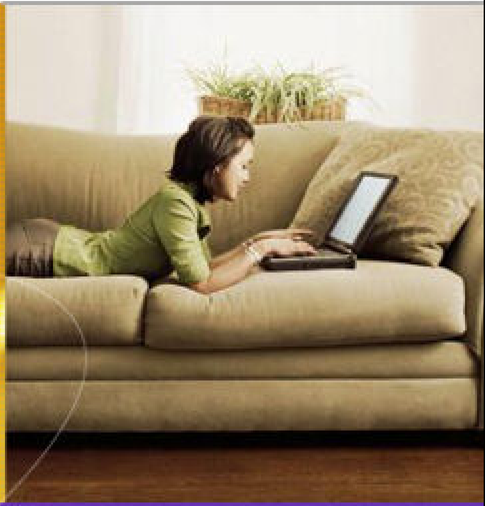
Key technologies for present and future optical networks



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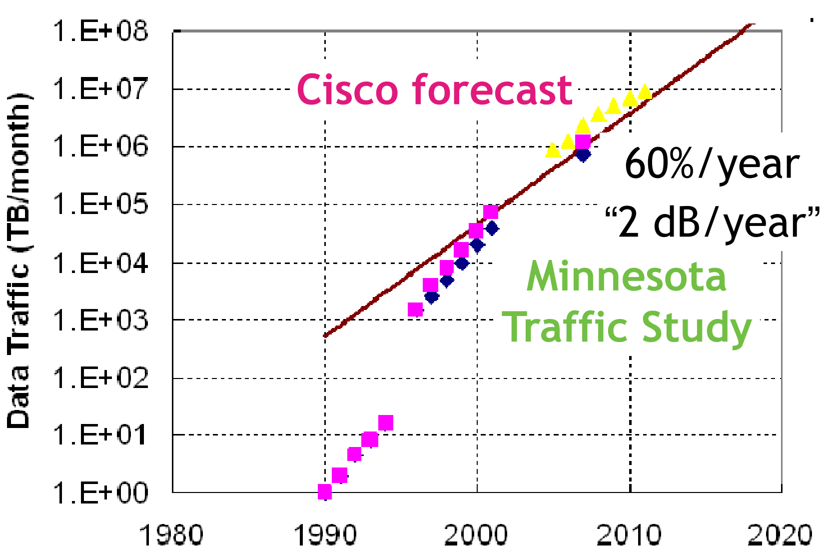
The need for digital transport is growing exponentially

Information is of little use if you have to keep it to yourself

- Humans have a desire to interact (Cell phones, YouTube, …)
- Requires huge transport capacities (especially for real time app's)

Computers also want to talk:

- 1 Flop triggers ~1 Byte/s of transport
- Coupled with exponential growth in computing power



Telepresence

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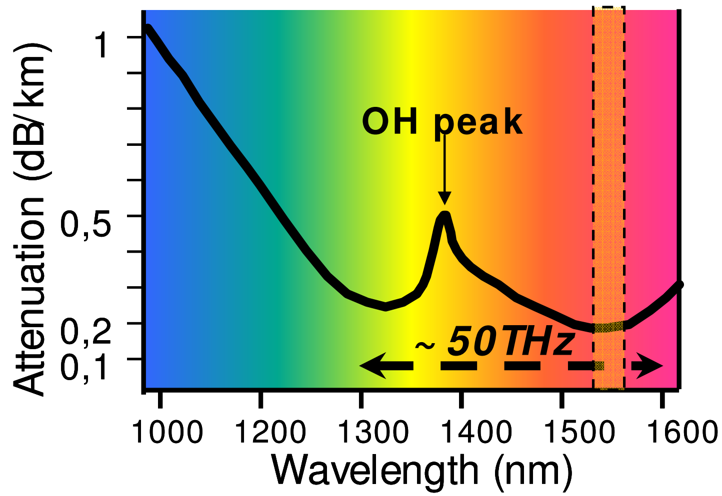
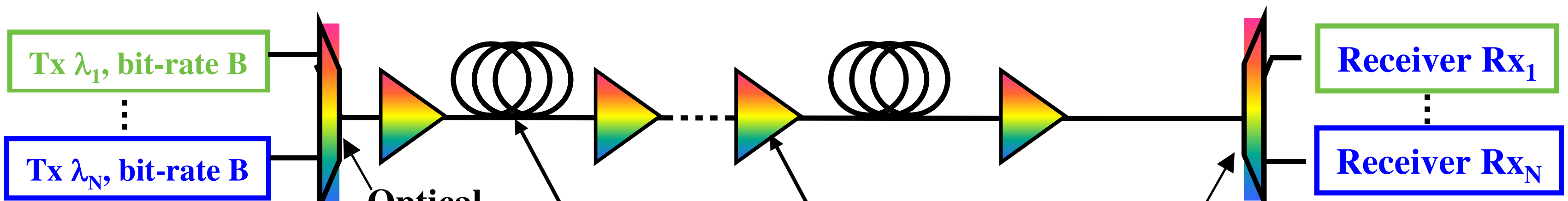
Fiber-optic transmission systems to provide high capacity - Basics

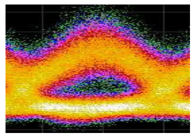
- Guided, isolated from ext. interferences
- **Very low attenuation**
  - 0.3dB/km @ 1310nm
  - 0.2dB/km @ 1550nm (down to ~0.16dB/km)

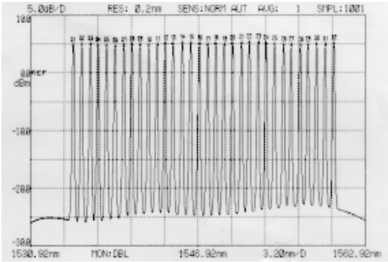


Huge available bandwidth ➔ high capacities ?

- Virtually 50THz
- In practice, operate w/ 4-5THz bandwidth all-optical Erbium Doped Fiber Amplifiers







Wavelength(nm)

Wavelength Division Multiplexing

Typical bandwidth: 1529-1565nm

50-100GHz channel spacing

➔ **Capacity = sum of channel rates**

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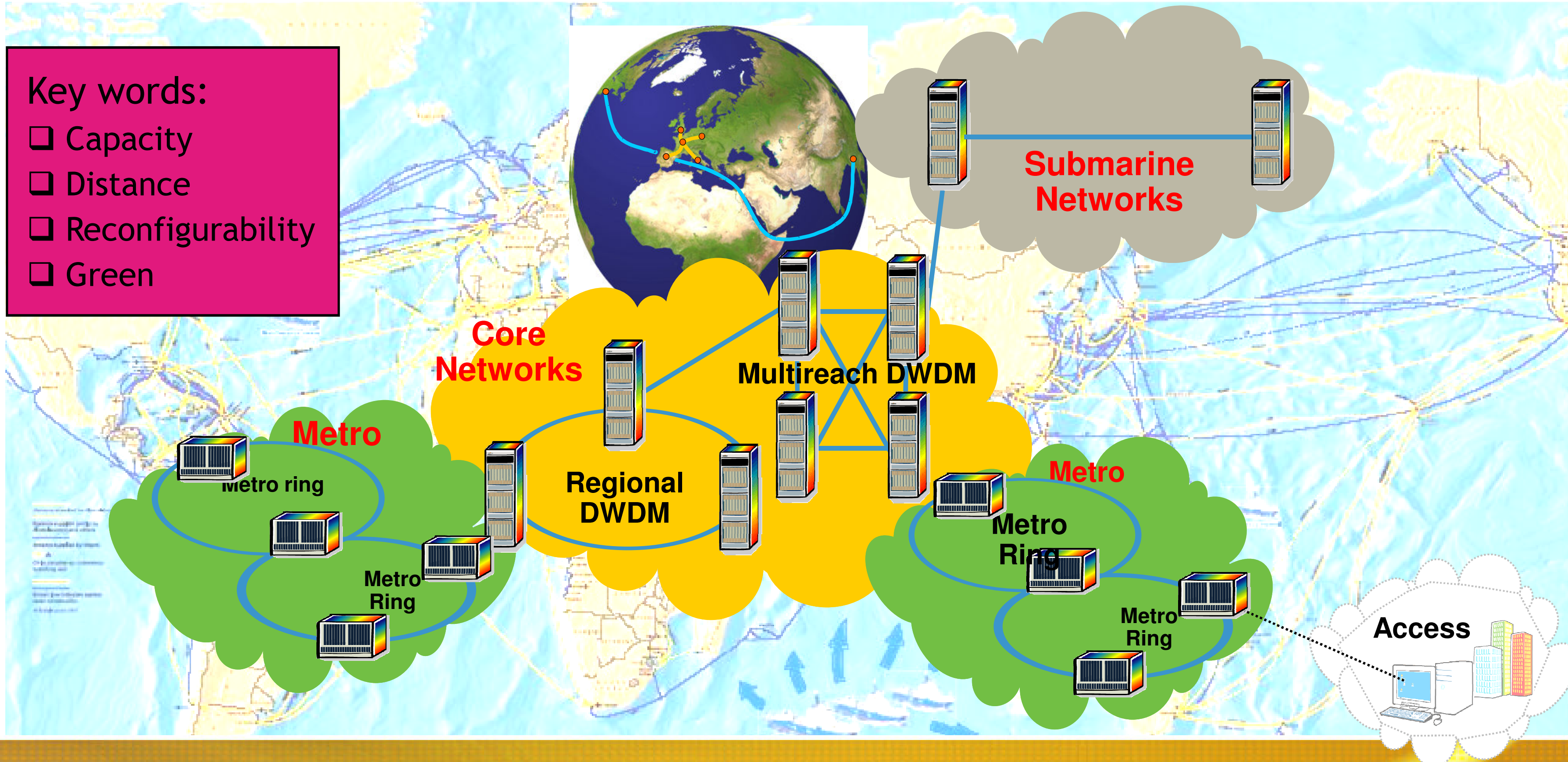
Optical Networks in Telecommunications ? Everywhere

Key words:
- ❑ Capacity
- ❑ Distance
- ❑ Reconfigurability
- ❑ Green



Optical network to support the continuous increase of multimedia traffic

- from submarine & terrestrial down to metro/access networks
- from « point to point » to « multi-point to multi-point » reconfigurable networks

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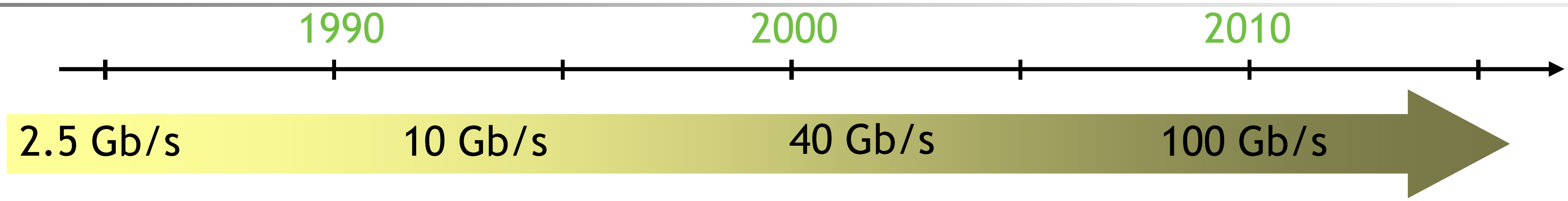
Trends in Telecommunications – from Capacity explosion …

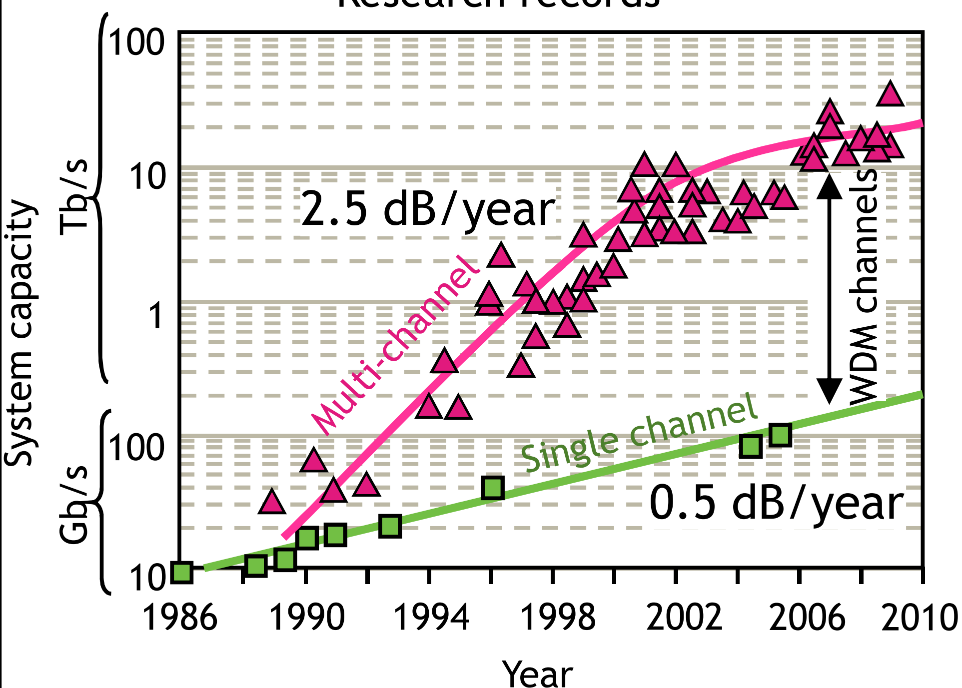
Greater capacity into a single fiber

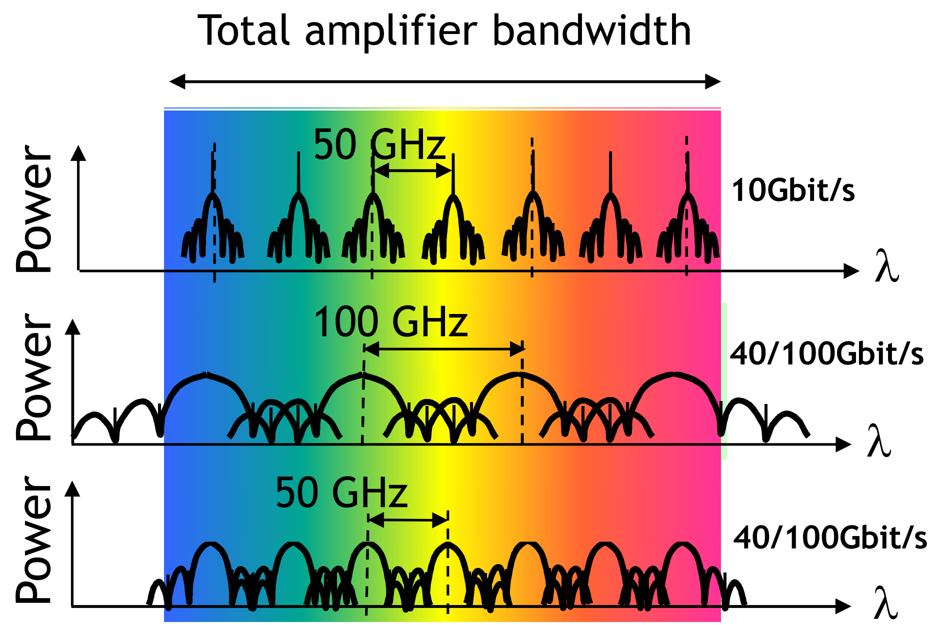
Per-channel bit rate



Trend #1 : greater *capacity* ➔ exponential growth, driven today by video traffic

Research records





Key points :

- Increase total capacity, not only channel rate !
- Reach the same distances as with today's rate

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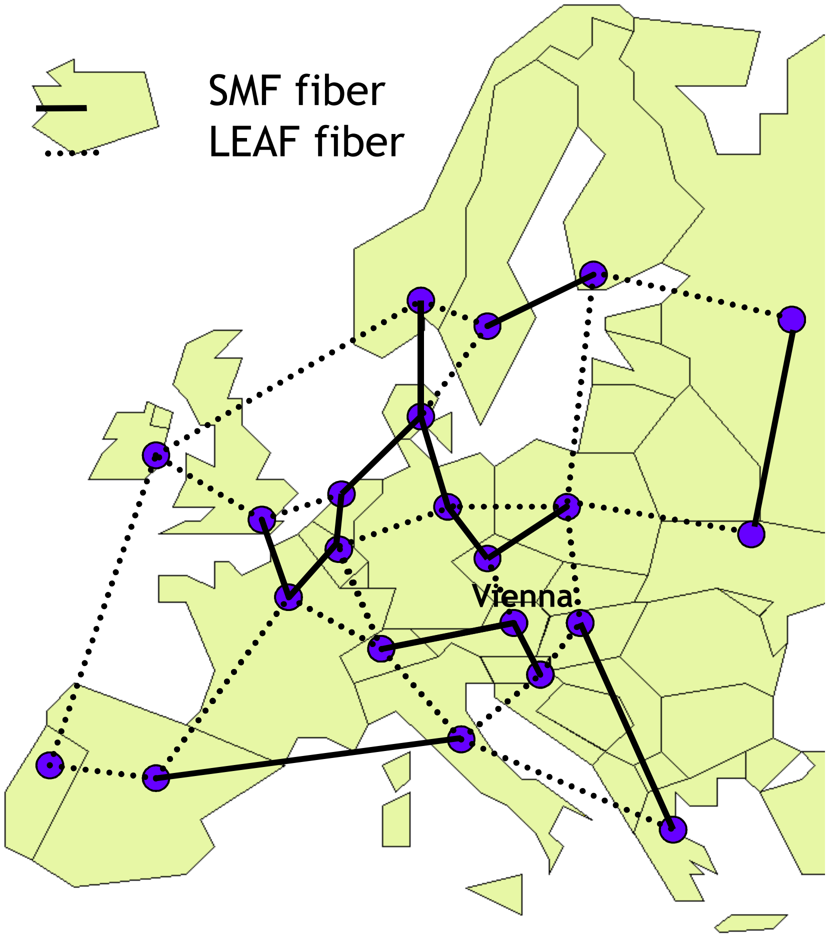
Trends in Telecommunications – … to Operational Automation
Transparent, reconfigurable mesh networks



Trend #2: *Higher transparency* ➔ photonic pass-through, eliminates regeneration

Key points :

- Bridge longer distances
- Mix bit-rates over the same fiber
- Mix several fiber types across full fiber path

Trend #3: *Full remote reconfigurability* ➔ remotely configure a given wavelength

Key points :

- Eliminates need to forecast traffic
- Eliminates manual intervention
- Provides restoration/protection with resource opt.
- Feeds ctrl plane with photonics parameters…

Trend #4: *Energy consumption reduction*

Key points :

- Keep track of power-sensitive building blocks
- Photonic bypassing of electronic processing

Solutions to transform WDM to manageable networking photonic layer are implemented
Still space for research, innovation, product evolution

TREND 1: GREATER CAPACITY

System Evolution in metro/core terrestrial networks

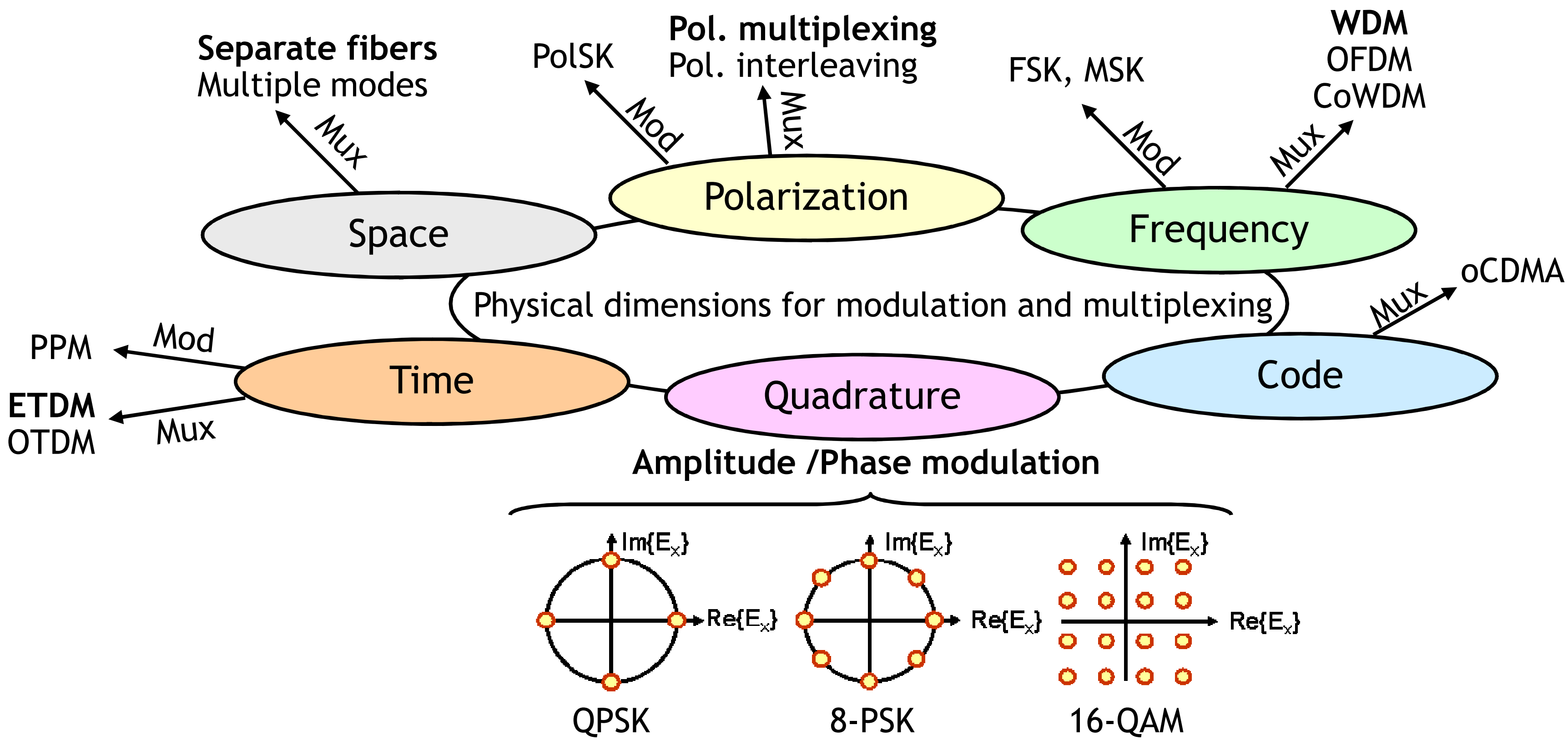
SE = Spectral Efficiency = Channel Bit Rate / Channel Spacing (b/s/Hz)

1990s	2000	2010	2020
2.5-10 Gb/s channel rate	10 Gb/s channel rate	100 Gb/s channel rate	1 Tb/s ! channel rate
8,16, 40 channels	100 channels	100 channels	100 channels
20-160 Gb/s Capacity	1 Tb/s Capacity	10 Tb/s Capacity	100 Tb/s Capacity
SE = .025-.05	SE = 0.2	SE = 2.0	SE = 20 !
History	*History*	*Planned*	*Needed*

➔ When the channel bit-rate increases, the system capacity increases only if the spectral efficiency increases.

Even w/ aggressive 2020 target, traffic growth will exceed capacity growth by factor 10

Signal spaces in optical communications



ETDM: Electronic time-division multiplexing
OTDM: Optical time-division multiplexing
PolSK: Polarization shift keying
FSK: Frequency shift keying
MSK: Minimum shift keying

WDM: Wavelength-division multiplexing
OFDM: Orthogonal frequency-division multiplexing
CoWDM: Coherent WDM
oCDMA: Optical Cade division multiple access
QPSK: Quadrature phase shift keying

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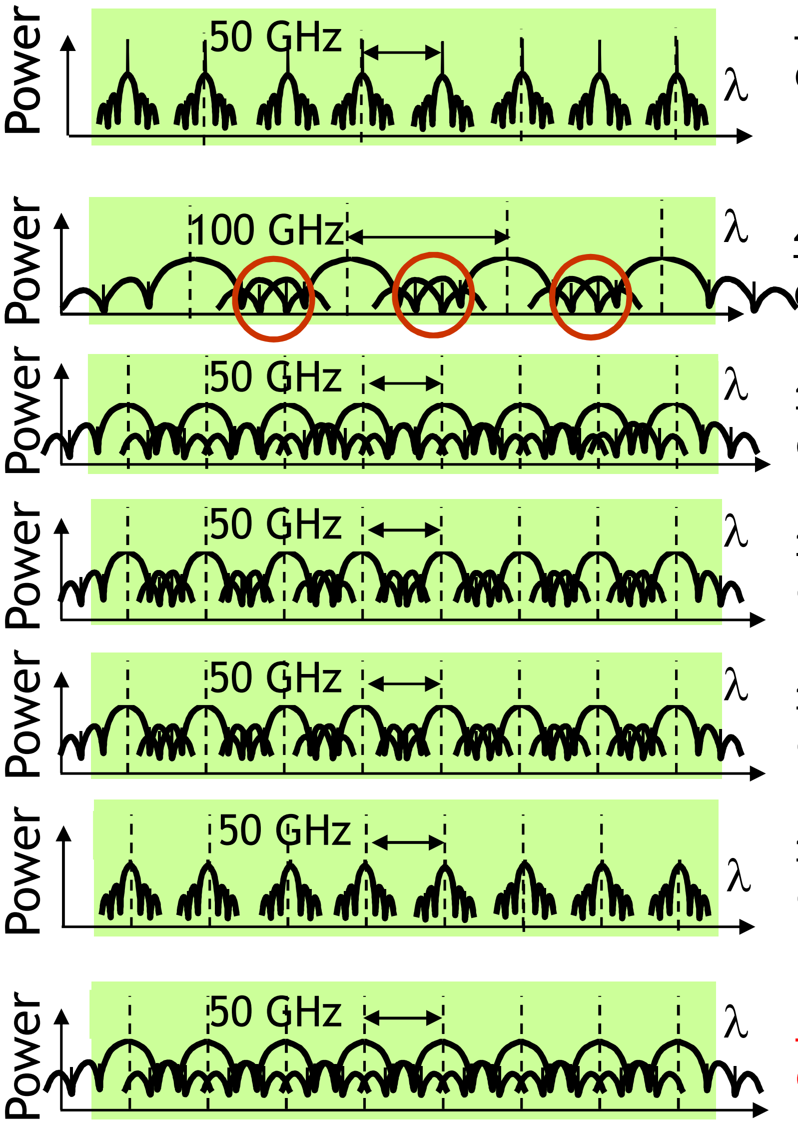
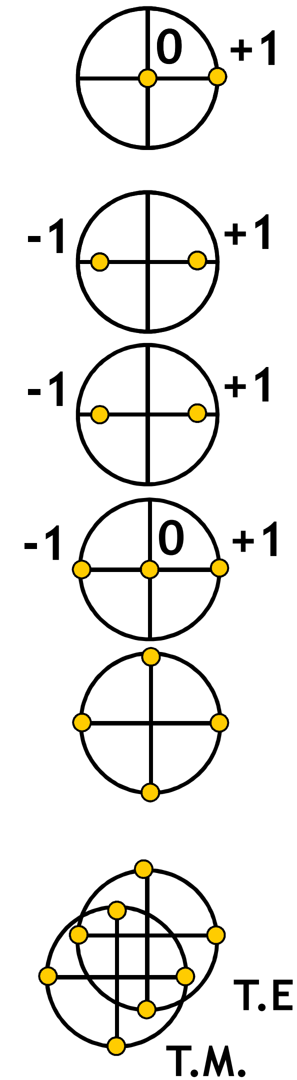
WDM system capacity – « almost mature » technologies

Increasing the spectral efficiency



		Efficiency
10 Gbit/s NRZ	capacity = 80 Gbit/s	20%
40 Gbit/s DPSK	capacity = 160 Gbit/s	40%
40 Gbit/s P-DPSK	capacity = 320 Gbit/s	80%
40 Gbit/s PSBT	capacity = 320 Gbit/s	80%
40 Gbit/s QPSK	capacity = 320 Gbit/s	80%
40 Gbit/s Coherent PDM-QPSK	capacity = 320 Gbit/s	80%
100 Gbit/s Coherent PDM-QPSK	capacity = 800 Gbit/s	200%



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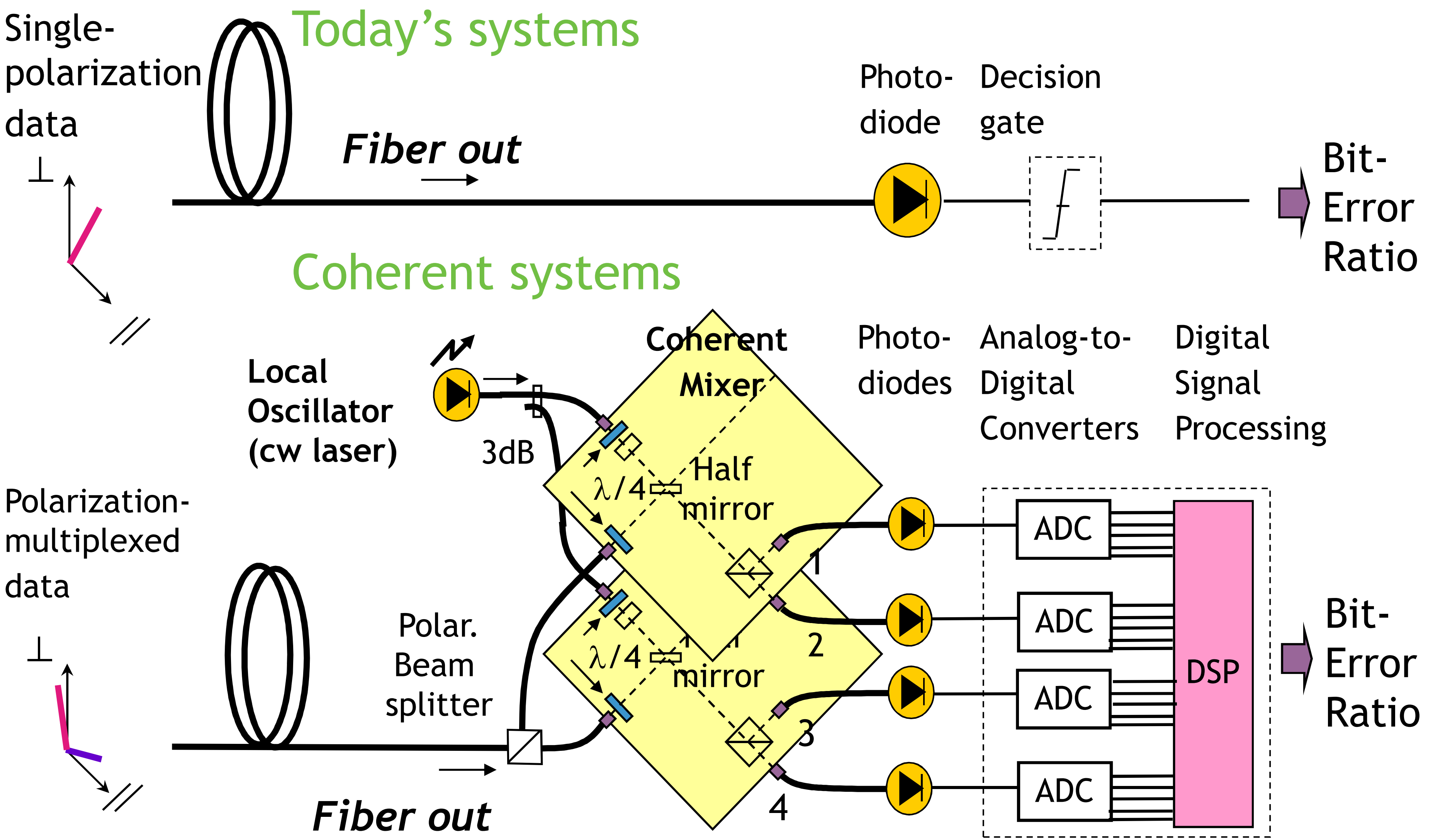
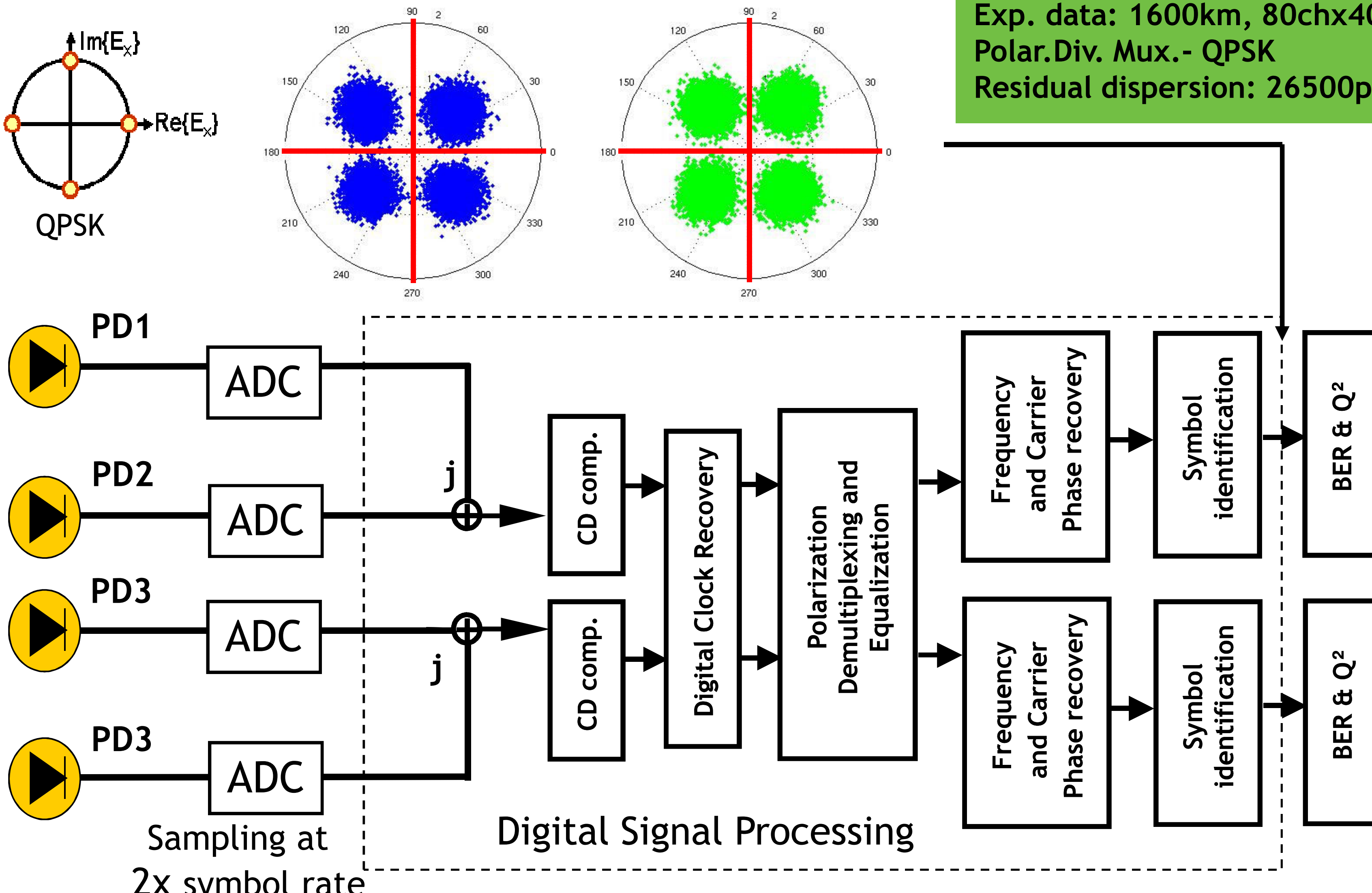
Coherent detection vs today's system reception scheme



The photocurrents PD1, PD2, PD3 and PD4 provide full information on real and imaginary parts of signal along TE and TM polarization axes

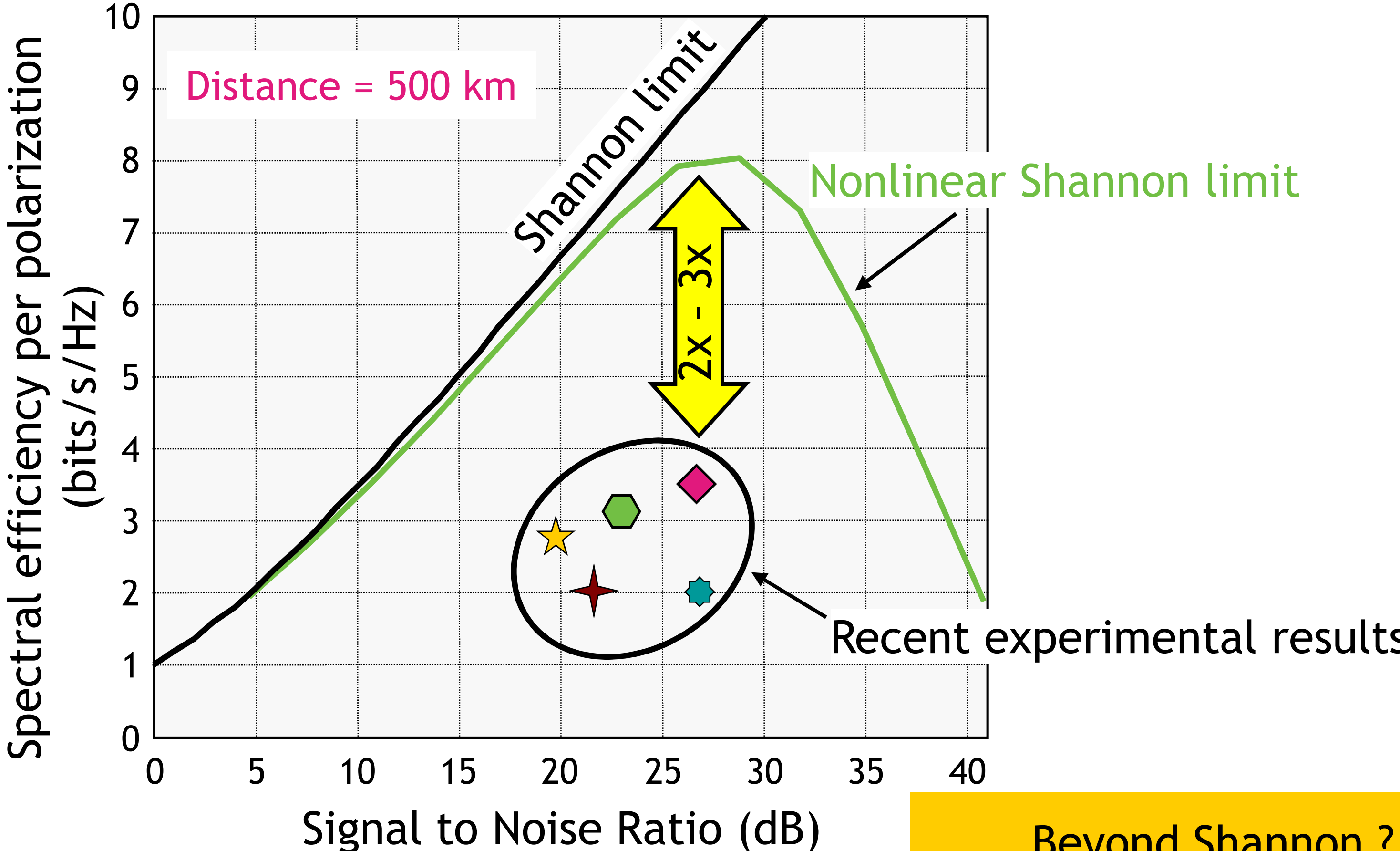
Coherent detection and signal processing

Exp. data: 1600km, 80chx40Gb/s,
Polar.Div. Mux.- QPSK
Residual dispersion: 26500ps/nm



Coherent detection enables advanced modulation formats and efficient signal processing

Record experiments and the non-linear Shannon limit



Beyond Shannon ?
Polarization and space mux

- At&t, NEC, and Corning, ECOC 2008 (106-Gb/s PDM-RZ-8PSK, distance = 662 km)
- KDDI, ECOC 2008 (50.5-Gb/s PDM-OFDM-16QAM, distance = 640 km)
- Alcatel-Lucent, ECOC 2008 (104-Gb/s PDM-16QAM, distance = 315 km)
- KDDI, OFC 2009 (56-Gb/s PDM-OFDM-32QAM, distance = 240 km)
- Alcatel-Lucent, OFC 2009 (104-Gb/s PDM-16QAM, distance = 630 km)

R.-J. Essiambre et al., OFC 2009

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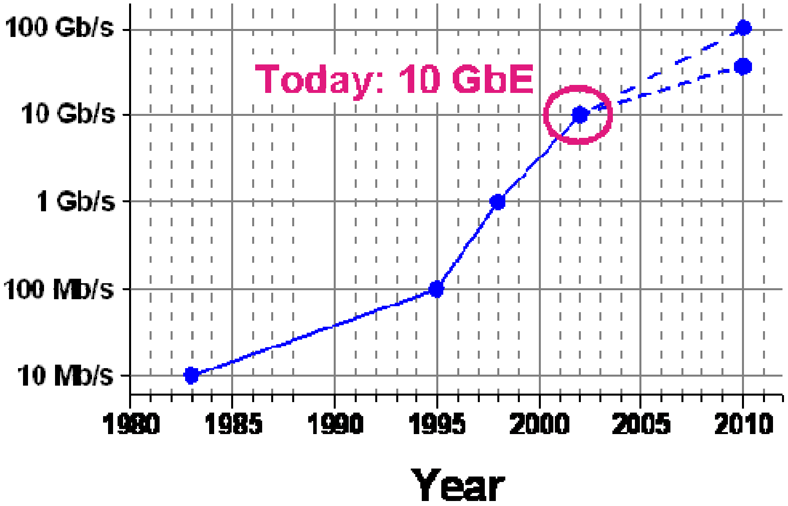
The next frontier: 400 Gb/s and …

Evolution of Ethernet rates



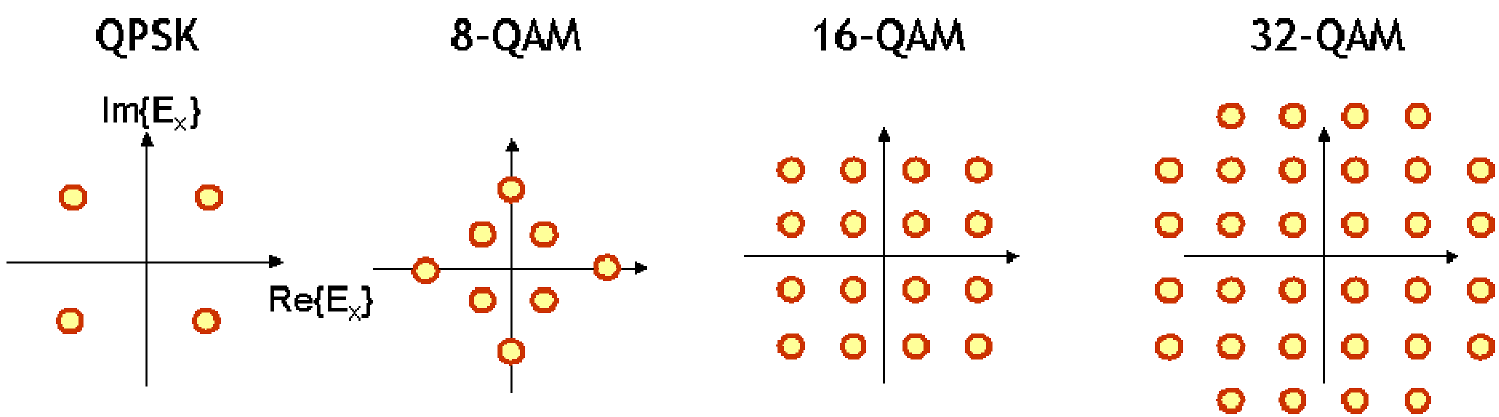
Fundamental problems:

- Bit rate = $\log_2(M)$ x symbol rate
- Higher A/D resolution requirements

Possible solution: Subcarrier multiplexing

But: doesn't solve spectral efficiency …

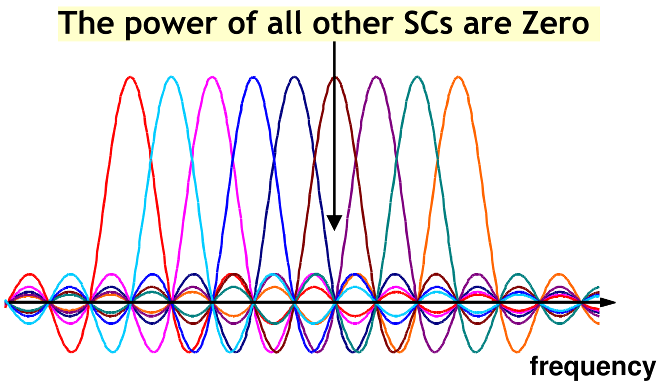
- Req'd SNR increases rapidly (→ limited reach)



QPSK	8-QAM	16-QAM	32-QAM
4 bits/Symbol	6 b/Symb	8 b/Symb	10 b/Symb
112 GBaud	75 GBaud	56 GBaud	45 GBaud

ADC expected to support 28Gbaud in 2010 for 112Gb/s transmissions

… and >1Tb/s Continuous Waveband



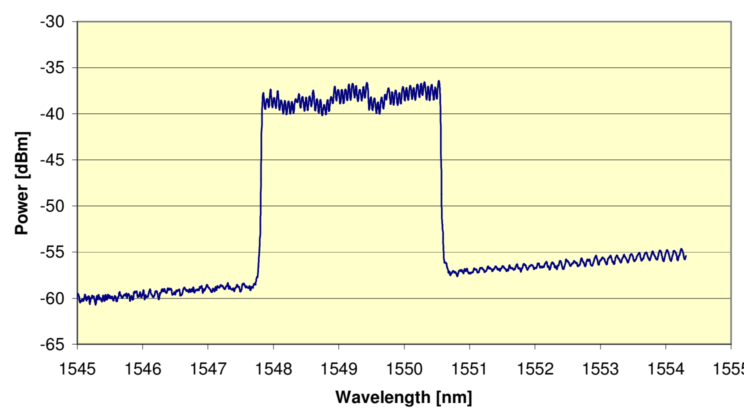
Electrical **orthogonal-frequency-division-multiplexed** (OFDM) subcarriers can be closely spaced in the spectrum without interference, since, at the peak of each subcarrier spectrum, the power of all other subcarriers is zero.

Transmission of 1.21Tb/s Continuous Waveband PDM-OFDM-FDM signal with Spectral Efficiency of 3.33bit/s/Hz over 400km of SSMF

Roman Dischler, Fred Buchali
Bell Laboratories, Alcatel-Lucent, Lorenzstr. 10, D-70435 Stuttgart, Germany
Roman.Dischler@alcatel-lucent.de

Abstract: We demonstrate generation, transmission and reception of a 1.21Tb/s continuous waveband PDM-OFDM-FDM signal with spectral efficiency of 3.33bit/s/Hz. After DCF-free transmission over 400-km SSMF a significant Q-factor margin of 2dB vs. EFEC limit was achieved.
©2008 Optical Society of America
OCIS codes: (060.1660) Coherent communications. (060.4230) Multiplexing

ECOC'08



10x121Gb/s WDM-OFDM spectrum in 340GHz bandwidth (3,3 bit/s/Hz)

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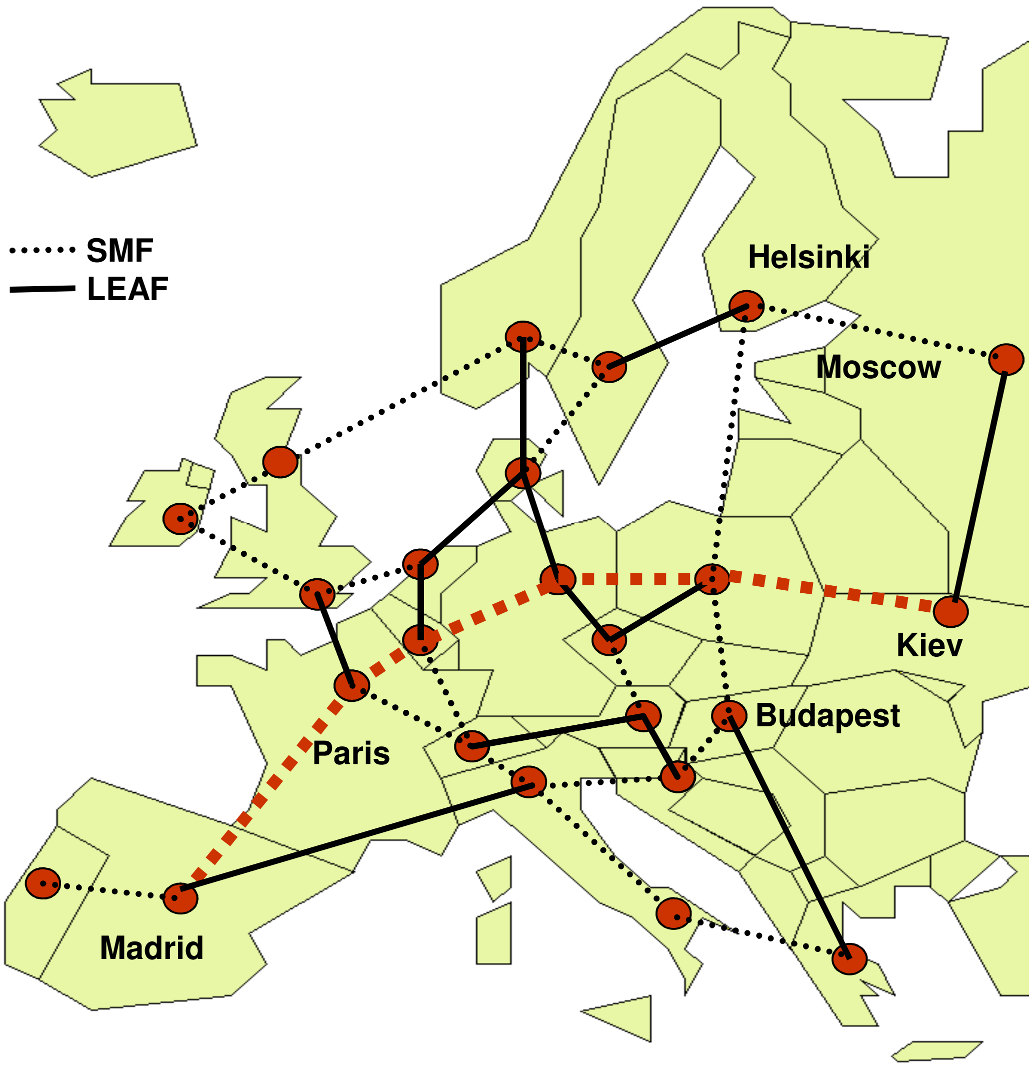
TREND 2: OPTICAL TRANSPARENCY

Towards transparent meshed backbone networks



Past installed Photonic Networks mostly opaque

- **Electrical-Optical-Electrical** regeneration at each node
- All data packets from all wavelengths, fibers, are processed and rerouted towards next node.
- But most of aggregated traffic in transit…

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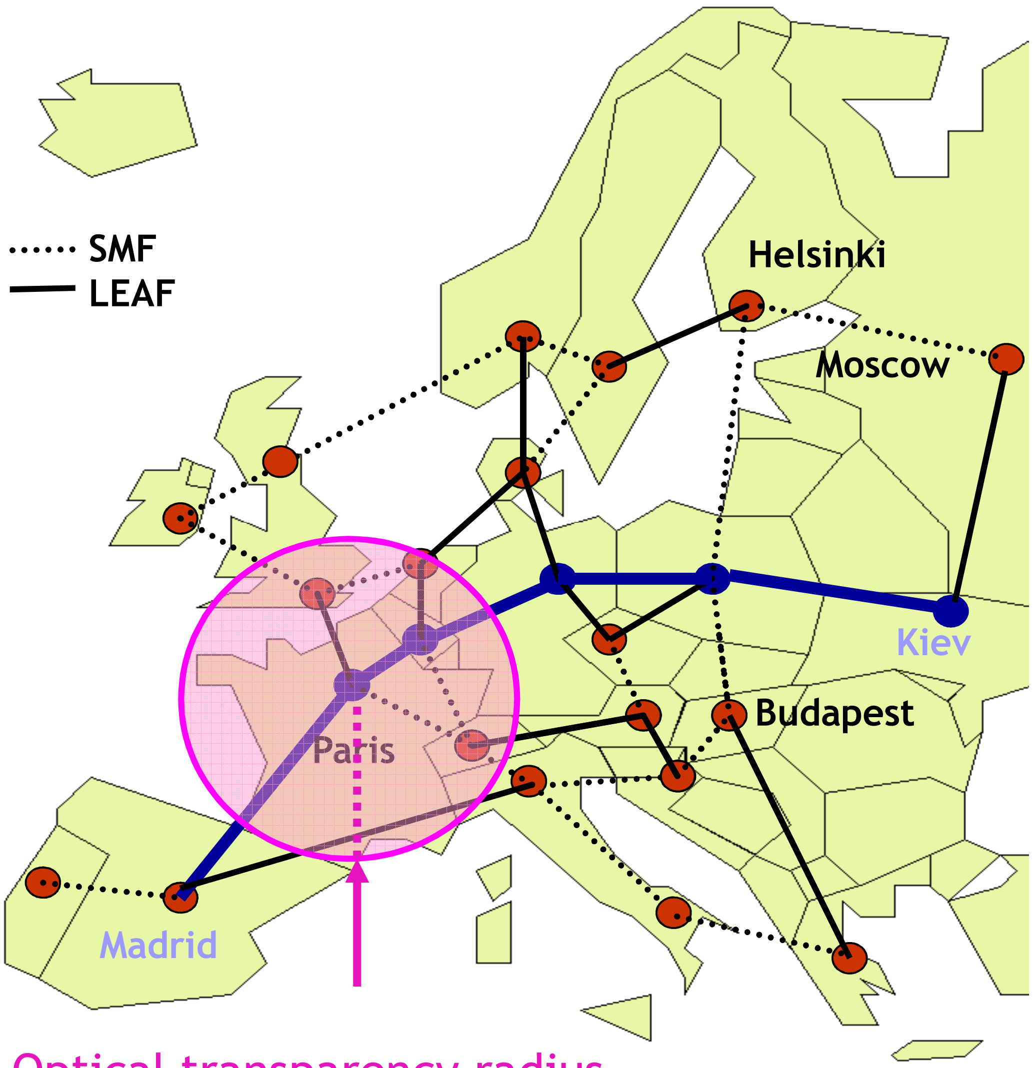
Towards transparent meshed backbone networks



Optical transparency radius

These last years :

- **Transparent nodes (ROADM) :**
  Photonic pass-through, avoiding electrical regeneration, up to the point where it cannot be be avoided.
  - Each wavelength may pass through node or be dropped

⇒ CAPEX and energy consumption reduction

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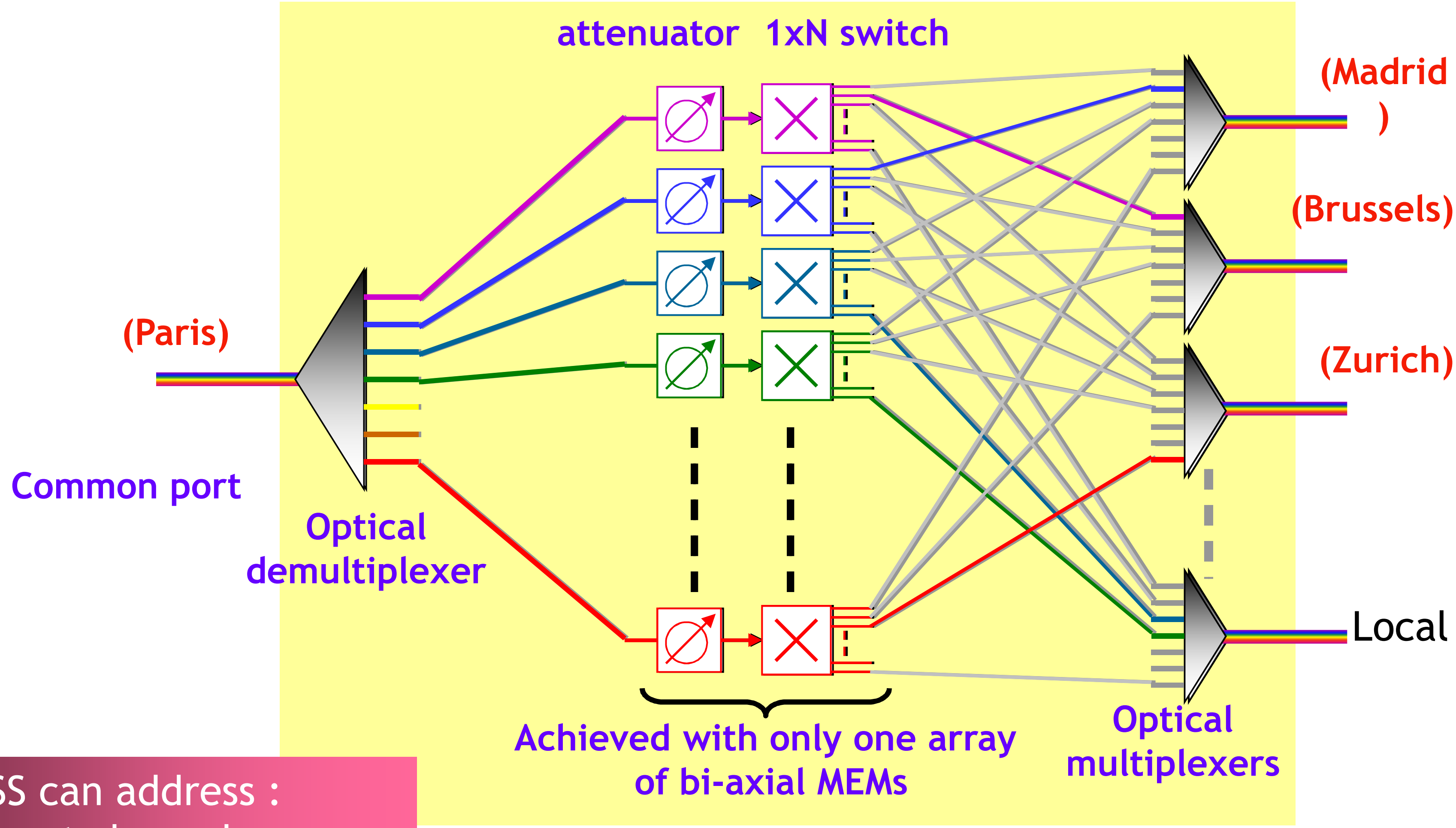
Transparent and reconfigurable node architecture

A key technological element: Wavelength Selective Switch (WSS)



The WSS can address :
- any input channel
- to any output port
- with adjustable loss

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Challenges related to transparent networks

Wavelength-selective switches' based nodes enable slow wavelength switching

Optoelectronic conversion occurs when

- Passing through an electronic packet router to enter/exit the network
- Physical limitations require optoelectronic regeneration

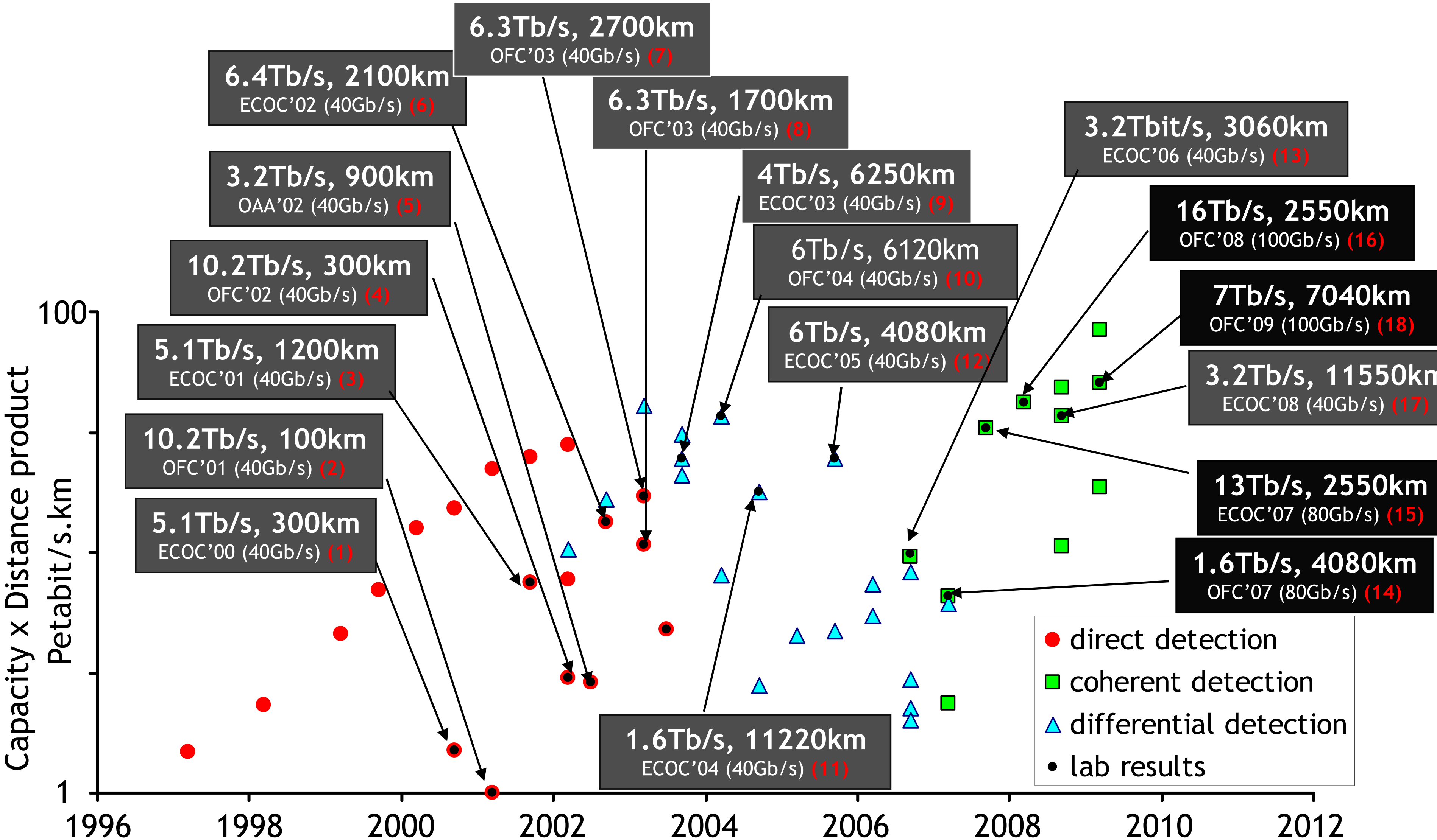
Efficiency in ressources dimensioning requires

- A fine tool to **predict quality of transmission**, accounting for:
- And a **planning tool** to assign routes, wavelengths and resources

Efficiency of transparency may require to reach long distances (1500km)

- **Whatever the bit-rate…**
  - Need efficient solutions: FEC, modulation format, fiber, link design, amplification scheme
  - Ex: Forward Error Correction enables error-free operation from 4 10^{-3} BER with 7% overhead
    - 10Gb/s useful data rate ←→ 10.7Gb/s effective bit rate in optical systems
  - Lab experiment: 160x100Gb/s over 2550km (OFC, 2008): **40 Petabit/s x km**

High bit rate, long distance WDM transmission



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A few words on submarine networks

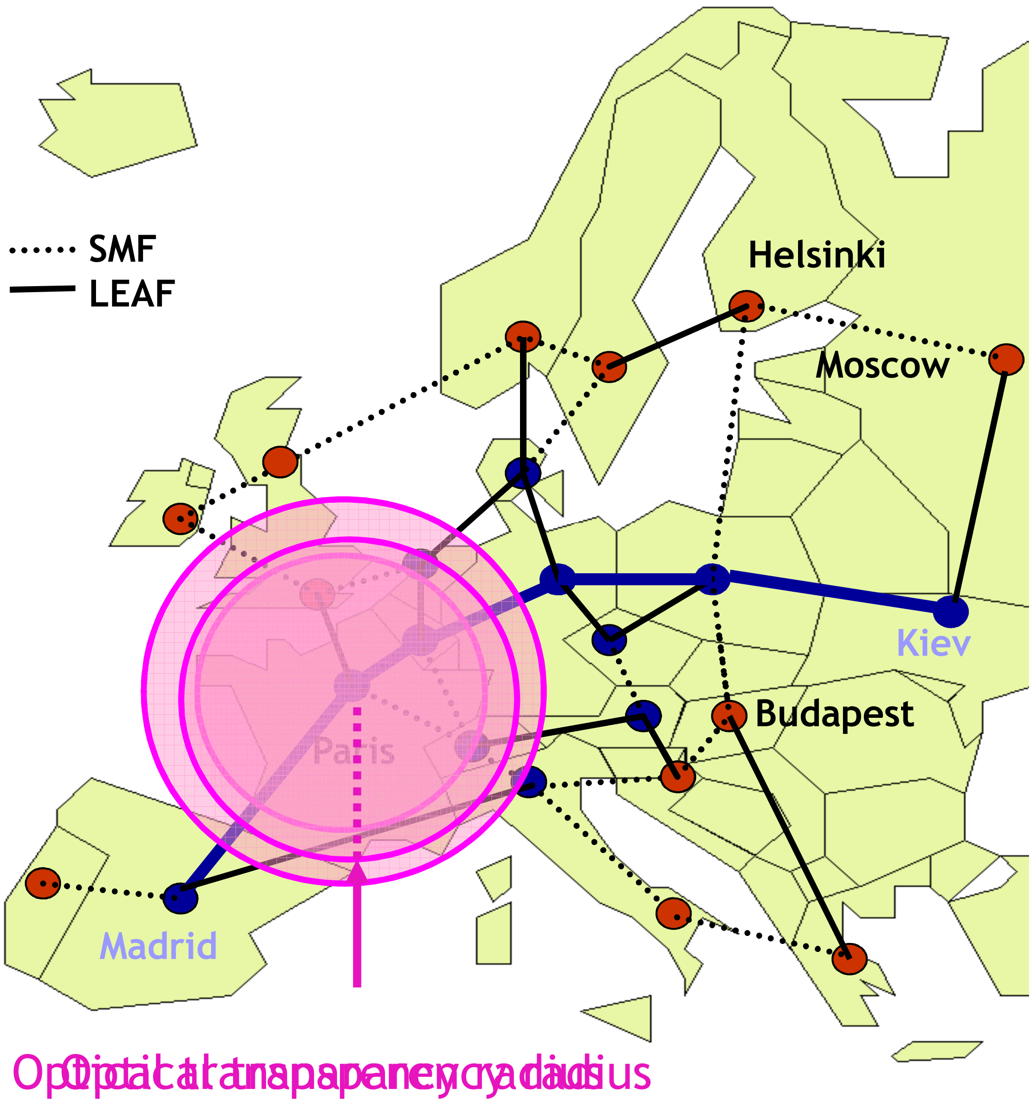
Submarine systems

- Point to point connections with possible fixed optical add/drop multiplexers
- From few 100km (unrepeatered) to 6000-12000km, w/ all-optical amplifiers
- Industrial solutions today: more than 100 x 10Gb/s
  - Under development: 40Gb/s per channel

- Research lab record: Capacity x distance product: C×D = 112Pbit/s·km
  - 155x100Gbit/s over 7,200km (G.Charlet et al, ECOC, September 2009)
  - Based on 0.166dB/km fiber from Sumitomo
  - Coherent PDM-QPSK
  - Raman+Erbium amplification
  - Bit-Error Rate better than 4.10^{-3} before Error Correction

TREND 3: FLEXIBILITY

Towards dynamic mesh backbone networks



Currently proposed solutions:

TUNABLE ROADM FOR DYNAMIC NETWORKS

- Possibility to have connection from **any port to any port** of the nodes

Opportunity for advanced functionalities **managed by the control plane (GMPLS):**

- Network reconfiguration on demand
- Optical Restoration

But dynamicity reduces the transparency radius…

➔ dynamic margin allocation

- Physical parameters monitoring feeding impairment aware routing algorithms in Network Elements

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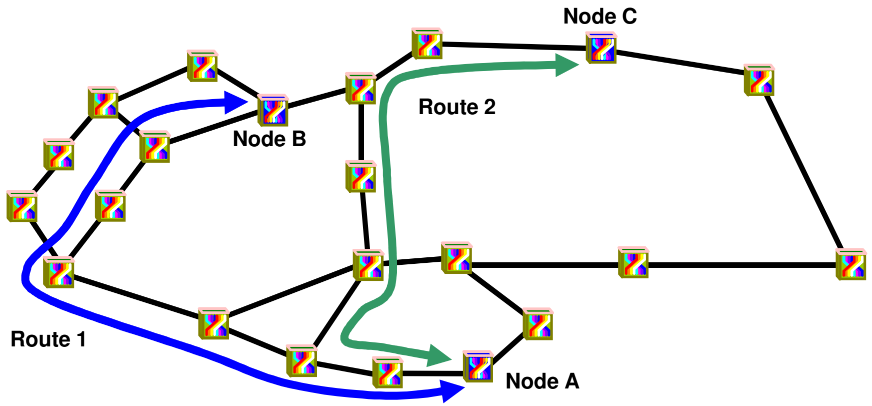
Dynamic Transparent Networks. What for ?

Rapid, on-demand wavelength reconfiguration in transparent networks

- **New wavelength services provisioned & re-routed on demand**
  - Push time scales from hours and days down to milliseconds and seconds, less human intervention
- Lightpath modification using transparent switching elements

Unification of network reconfiguration and restoration

- **Single mechanism provides reconfiguration**
  - On demand or event triggered (failure)
  - Higher layer or physical layer



Wavelength on route 1 from node A to B is reconfigured to route 2 from node A to C

- No operator intervention required
- Optical switching or restoration

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Research trends

Variable Bit-Rate optoelectronic terminals

Allow optical channels to run at a range of rates to accommodate different conditions

- Accommodate both variations in client requirements and limitations of the physical channel

OPEX impact arises from simplicity of deployment and inventory

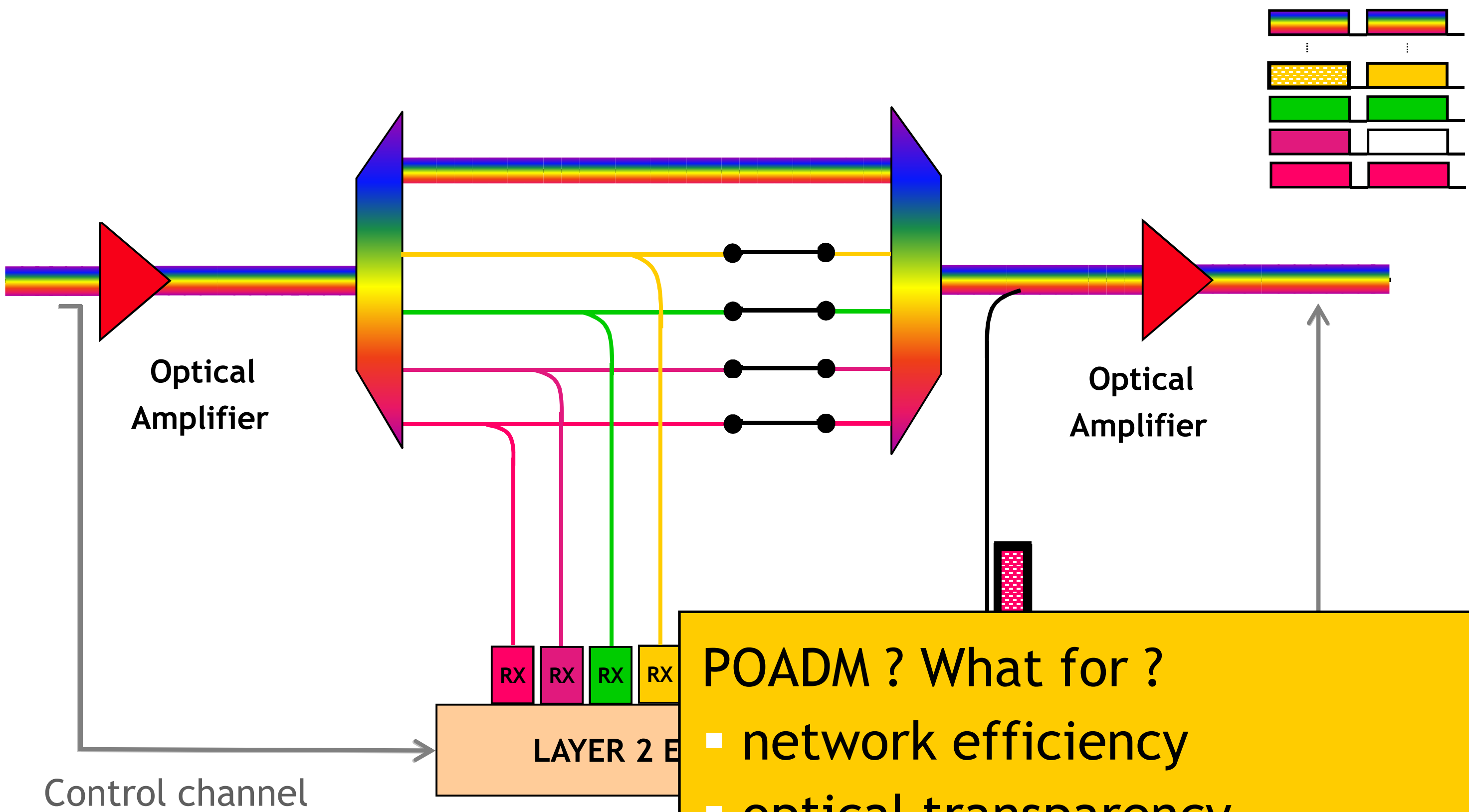
- One linecard for multiple applications
- Hardware can remain the same when upgrading capacity
- Degradation in physical plant can be dealt with by scaling back the rate rather than repair – analogous to modems

Progressive equipment investment, energy consumption, adapted to network needs

Total network capacity can be increased with zero blocking probability.

Research trend: Optical Packet Switching
Packet Optical Add/Drop Multiplexer (**POADM**)

Market segment: Metro **ring network** with add/drop features at nodes



POADM ? What for ?
- network efficiency
- optical transparency

➔ Possible gains in equipment and nrj

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TREND 4: GO GREENER

Energy bill of telecommunications, and telecommunication networks

Telecommunications to save energy ?

- Remote conferencing instead of long-reach travels…

Energetic cost of transmitted bit per km decreases with time

- **But data traffic needs increases exponentially, at faster rate**

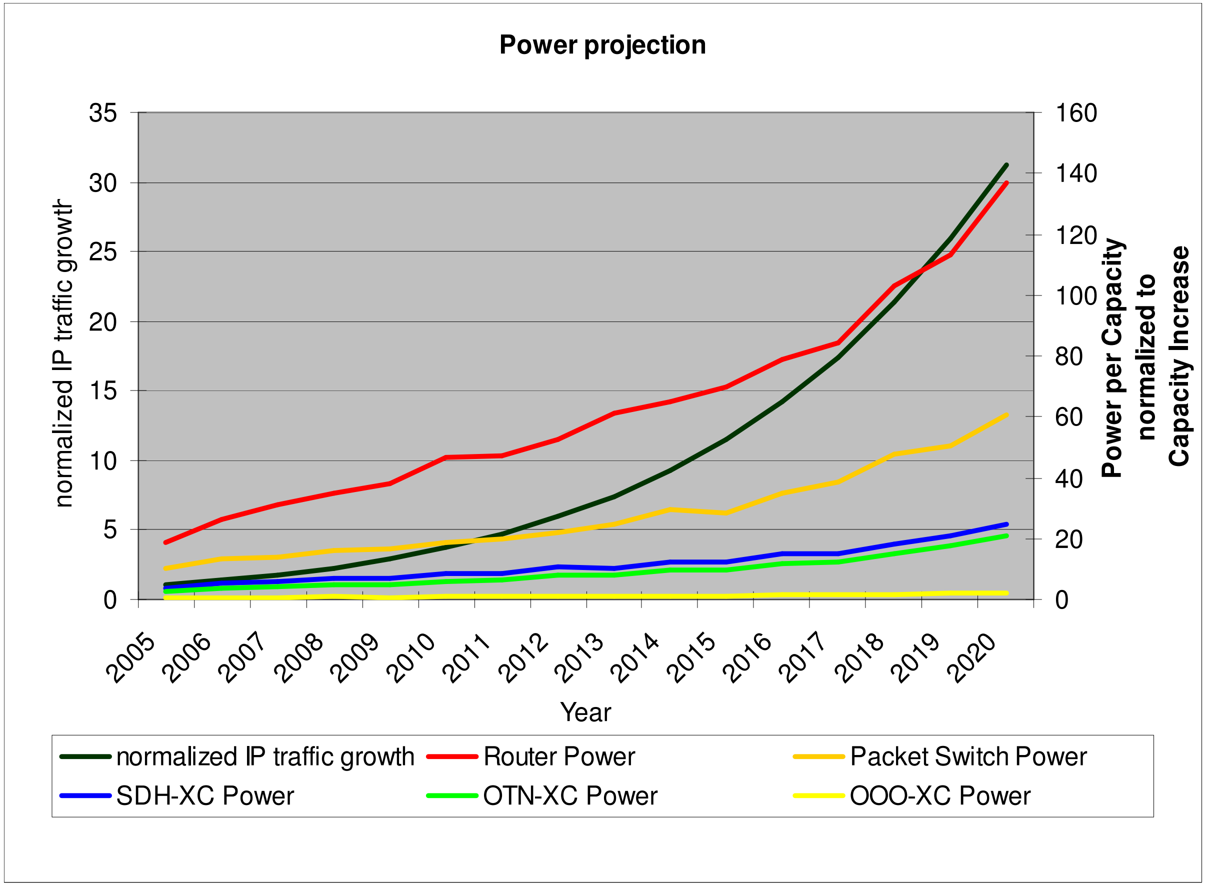
A few figures

- Google data centers consumes 100s of MW (of which 50% in cooling)
- British Telecom is the largest energy consumer in UK.
- In 2015, routers in Japan to consume 15% of national electric energy
- CISCO router supporting 92Tb/s w/ 40G linecards consumes more than 1MW

Energy control is a big challenges to face, with an important role for optics

- Avoid unnecessary electronic processing (transparency, optical by-pass)
- Energy-aware dynamic network solutions, adapted to traffic evolutions
- Integrated components, such as Photonic Integrated Circuits

An interesting picture about power consumption
Power Consumption vs. Network Capacity trend for different network functions



Hypotheses:

- Mix of 10G, 40G & 100G interfaces with a tendency to have higher speed interfaces over time
- OOO XC config based 25:75 add/drop: pass-thru ratio
- Assumes that Network Capacity Trend equally increases demand on all network functions

Need to shift as much capacity as possible from routers down to XC and Photonic domain to sustain the IP traffic growth!

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Fiber-based access networks: Passive Optical Networks (PON)

Optical access by Gigabit/s PON (GPON)

- Why optical fiber ?
  - Consumes 18x less energy per user than VDSL2
  - 2.5Gb/s downstream, 1.6Gb/s upstream
  - Sharing of this capacity among multiple users (time-division multiplexing)
- Distance to central-office can go up to 60km when amplifier-assisted, not a few 100s meters from set-top box to DSLAM.
  - Orange research team: around 820 central offices with DSLAM versus 48 edge nodes with GPON for 1.4M subscribers in North-West France (Brittany).

10GPON solutions recently proposed by system vendors

WDM dimension can also be exploited to increase capacity,

- And provide Peer to Peer connections, capacity on demand…

Summary

Data services are still fueling an exponential traffic growth

- Human-generated traffic; Machine-generated traffic
- Impact of cloud computing, of new applications, etc...

WDM has enabled traffic growth over the last 20 years

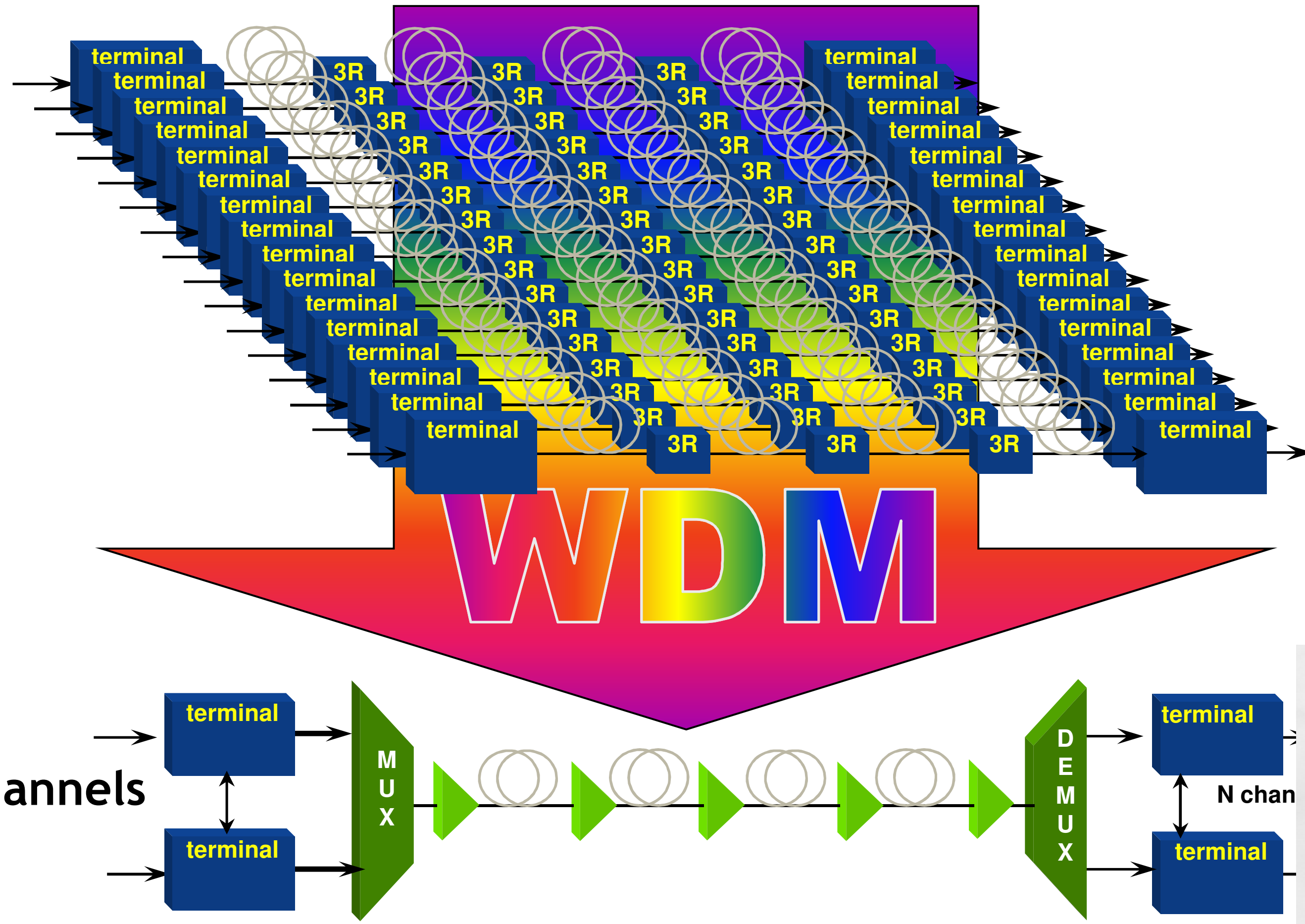
- 100-Gb/s research has come a long way over the last 4 years
- Bandwidth should no longer be taken for granted; large space for innovation

Optical transport networks are moving towards transparency, and reconfigurability, as an integral part of the future Internet

- ...w/ search of ideal Routing / Switching configuration for energy efficiency www.alcatel-lucent.com

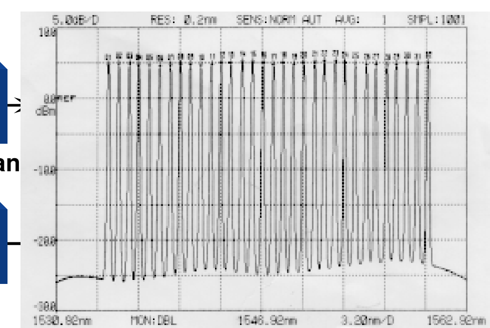
Thank you

Basic technologies:
Wavelength Division Multiplexing (WDM) of High Speed TDM channels



N channels

WDM channels



WDM = economical solution to reach multiterabit/s capacity

100G: The Drivers

A: Need for more capacity (service driven)

Request for higher bandwidth is mainly driven by the evolution of services (e.g.: IP-TV, HD-TV, VoD, gaming, file sharing, Peer-to-peer, grid computing, inter-connection of supercomputers, Datas-centers, Research projects)

B: Need for a higher rate at service interfaces (technology driven)

Technical issues lead to request interfaces at routers or computers w/ higher bitrate:

- unsatisfactory current Link Aggregation Groups (LAG):100GE interface seen as the solution
- Increase statistical multiplexing efficiency w/ higher rate interface ⇨ reduce cost/bit

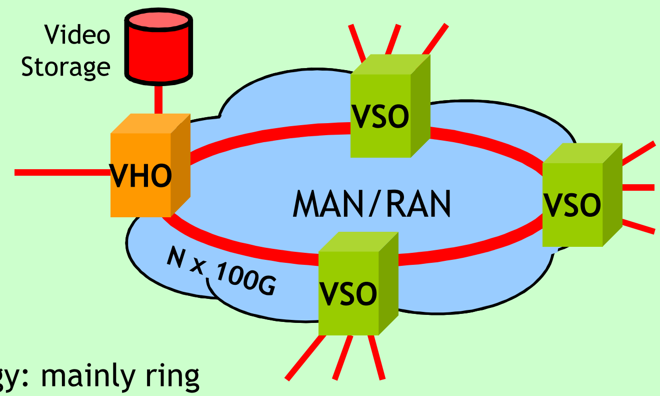
C: Transport network optimization (cost driven)

- Reduced number of wavelengths leads to reduced network complexity (OPEX)
- Reduction of CAPEX
  - Better fiber/lambda utilization
  - Reduced network cost by increasing statistical multiplexing efficiency
  - Future proof systems, scalable to manage the expected demand “explosion”

100G: Applications

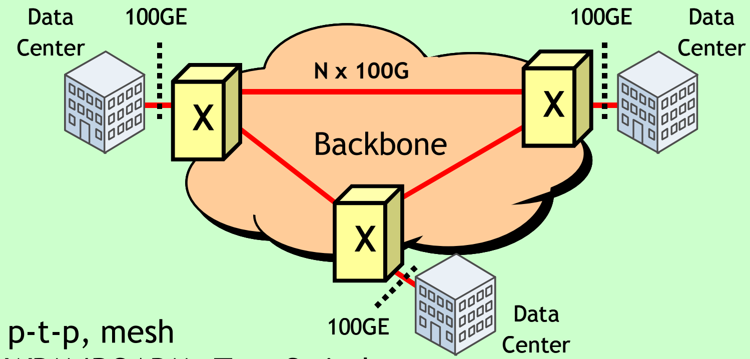
Service driven: transport of 100GE client signals (between routers, video severs or computers)

VoD:



Topology: mainly ring
Products: WDM/ROADM

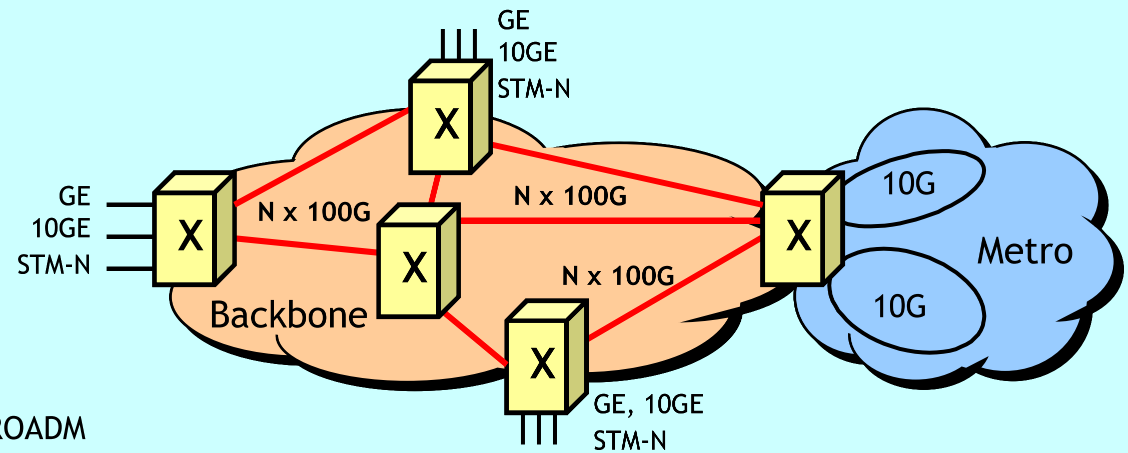
High Speed Data Center interconnection:



Topology: p-t-p, mesh
Products: WDM/ROADM, Tera Switch

Transport driven: concentration of several client signals <100G and transport via 100G

Transport Optimization:



Topology: mesh
Products: Tera Switch, WDM/ROADM

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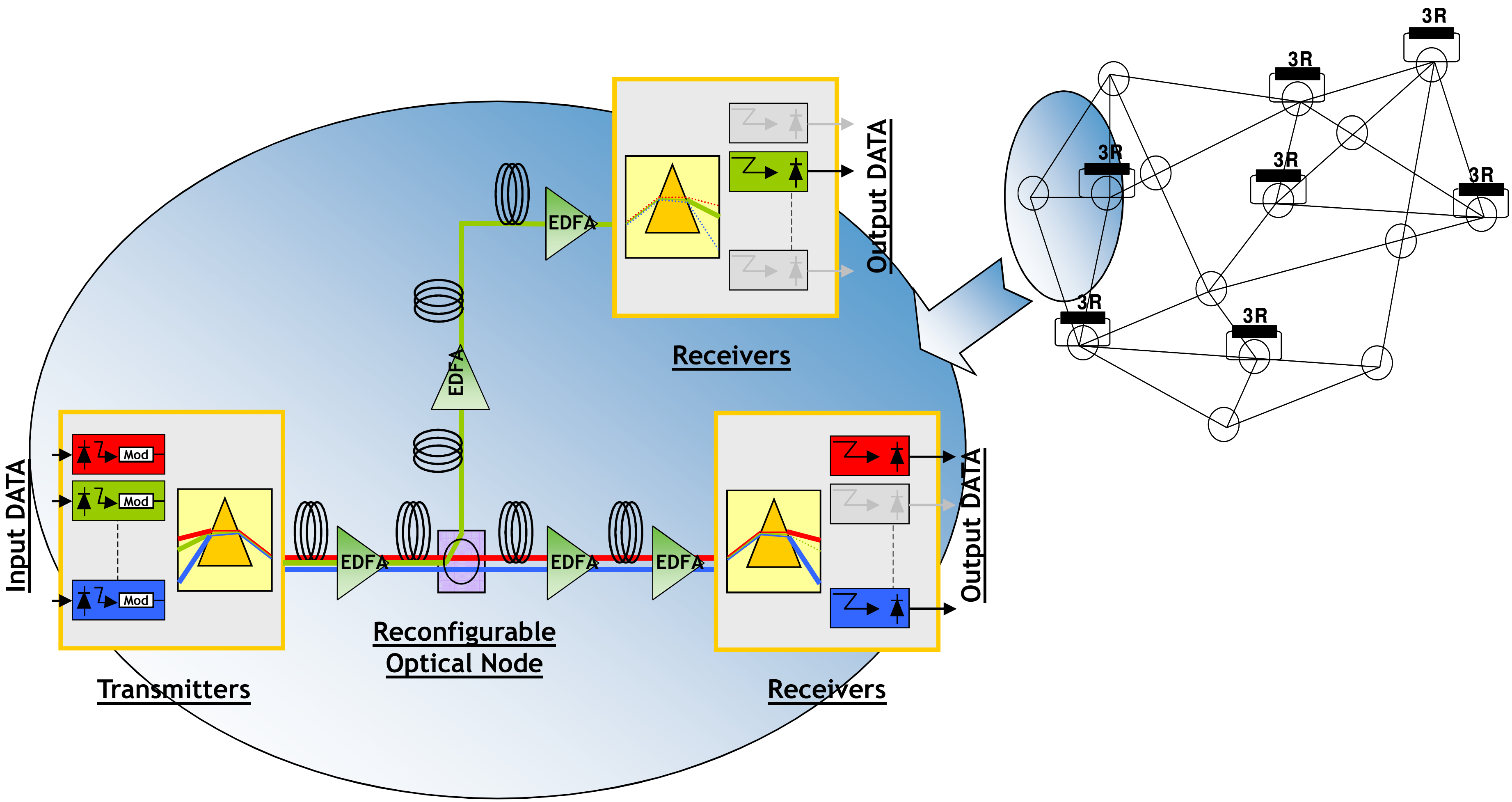
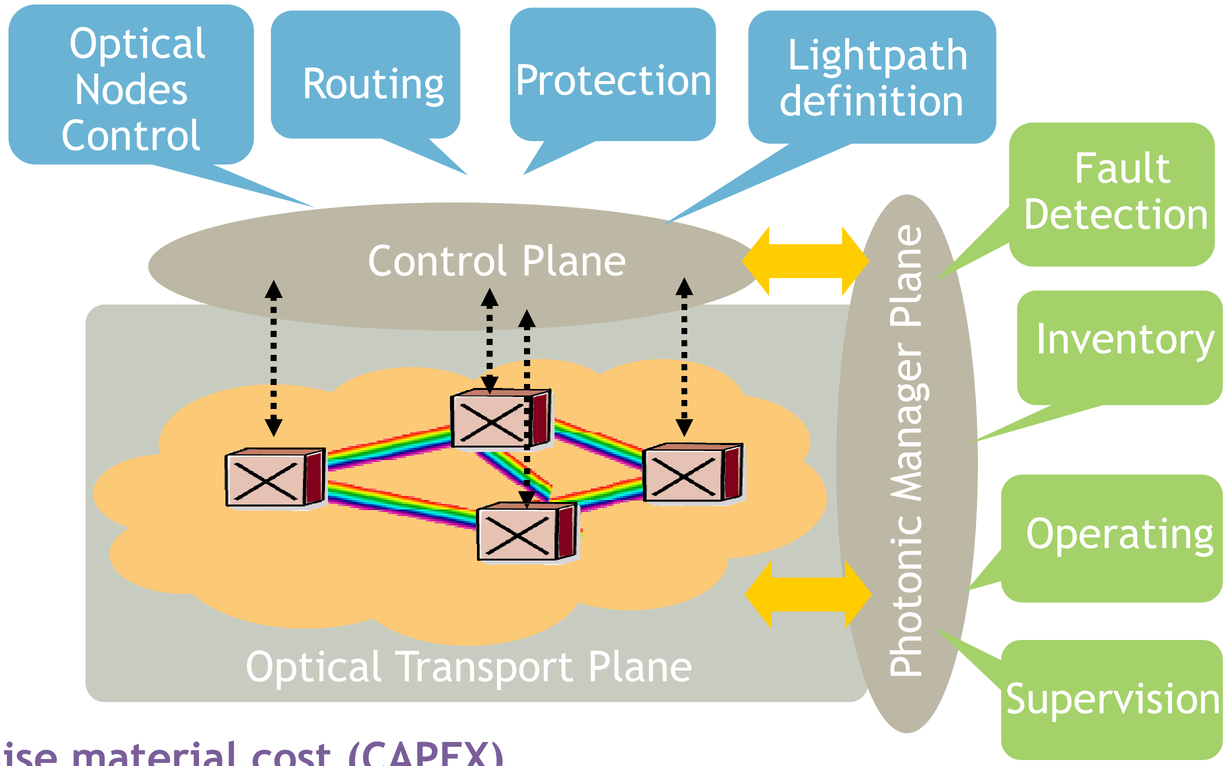
Basic technologies:
Reconfigurable and dynamic Optical Networks



Reconfigurable Nodes for Flexible Operation

Challenges in Optical transport network management: flexibility and transparency



Minimise material cost (CAPEX)

- Avoid regeneration , Optical Add/Drop Multiplexers (OADMs); Optical Cross Connects (OXC), mutualize « stock » => tunable functions

Minimise operation cost (OPEX)

- Suppress on-site intervention, ease commissioning tunable functions to support protection and restoration, efficient allocation of the network resources

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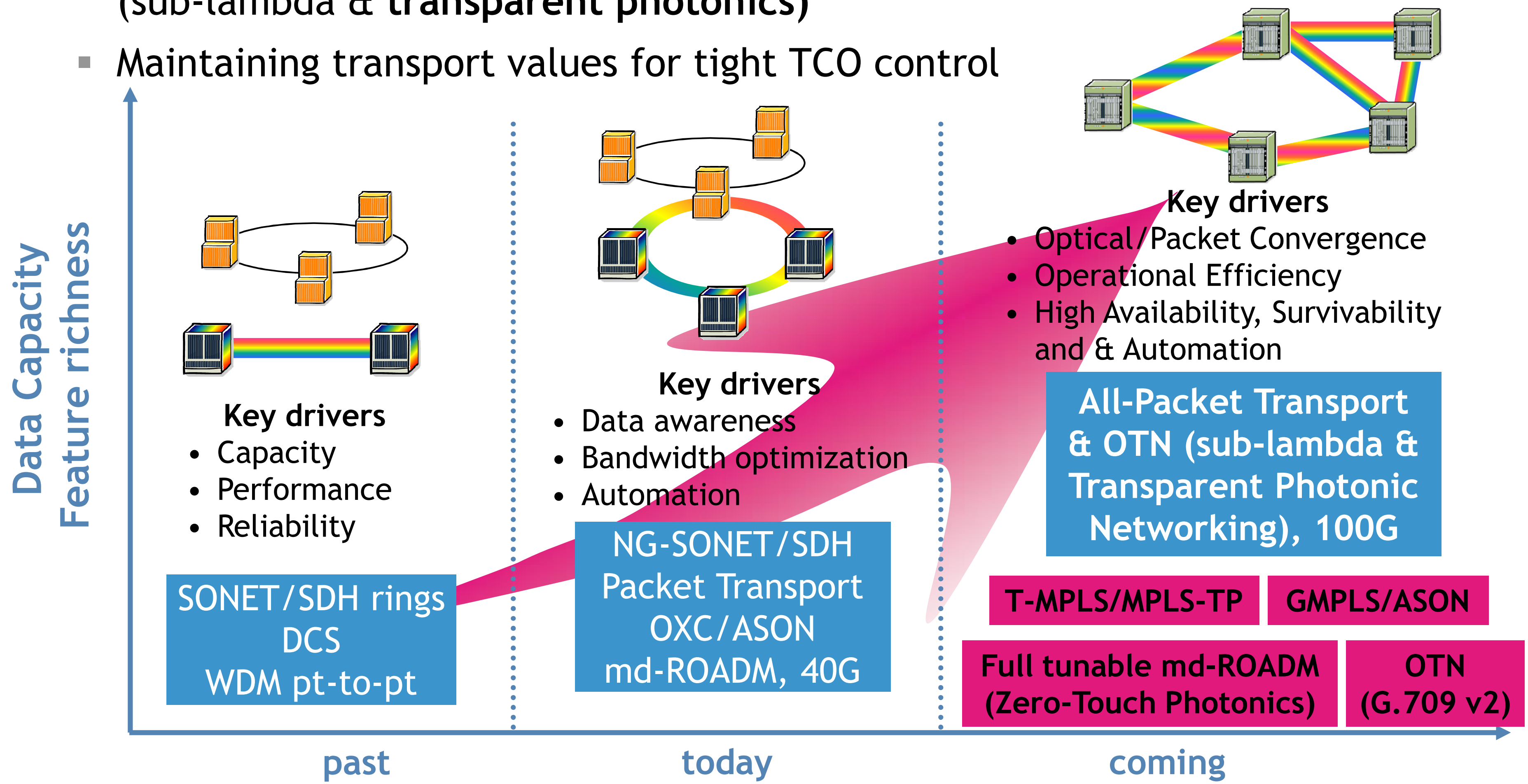
Network Transformation

Long-term vision of All-Packet Transport for All-IP services

- Seamless migration towards **all packet transport** & OTN networking (sub-lambda & **transparent photonics)**
- Maintaining transport values for tight TCO control



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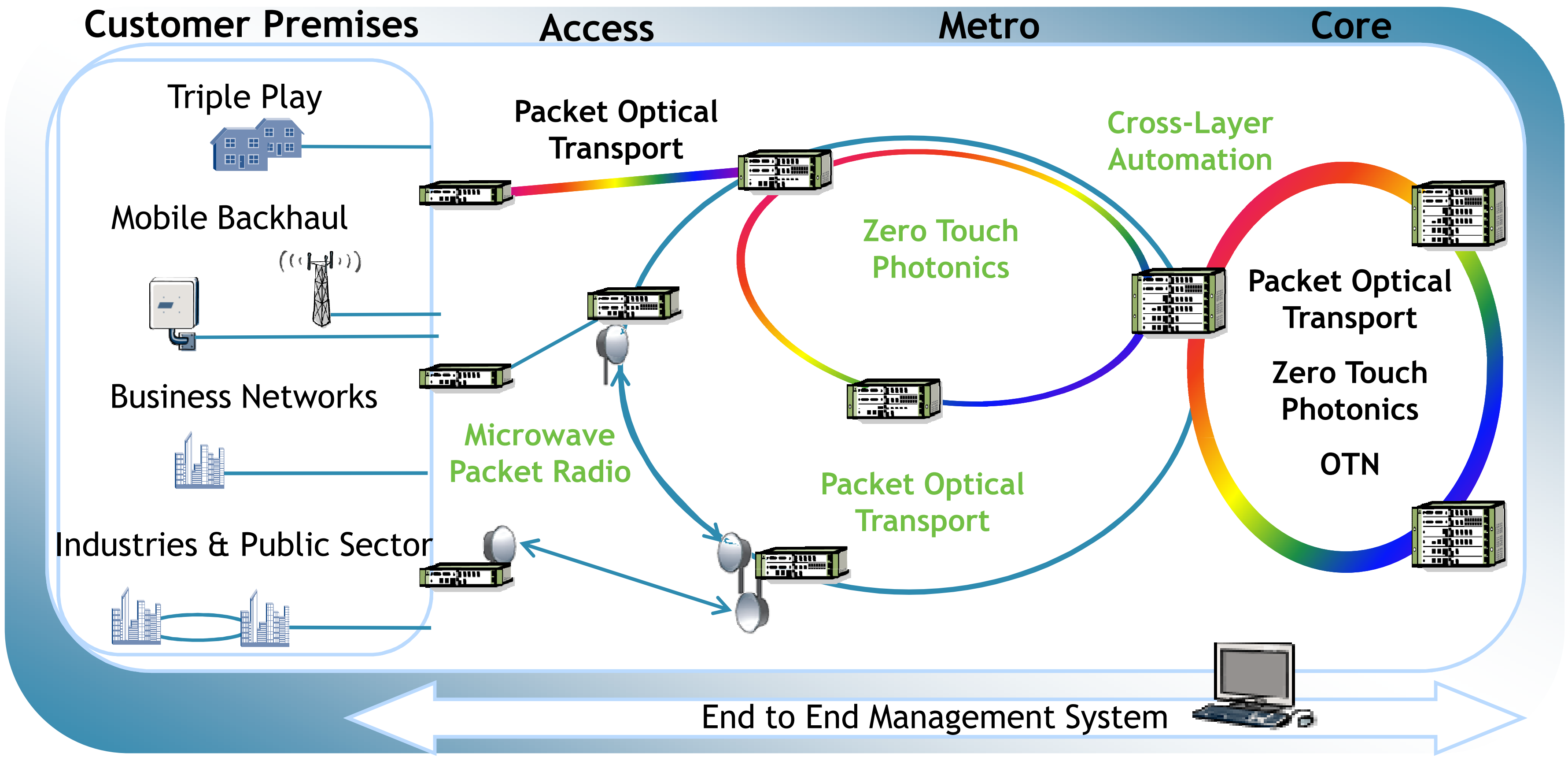
It's all about … Transport Innovations

skip ?



Solve **bandwidth bottlenecks**

Lowest cost per transported bit/km

Taming the **power challenge (green)**

Carrier grade **resilience** and **security**

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Thank you