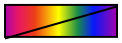
Optical Cross Connect (OXC)
Full λ conversion capability



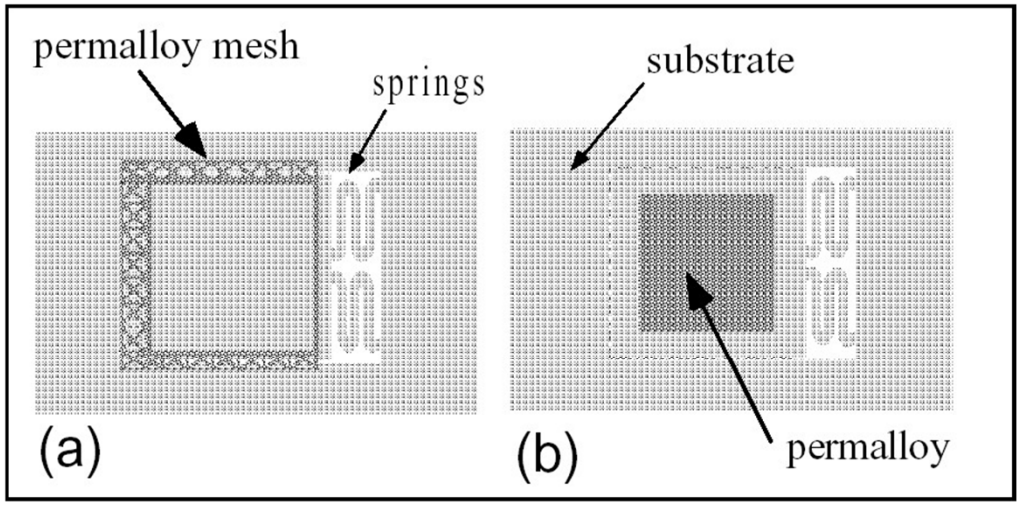
- All-Optical (optical core: 6 x 6 = 36 > 3 x 2x2 = 12)
- Full λ conversion capability
- Expensive optical λ converters
- “Opaque”

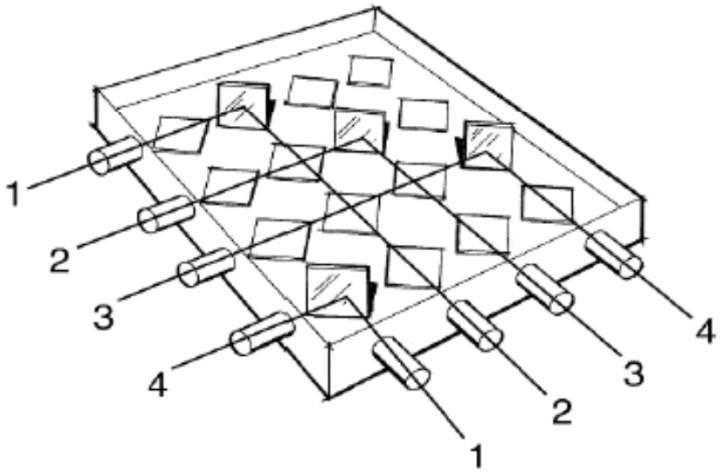
Optical Cross Connect (OXC)
Limited λ conversion capability

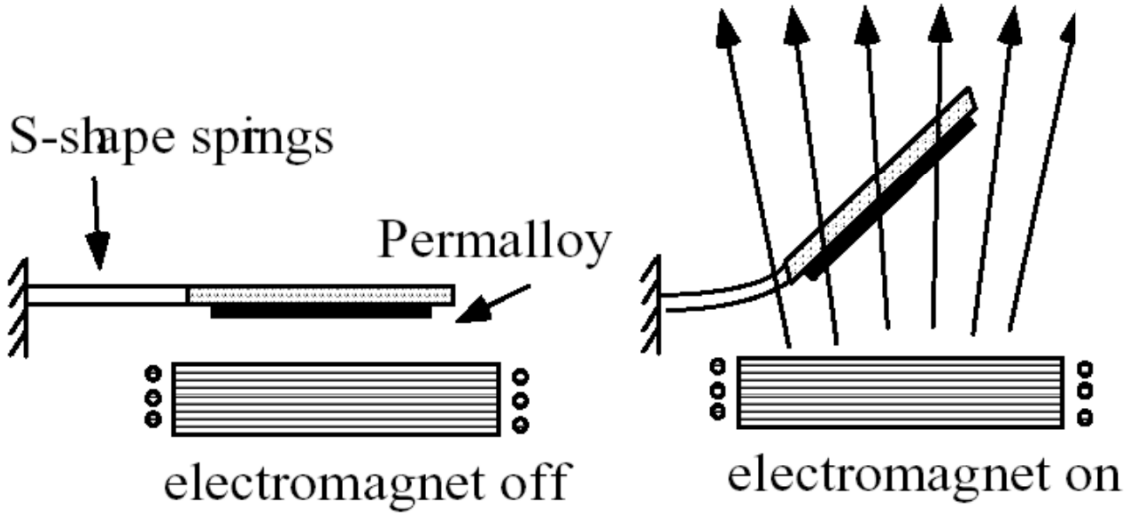


- Limited number of λ converters (Limited Conversion Capacity)
- Can be also limited in range if  is limited in range
- 4 x 3x3 = 36, but only 3 λ converters instead of 6

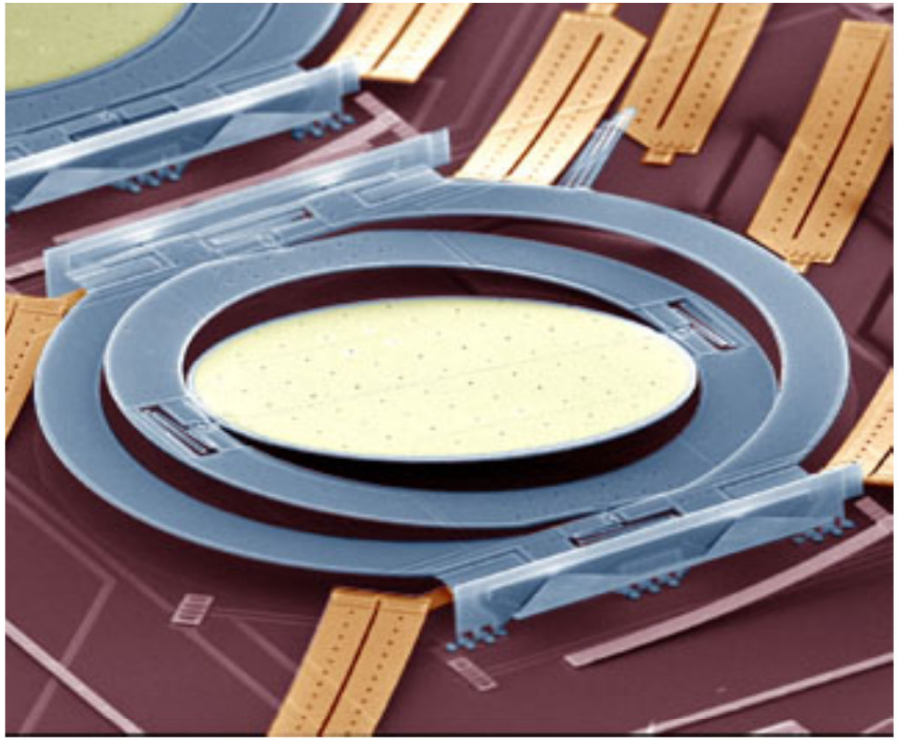
2D MEMS


permalloy mesh
springs
substrate
(a)
(b)
permalloy

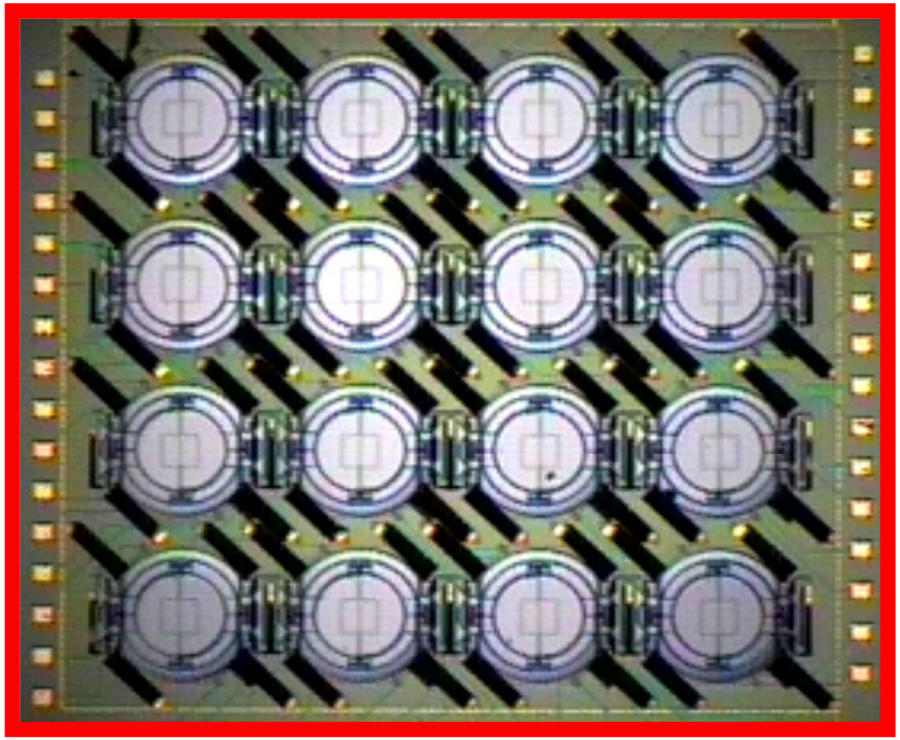

1
2
3
4
4
3
2
1


S-shape springs
Permalloy
electromagnet off
electromagnet on

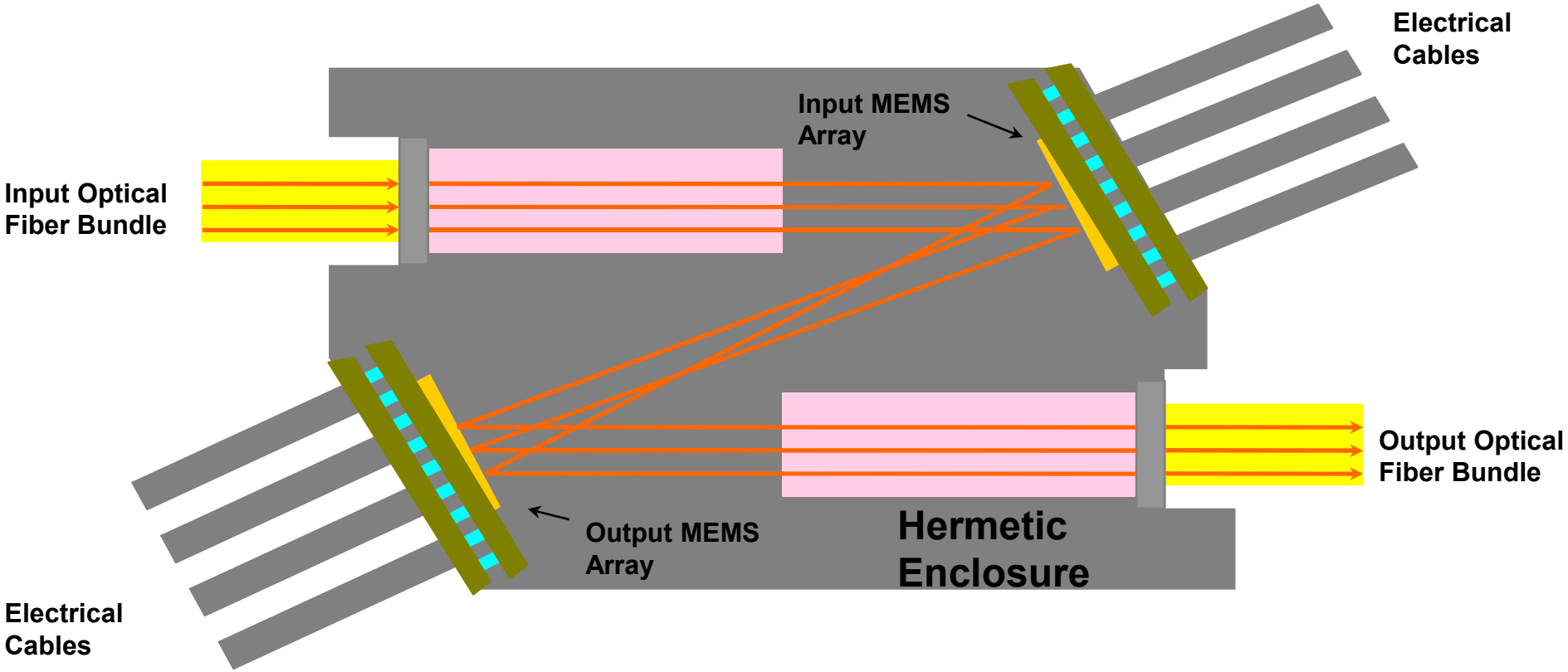
3D MEMS – micro-mirrors



Source: Lucent

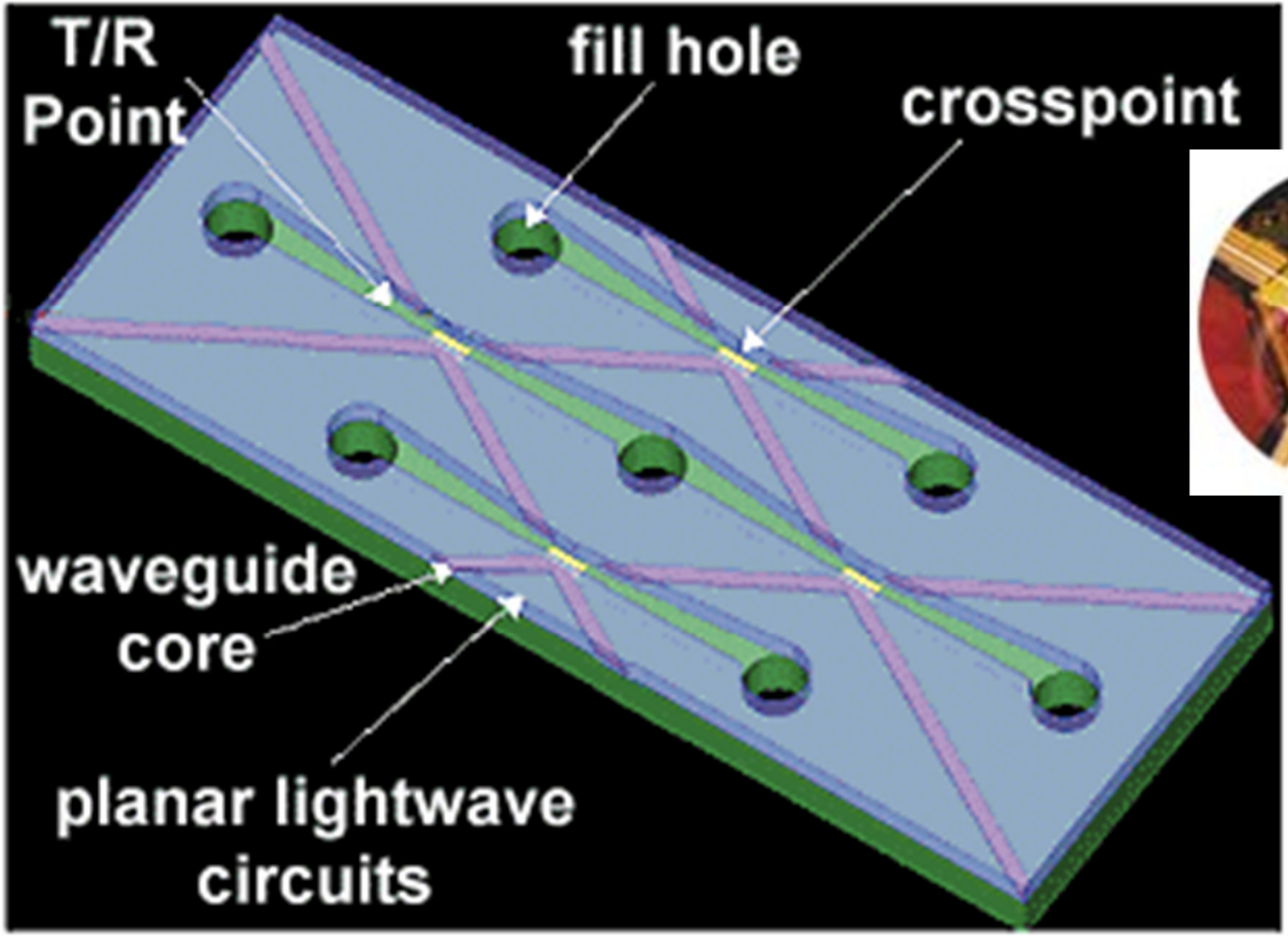


3D MEMS – working principle



Source: Lucent

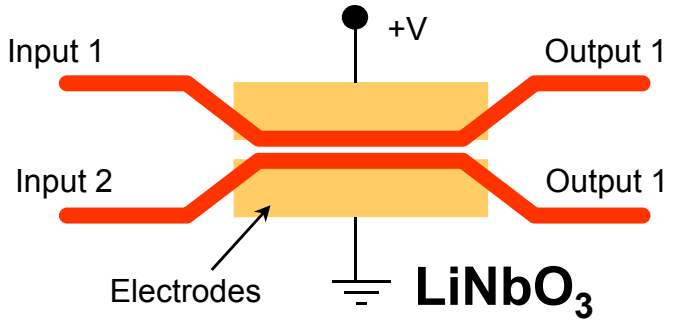
Buble-switch

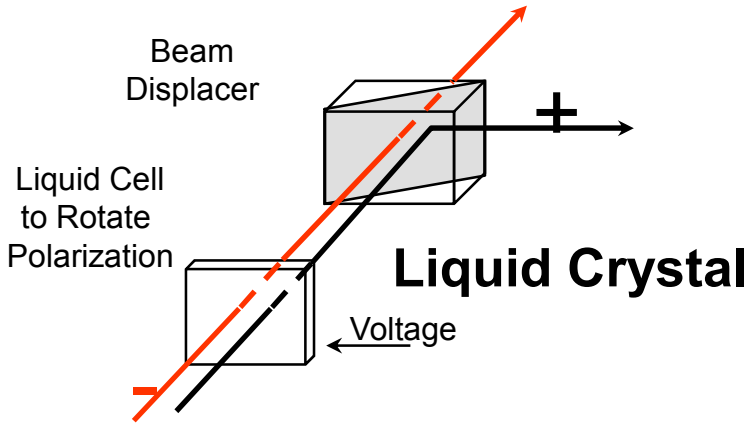


Source:
Agilent

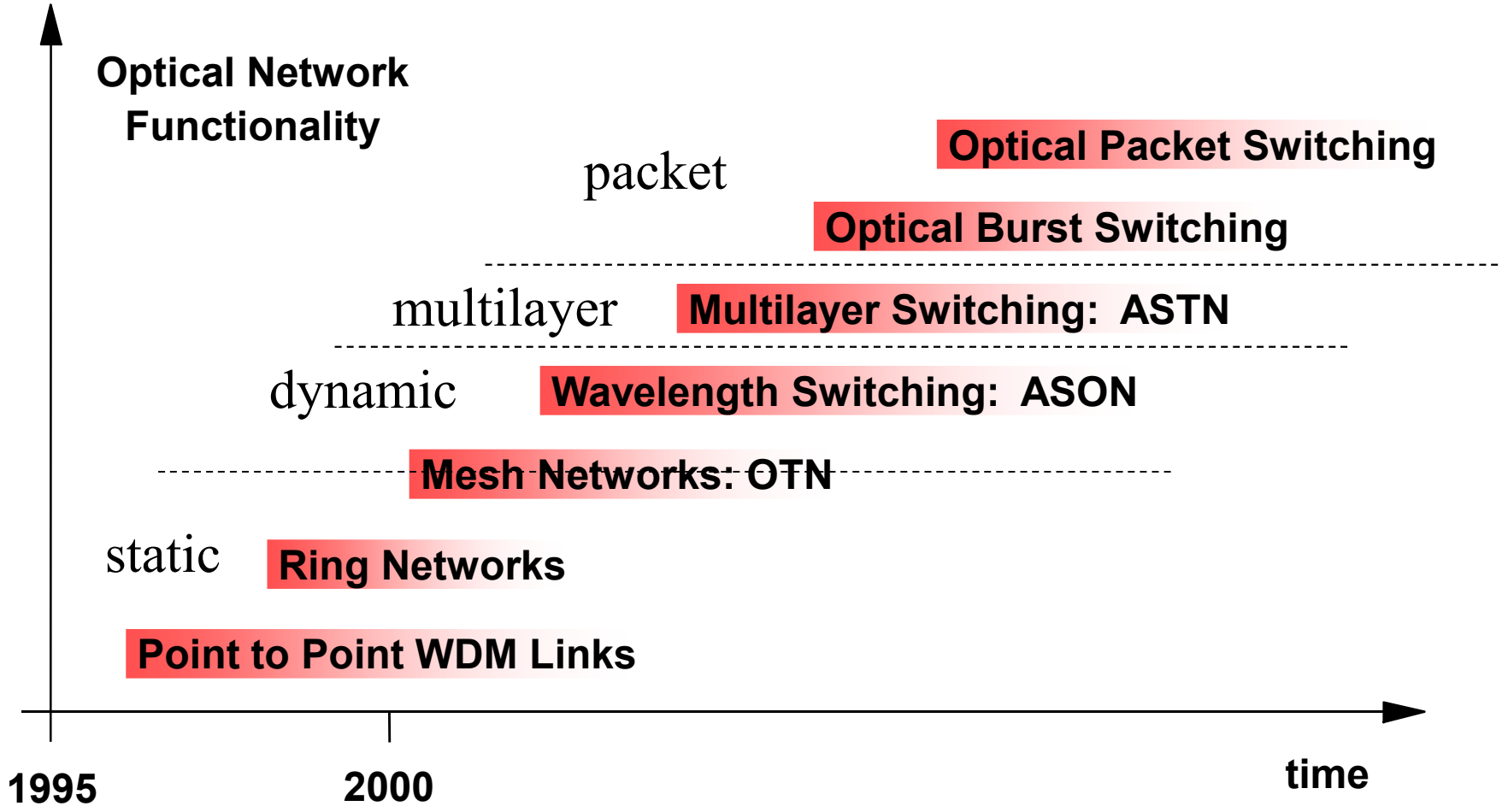
Some other Switch / Cross-Connect Solutions

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





Optical Networking Evolution Roadmap
III. Multi-Layer



III. Multi-Layer

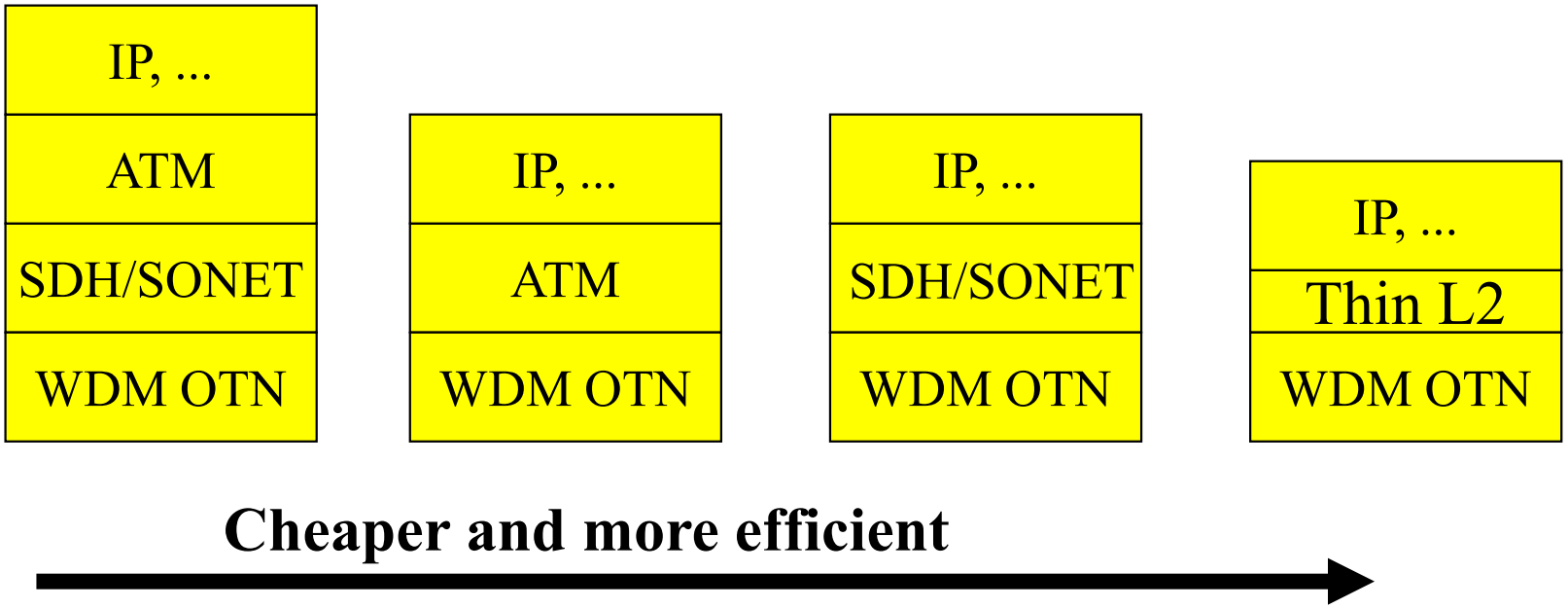
Single Layer:

- 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?