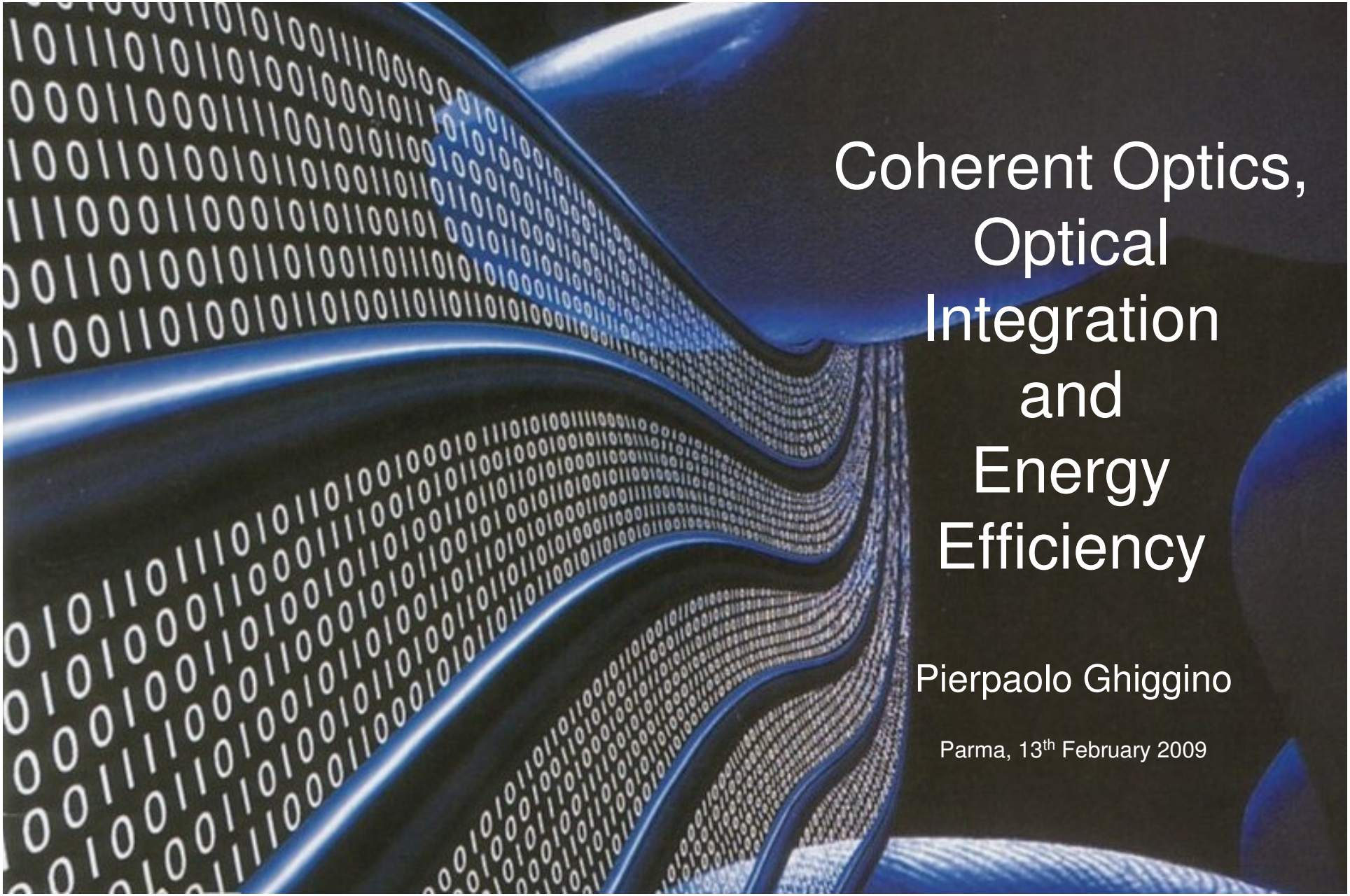

Coherent Optics, Optical Integration and Energy Efficiency

Pierpaolo Ghiggino

Parma, 13th February 2009

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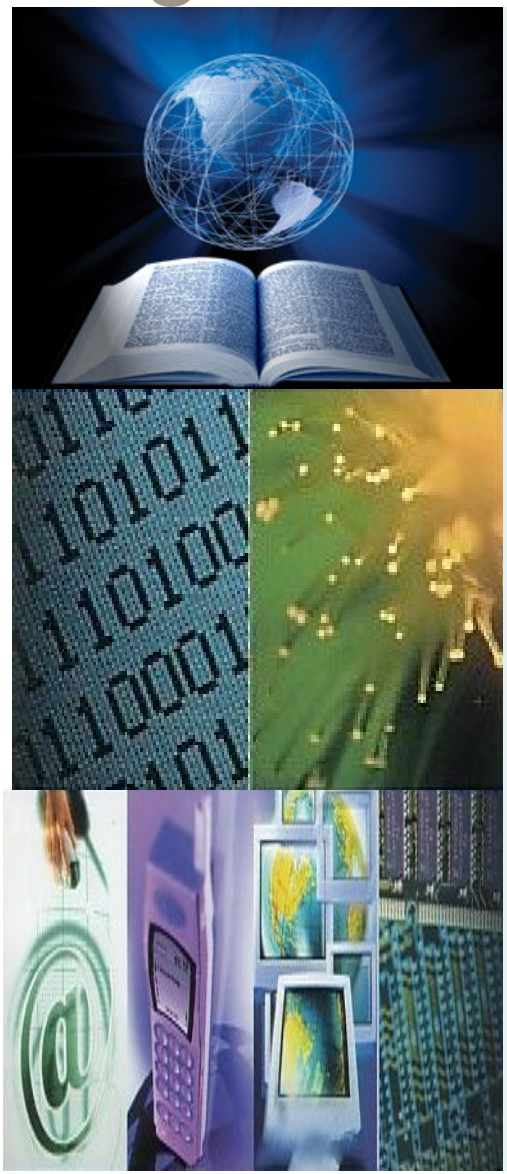
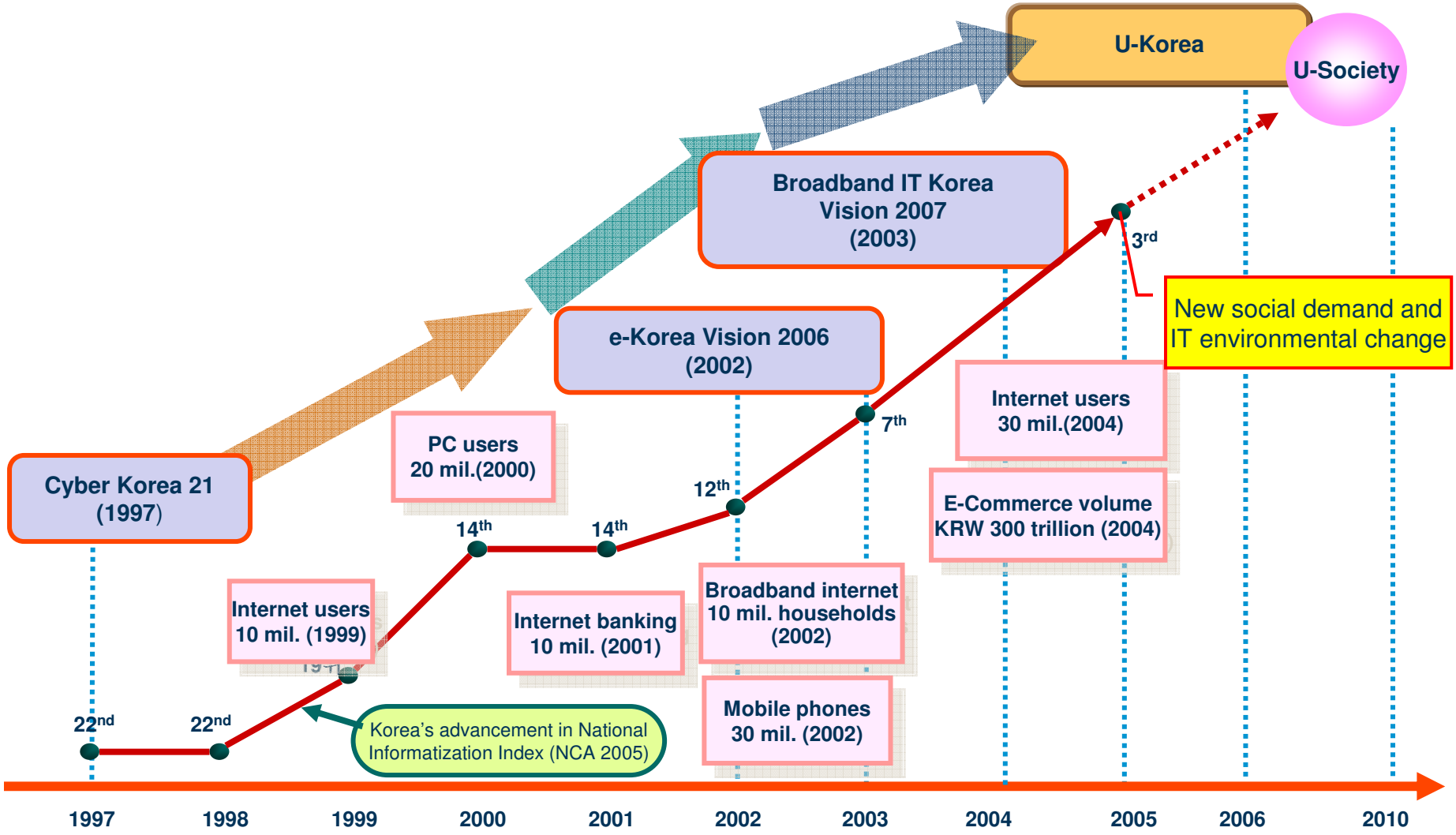
Agenda



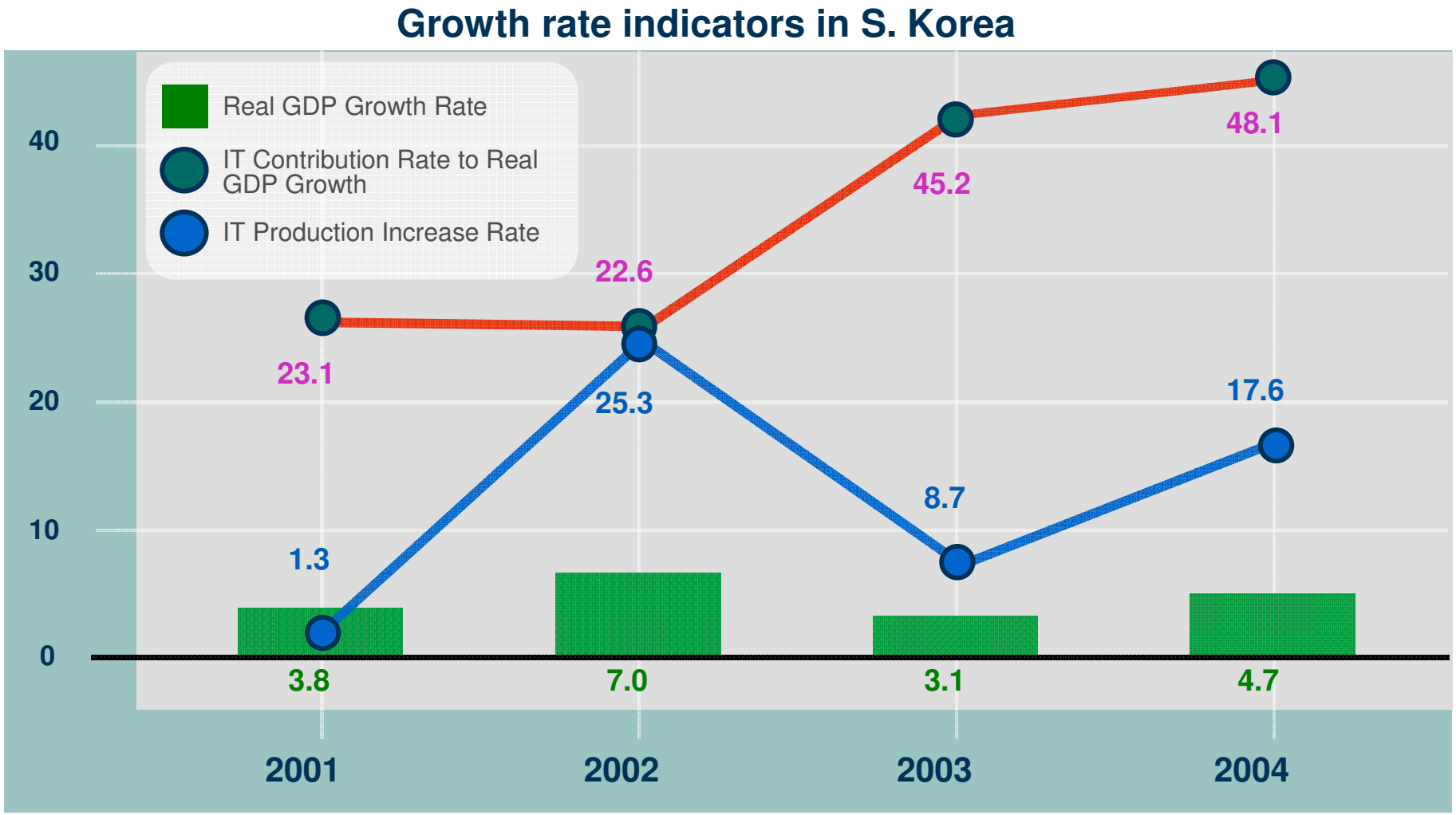
- ICT, economic growth and the environment
- The effect of bandwidth growth
- Optointegration progress and high speed coherent systems
- Conclusions

ICT: a catalyst for social changes



From J Yoon Impact of ICT Diffusion in Key Sectors of Korea

ICT and GDP growth



Source: Bank of Korea, Ministry of Information and Communication

ICT, CO_2 footprint and the environment

"The IPCC has unequivocally affirmed the warming of our climate system, and linked it directly to human activity (greenhouse gas emissions)."

Ban Ki-moon, UN Secretary-General

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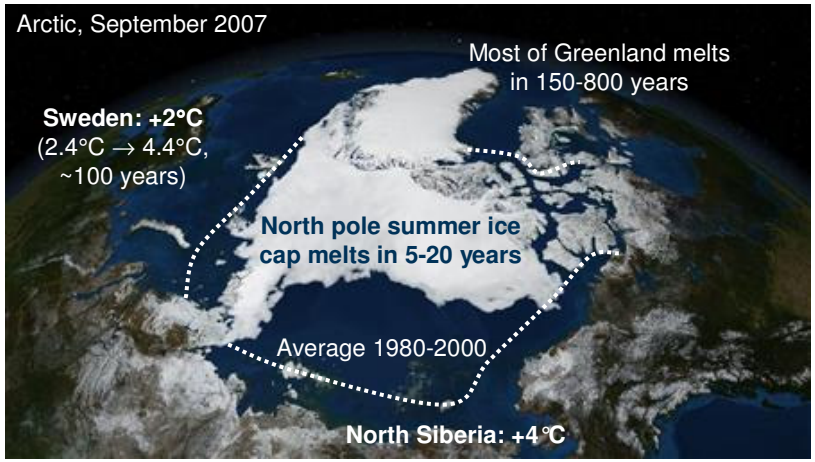
Global Warming / Climate Change



2100: 650 ppm / +4°C

2050*

???

*) IPCC predictions 2050

2050*

385 ppm
+67%

1.7 ppm
+180%

+0.6°C

+1°C
~100 years

Temperature 12 ± 3°C

2050*
+1°C

~15°C

-0.4°C

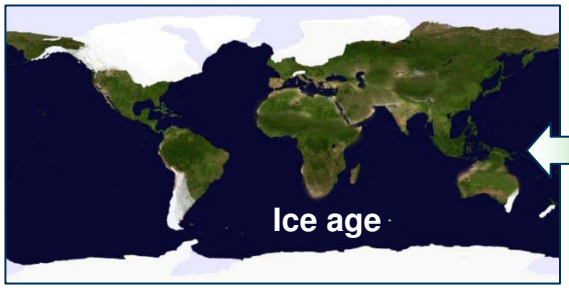
CO_2 230 ± 40 ppm

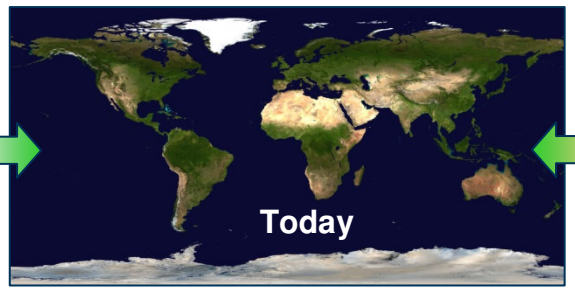
Earth orbit variations

← 500 000 years →

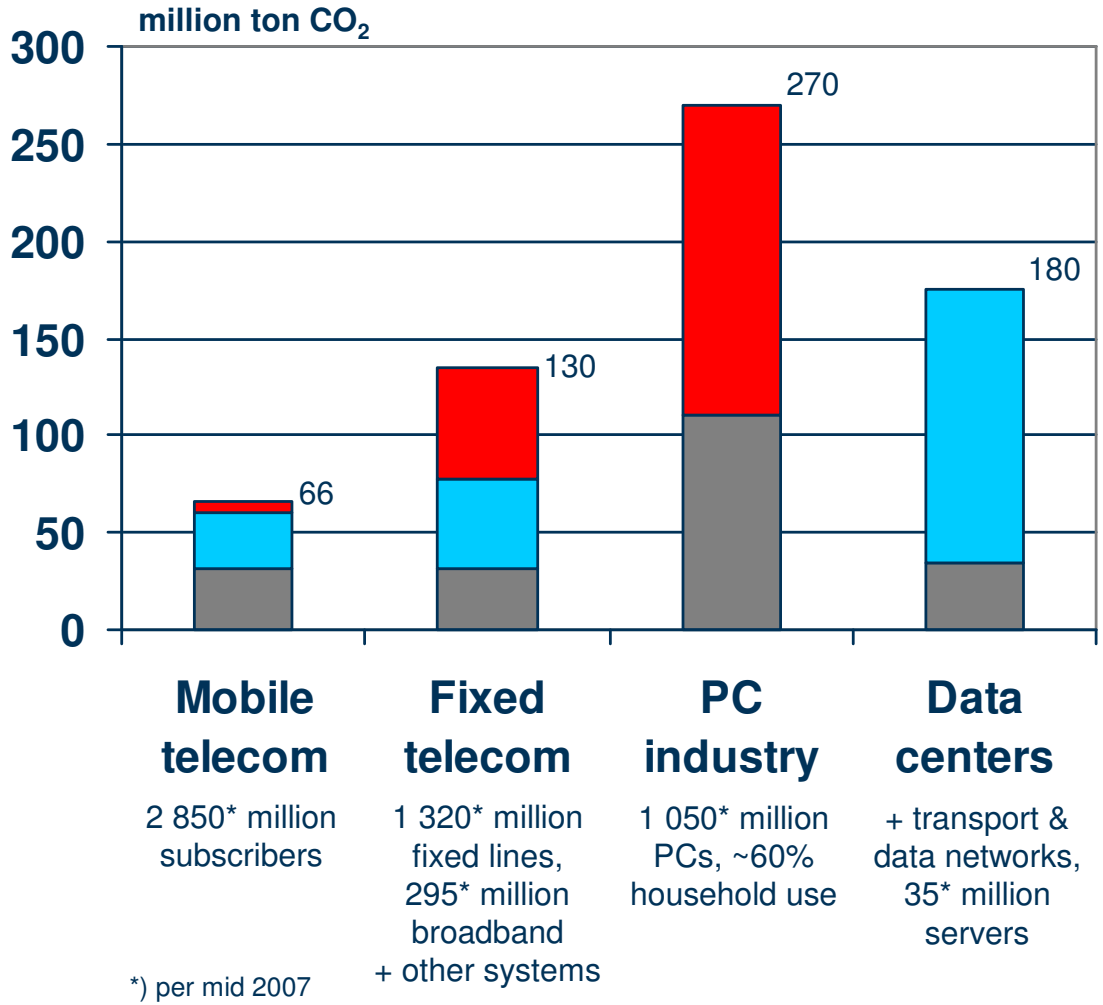
← 2 000 years →

Methane 0.5 ± 0.15 ppm





CO_2 emissions from ICT in detail



*) per mid 2007

- **User equipment operation** (field studies)
- **Network operation** (operator studies)
- **Manufacturing & business overhead** (LCAs, div. reports)

- **ICT growth**
- **Improvements per unit**
  - Laptop, LCD and power management trends for PCs
  - DC virtualization, cooling and power efficiency
  - ”Moore’s law”, stand-by

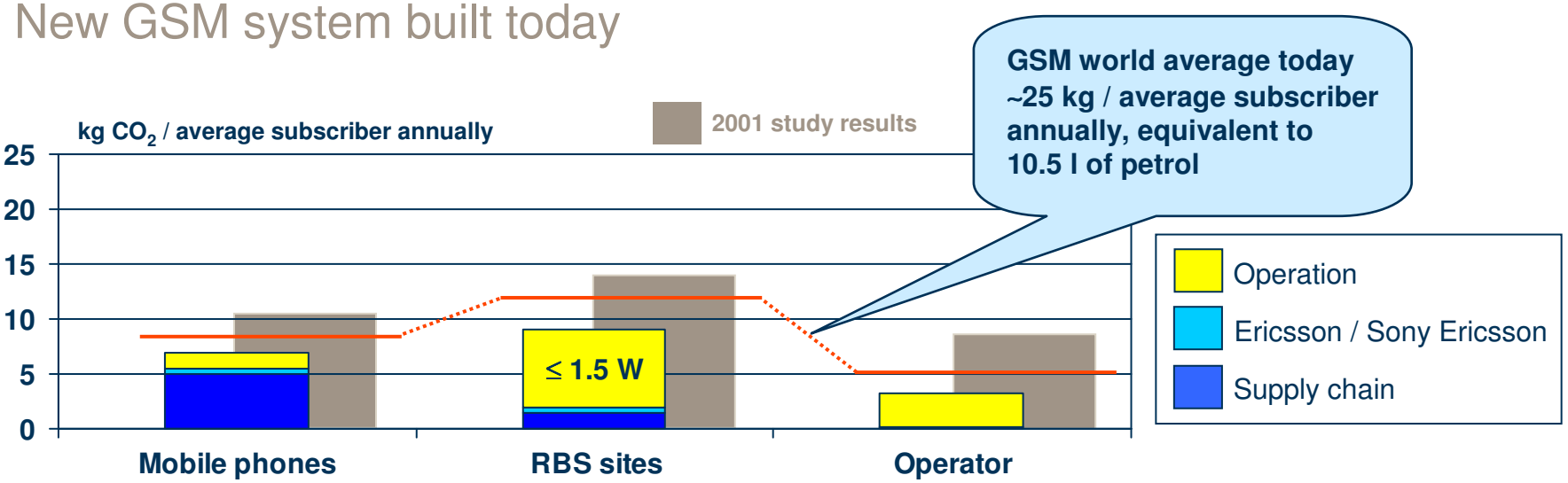
ICT runs on electricity (0.6 kg CO_2e / kWh)

ICT total (the carbon footprint):

~1.5% of global CO_2e

Carbon footprint of mobile telecom

New GSM system built today



The PBA
"12% of weight,
2/3 of total CO2
from production"

Steel & Concrete

The operator's
Business overhead

1 year of mobile telecom compares to < 1 hour driving

Mobile telecom total: 0.2% of global CO_2

Latest reports with a global focus

- **Gartner** (2007) estimates ICT's own carbon footprint to about **1.5%** of total CO_2e)
- **GeSI** (2008) estimates ICT's own global carbon footprint to **2%** of total CO_2e in its recent **Smart 2020** report
  - Include printers and overestimate telecom by about +50%, otherwise only smaller differencies to Ericsson/Gartner
  - Uses a lower figure for total CO_2e compared to IPCC
- **GeSI** / **Smart 2020** further estimates ICT's reduction potential in 2020 to be **15%**
  - Structural changes from ICT use somewhat downplayed
  - Emphazis is on efficiency gains in logistics, production and building management systems
  - Smart grids is believed to ba able to make a large positive impact already in 2020 (not in line with other studies)
- **WWF** and partners has also issued a report with nearly the same figures: **2%** from ICT itself, but with a reduction potential of **3%-12%-22%** in a low-medium-high use scenario for ICT in 2030

2% impact with 5%-20% overall reduction potential

If the world needs ICT
ICT needs bandwidth

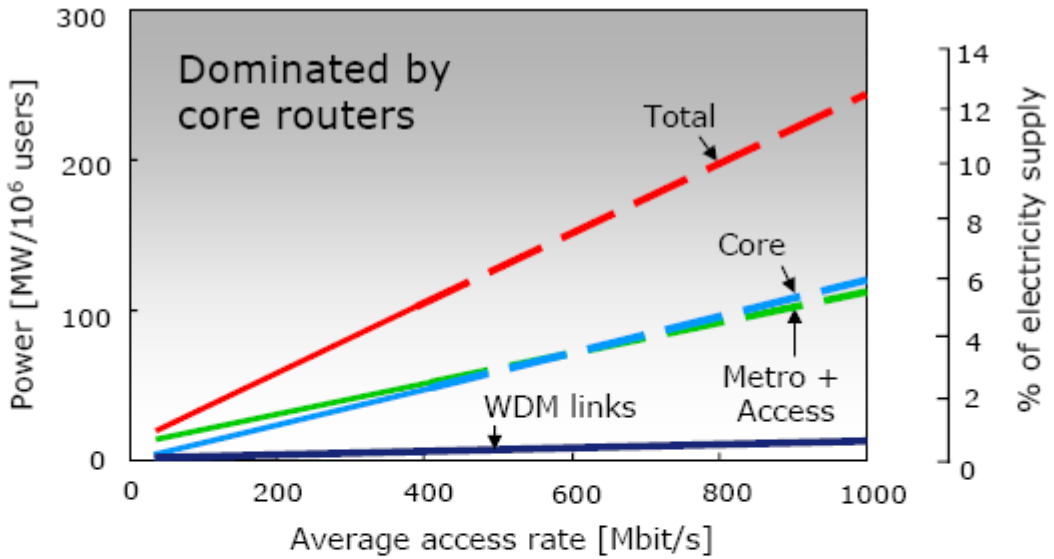
„In 2015 five billion people will be connected permanently via telecommunication networks. The data transport will increase by a factor of 100 compared to 2007“

Simon Beresford-Wylie, CEO NSN,

Die Welt, April 7th,2007

Trends and challenges

The energy challenge – Power consumption



- If ***33%*** of the world's population were to obtain broadband access:

Access rate	1Mbit/s	10Mbit/s
Power consumption	100GW	1TW
Percentage of world's 2007 electricity supply	5%	**50%**

Need to reduce total power consumption

Sources: Jayant Baliga, COIN-ACOFT-07, Stephan Rettenberger, IIR-WDM Cannes 2008

The underlying issue

Market price we pay for services

Telephony

$$\frac{\$0.05}{\text{min}} \times \frac{1\ \text{min}}{60\ \text{s}} \times \frac{1\ \text{s}}{64\text{x}10^{3}\ \text{bits}} = 13{,}000\ \text{p\$/bit}$$

Web Browsing

$$\frac{\$20}{\text{mo}} \times \frac{1\ \text{mo}}{30\ \text{d}} \times \frac{1\ \text{d}}{3\ \text{h view}} \times \frac{1\ \text{hr}}{60\ \text{min}} \times \frac{1\ \text{min}}{6\ \text{pages}} \times \frac{1\ \text{page}}{5\text{x}10^{6}\ \text{bits}} = 1{,}250\ \text{p\$/bit}$$

Video Rental

$$\frac{\$3/\text{movie}}{6\text{x}10^{6}\ \text{bit/s}} \times \frac{1\ \text{hr}}{3600\ \text{s}} \times \frac{1\ \text{movie}}{2\ \text{hr}} = 70\ \text{p\$/bit}$$

TV viewed

$$\frac{\$20}{\text{mo}} \times \frac{1}{30\ \text{d}} \times \frac{1\ \text{d}}{7\ \text{h view}} \times \frac{1\ \text{view}}{2\ \text{ch x } 3600\ \text{s/hr}} \times \frac{1\ \text{ch}}{5\text{x}10^{6}\ \text{bit/s}} = 2.5\ \text{p\$/bit}$$

TV to home

$$\frac{\$30}{\text{mo}} \times \frac{1\ \text{mo}}{30\ \text{d}} \times \frac{1\ \text{d}}{24\ \text{h svc}} \times \frac{1\ \text{svc}}{100\text{ch x } 3600\ \text{s/hr}} \times \frac{1\ \text{ch}}{5\text{x}10^{6}\ \text{bit/s}} = 0.02\ \text{p\$/bit}$$

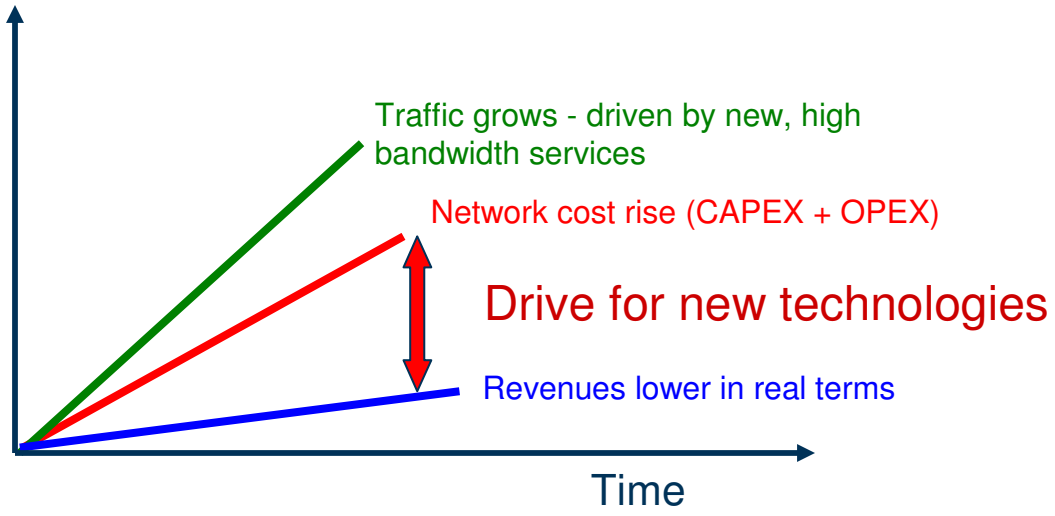
UHDV to home

$$\frac{\$30}{\text{mo}} \times \frac{1\ \text{mo}}{30\ \text{d}} \times \frac{1\ \text{d}}{24\ \text{h svc}} \times \frac{1\ \text{svc}}{100\text{ch x } 3600\ \text{s/hr}} \times \frac{1\ \text{ch}}{25\text{x}10^{6}\ \text{bit/s}} = 0.004\ \text{p\$/bit}$$

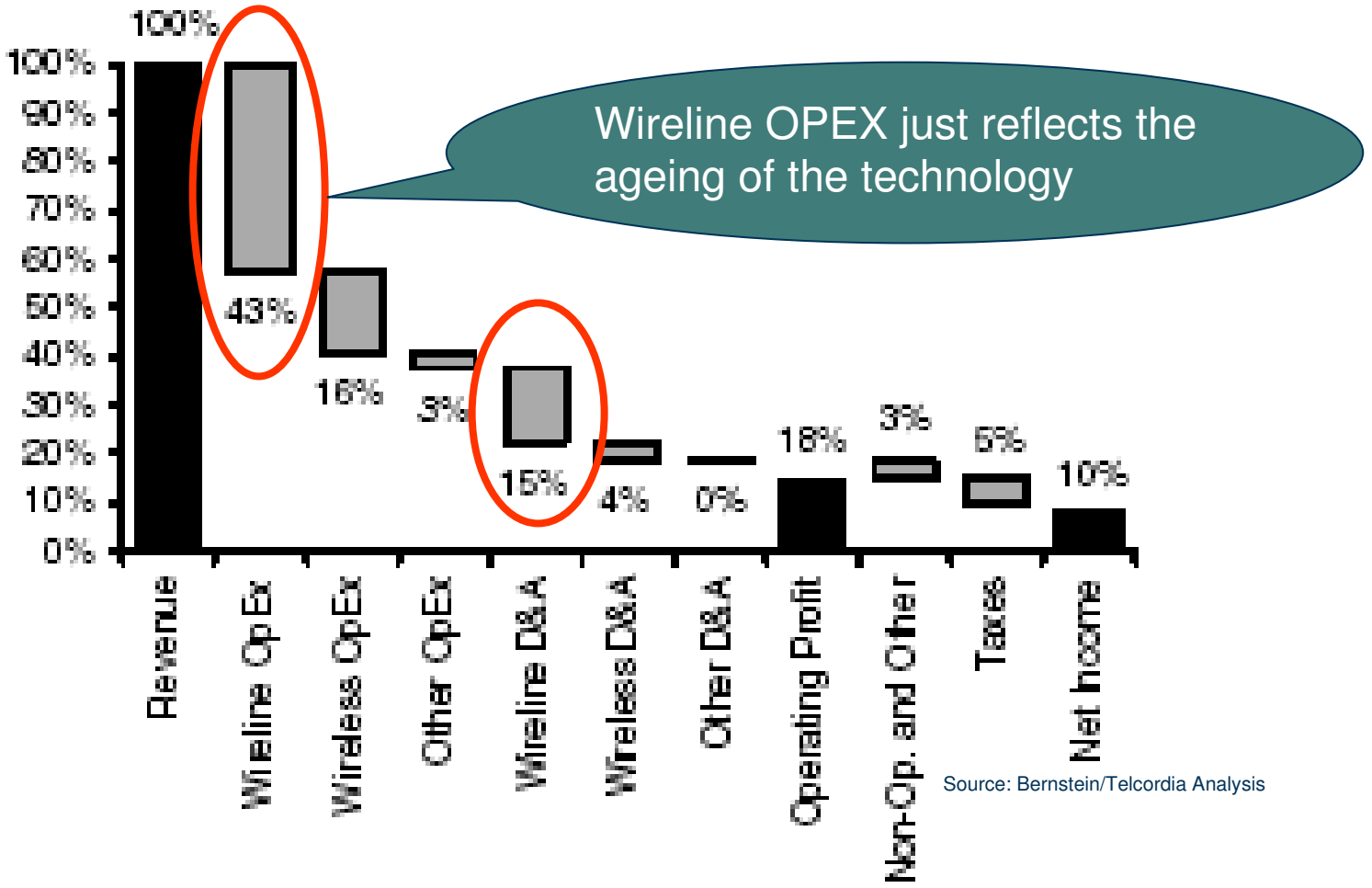
Note: p$ = 10^{-12} $

… and its implication

- Greater bandwidth needed for new revenues
- …but cost rises faster
- …and margins reduce



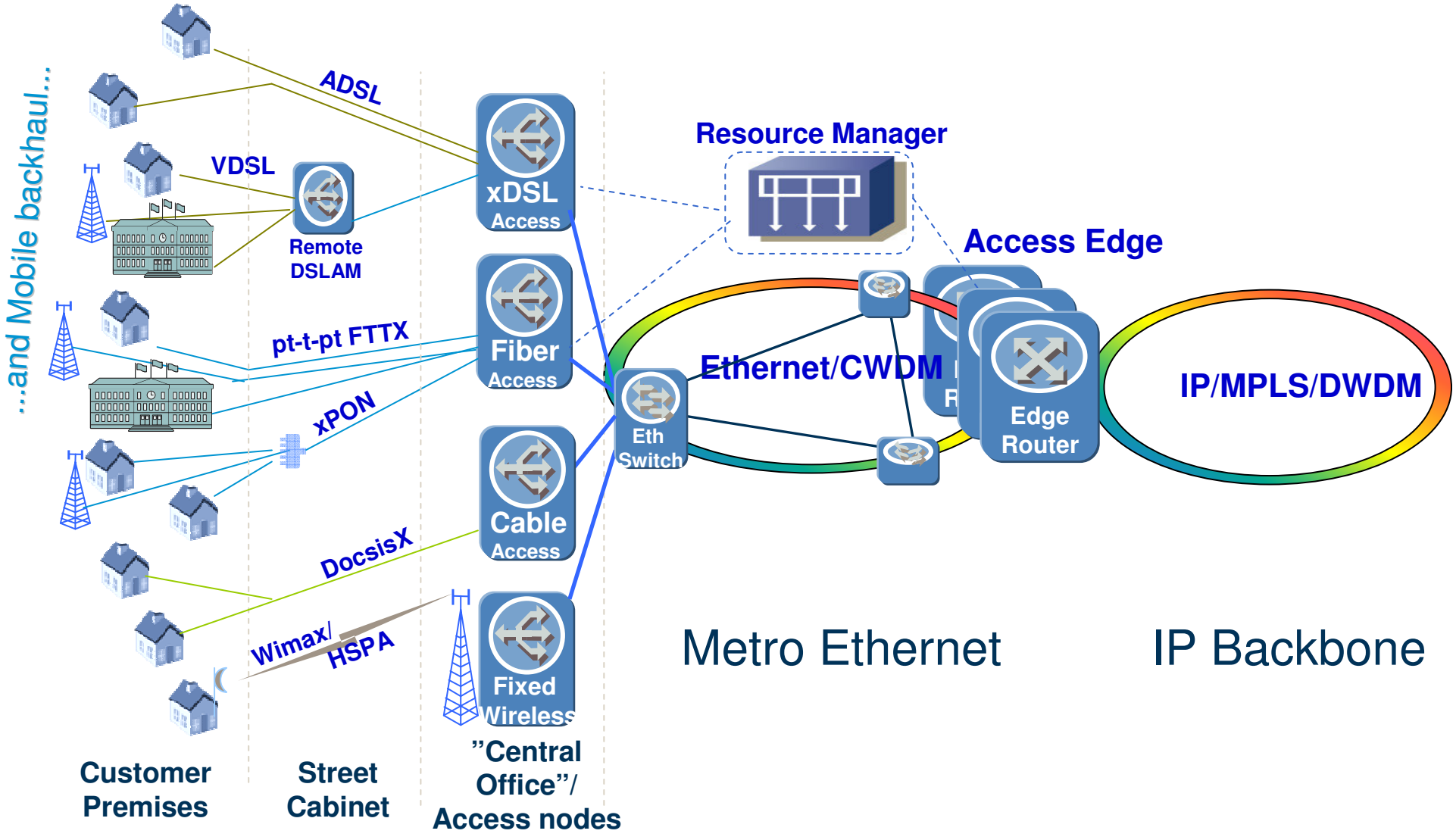
RBOCs expense structure (2003)



Source: Bernstein/Telcordia Analysis

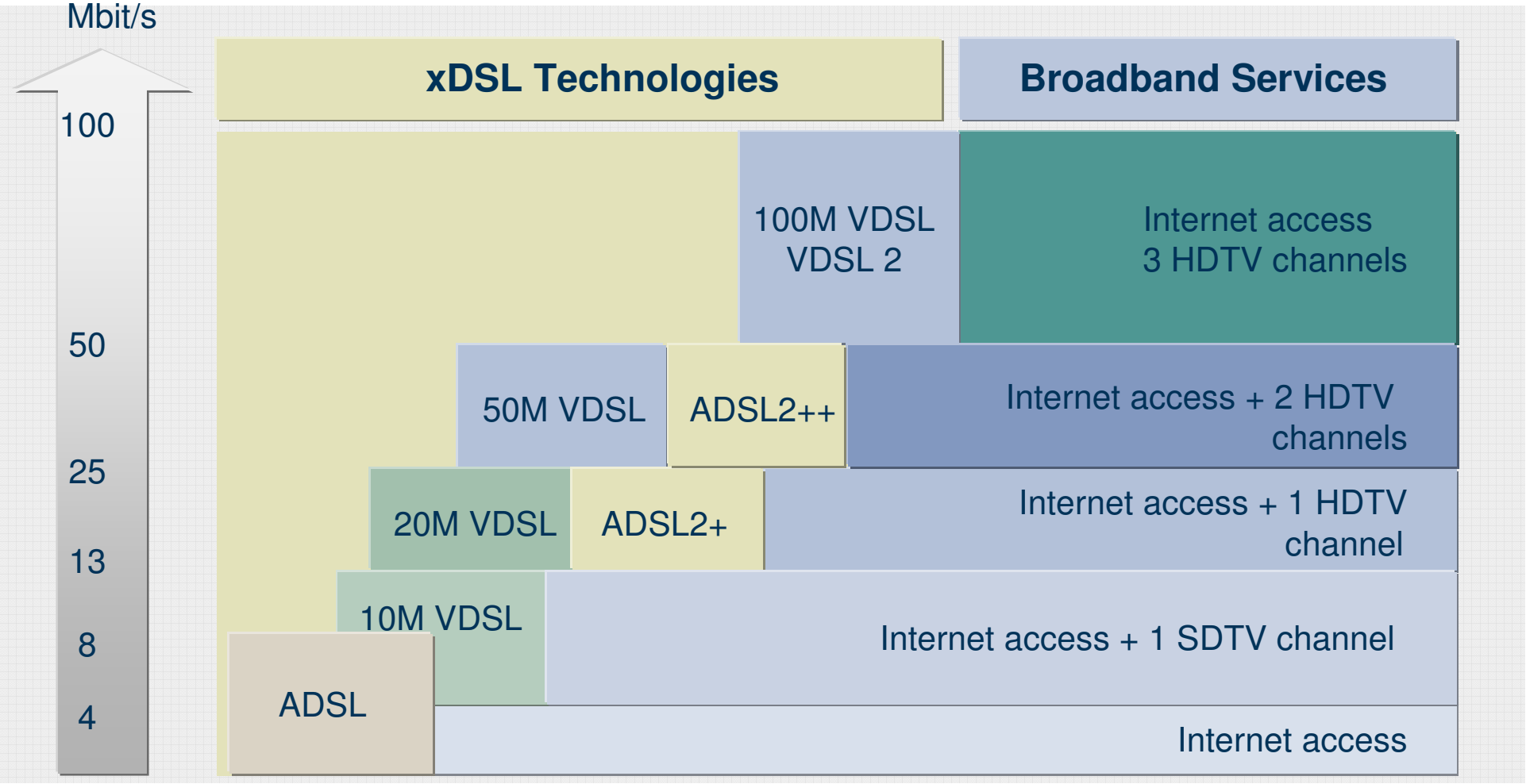
- **Competition complicates matters further when <u>it costs money</u> to operate a high customers churn i.e.:**
- **Loosing a customer means spending MORE to connect and reconnect the wire!**

Broadband architecture: today's scenario

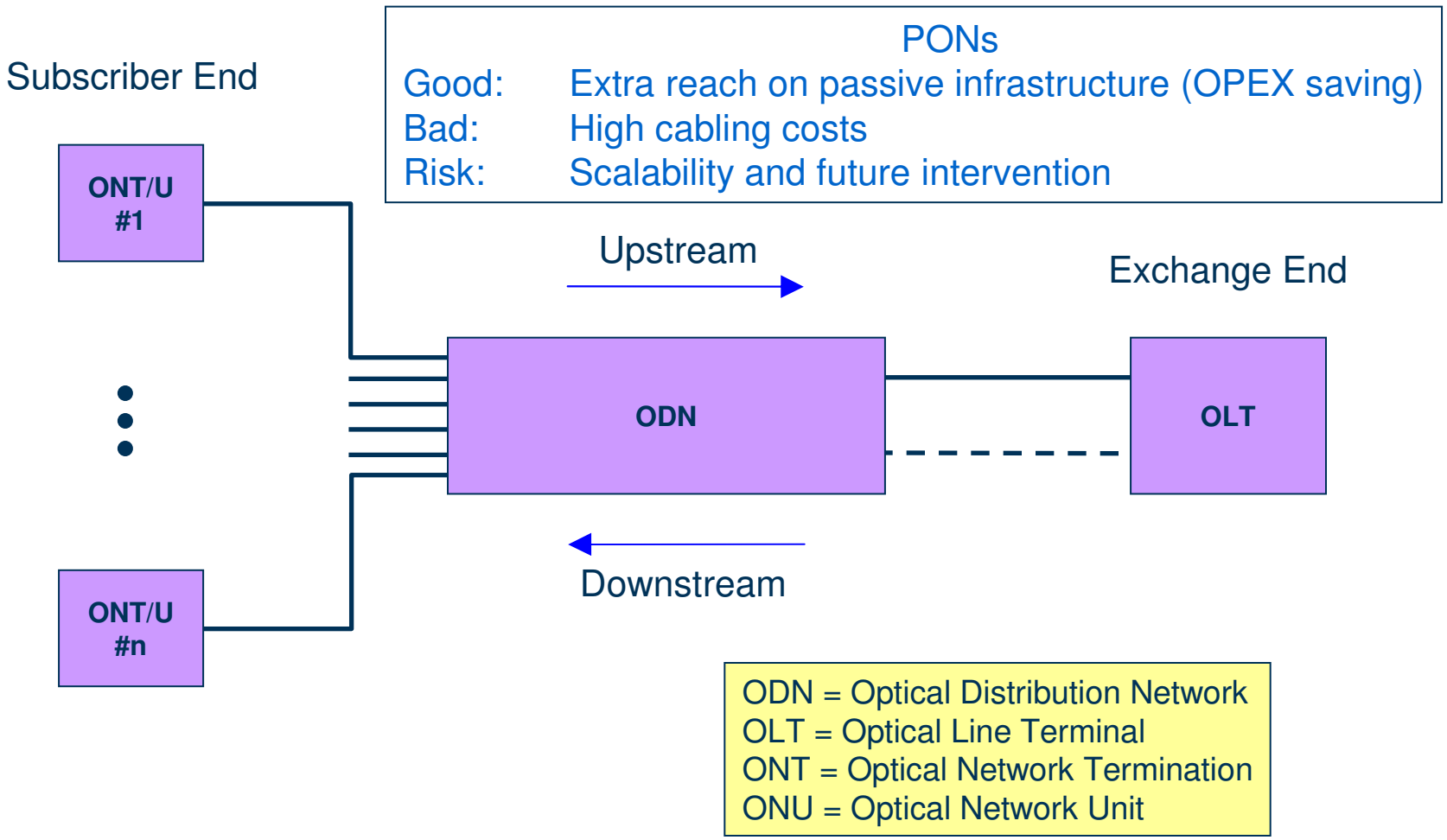


Several technologies with different degree of maturity define the starting point

Today services map



Fiber in access is inevitable



Current solutions: PONs comparison

PON Type:	ITU-T BPON	ITU-T GPON	IEEE EPON
Downstream data rate (Mbit/s)	down: 1244, 622, 155 19 - 38 Mbps per subscriber	down: 2488, 1244 19 - 38 Mbps per subscriber	down: 1250 39 - 78 Mbps per subscriber
Upstream data rate (Mbit/s)	up: 622, 155 9 - 19 Mbps per subscriber	up: 2488, 1244, 622, 155 19 - 38 Mbps per subscriber	up: 1250 39 - 78 Mbps per subscriber
Line coding	NRZ (+ scrambling)	NRZ (+ scrambling)	8b/10b
Minimum split (on TC layer)	32	64	16
Maximum split (on TC layer)	64	128	not specified
Maximum logical reach supported by TC layer	20 km	60 km (with 20 km differential between ONTs)	10 km, 20 km
Layer 2 protocols	ATM	Ethernet, TDM over GEM (GPON Encapsulation Mode),	Ethernet
Standards documents	ITU-T G.983 series	ITU-T G.984 series	IEEE 802.3ah
TDM support	TDM over ATM	native TDM, TDM over ATM, TDM over Packet	TDM over Packet
Typical downstream capacity (for IP data throughput)	520 Mbit/s (for 622 Mbit/s line rate)	1170 Mbit/s (for 1.244 Gbit/s line rate)	910 Mbit/s
Typical upstream capacity (for IP data throughput)	500 Mbit/s (for 622 Mbit/s line rate)	1160 Mbit/s (for 1.244 Gbit/s line rate)	760-860 Mbit/s
OAM	PLOAM + OMCI	PLOAM + OMCI	Ethernet OAM (+ optional SNMP)
Downstream security	ìChurningî or AES	AES (counter mode)	not defined

Is all this good enough?

- Deployment cost is mostly due to laying fiber cables
- The fiber medium offers about 200x125 GHz = 25,000 GHz of useable bandwidth
- Current pons offer on average no more than 2.5 GHz of bandwidth shared among 32 users
  - Not much different than xdsl technologies
  - It is as efficient as we were to drive ~ 500,000 Hp cars
- Can optical systems and devices allow significant better use of the expensive infrastructure?

Back to the issue

Let's assume that:

- *Networks and ownership costs must reduce over time while delivering increasingly higher bandwidth services*

Then

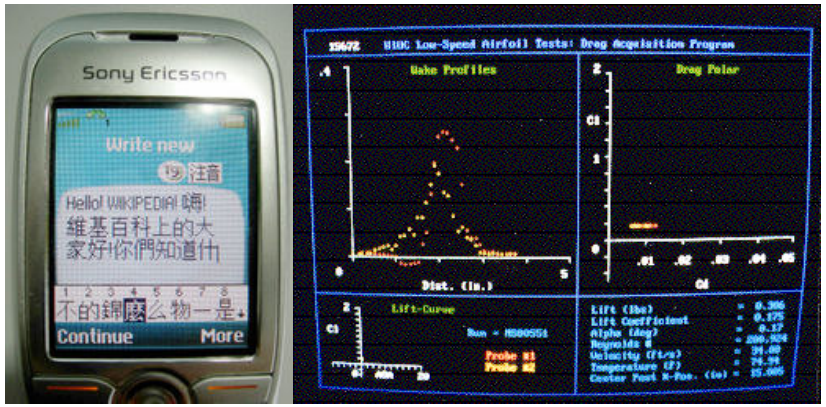
- *More bandwidth and less equipment is required to cover the same area*

So

- *(Bandwidth x Distance) product must increase for the access infrastructure*

And

- *A wise use of photonics in the access network is the only likely sensible answer!*



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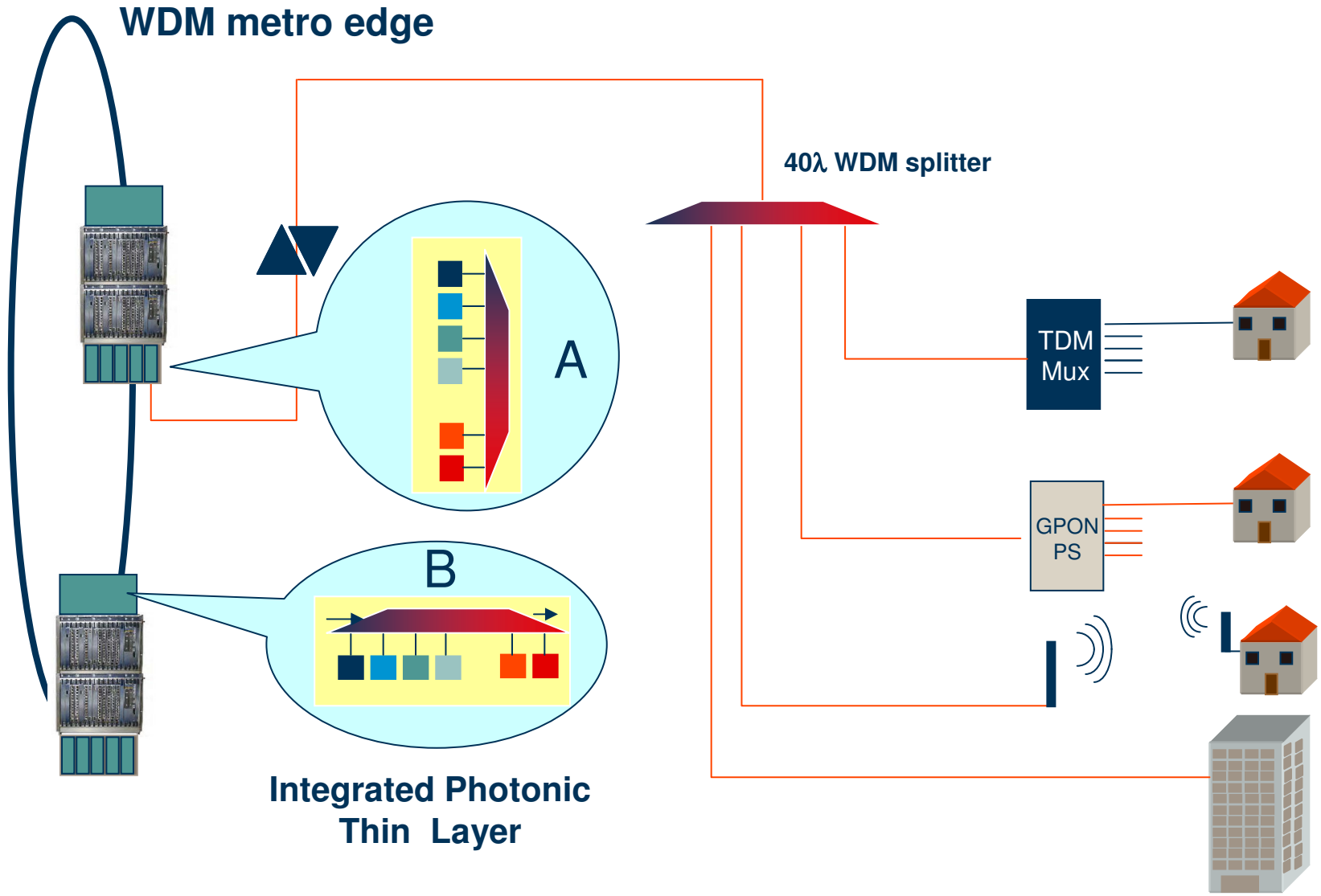
Future key focus

Opto integration

Scalability

Infrastructures

The end point reference network



Optical Integrated Technology

- **This is key to support the telecom evolution**

- **Opto-integration technology is *already* mature for market**

  - **Claims of more than 10,000 cards deployed in transport networks employing 10x10Gb/s integrated modules with 130 Mhours of life traffic without failures**

  - **10x40 Gb/s and 40x10 Gb/s have beeen demostrated in research**

  - **Commercial products also exists for multiple transceivers employing Silicon monolithic opto-electronic devices manufactured using conventional CMOS process**

  - **Several traditional devices employed in conventional DWDM & R-OADM systems also have impressive level of integration**

IC vs Silicon Photonics Integration

Electronics

- Large economy of scale
- Wafer scale integration
- Only two basic structures (transistor and interconnect)
- Focus on one material (Silicon)
- Miniaturization
- Packaging cost!
- Support the ASIC model
  - Pull from volume markets
  - Pull from different applications
  - Protect design differentiation

Photonics

- Too many degree of freedom
- Material types
- Many Component types
- Too many wavelength ranges

So:

- No generic platform to support different applications
- Relatively limited volume

Not an industry yet!

Recent Technology Progress is Impressive

- Low loss waveguides (IMEC, IBM, NTT…)
- Compact wavelength routers (IMEC…)
- Utra-compact high Q microcavities (U. Kyoto…)
- 10-40 Gb/s receivers (LETI…)
- 10-40 Gb/s modulators (INTEL, Luxtera, Cornell…)
- Raman silicon laser (INTEL…)
- All-optical switching + λ-conversion (NICT+IMEC, Cornell, U. Karlsruhe…)
- Integration with CMOS (Luxtera…)
- Hybrid InP-SOI laser (UCSB and INTEL)
- InP microlaser on SOI (IMEC+LETI+INL)

Access networks will increase further the bandwidth race

- With xDSL and mobile broadband each user will handle some 1-10 Mb/s of bandwidth
- With current PON this will rise to some 2.5 Gb/s of bandwidth 50 to 150Mb/s
- With NG PON (DWDM-PON) we will reach 100 Mb/s to 1Gb/s per user and 10Gb/s per SOHO
- **This calls for pretty powerful and high density network elements in terms of transport and switching capacity for metro and core networks**

So where do coherent systems fit in all of this?

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Answer 1 - (No brainer)

There is a call for high speed and advanced transmission techniques

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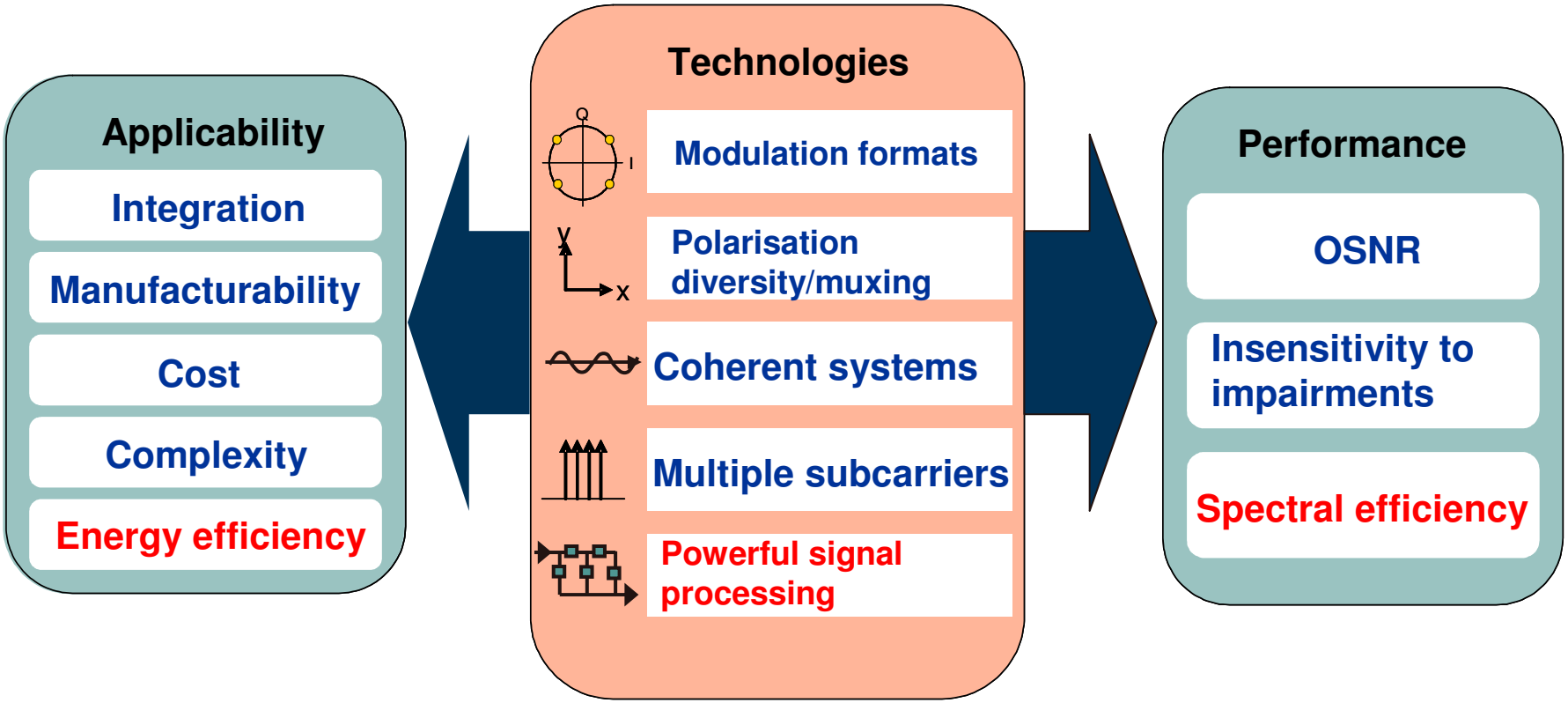
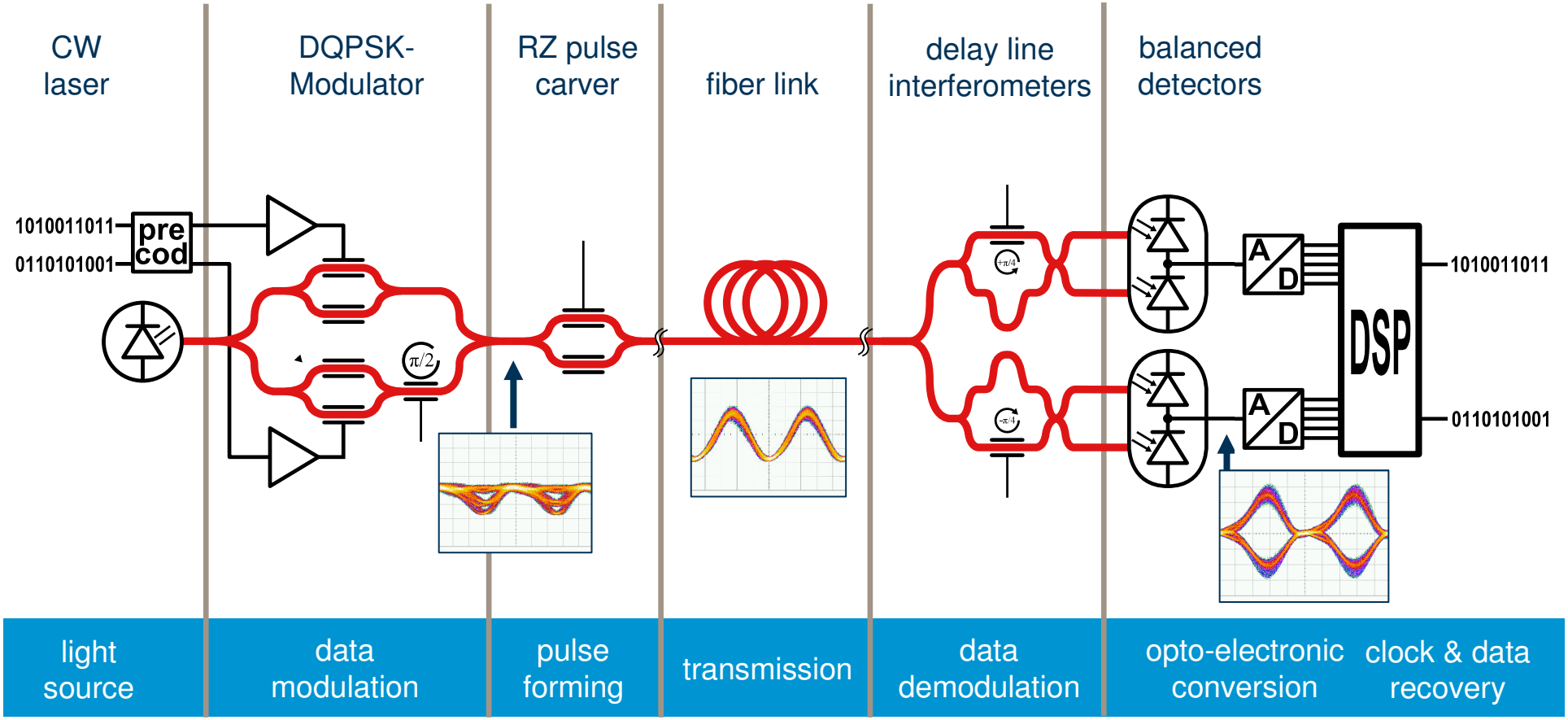
New tecnology map for high speed transport



Today needs are toward a lean signal format using lean digital processing

Example: RZ-DQPSK

Modulation and interferometric detection

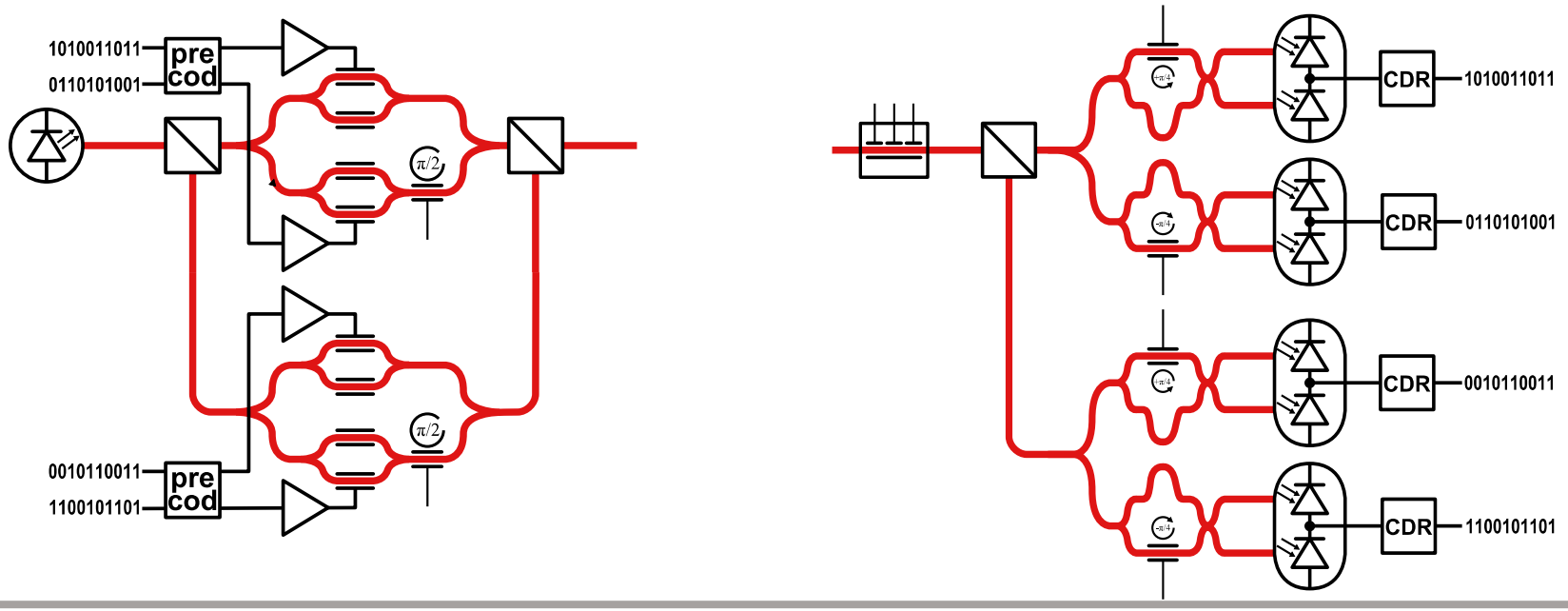


Penalities from unbalanced receiver tolerances and linear and non-linear phase noise can be mitigated using digital post processing

Implementation complexity is blurring

Example: DQPSK with Polarisation Multiplexing….

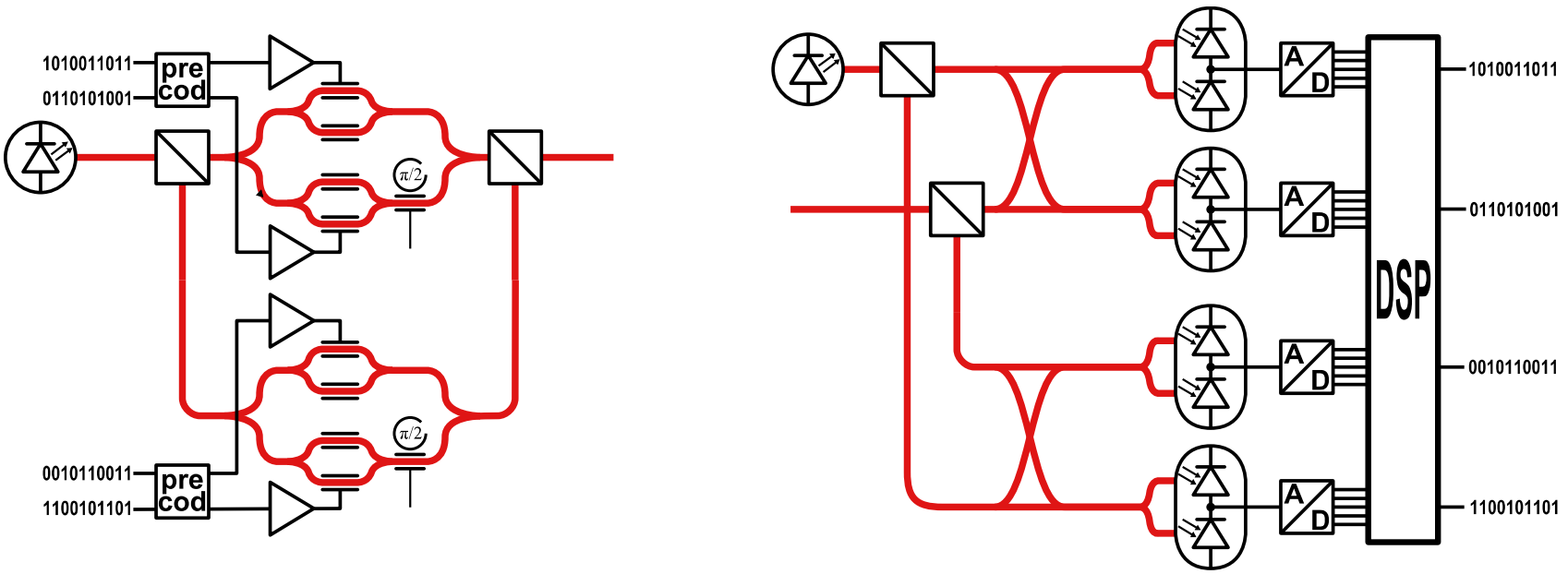
- Popular scheme (only useable once)
- Low baud rate (~28GBaud for 40 Gb/s) but price on polarisation multiplexing complexity
- Compatibility with DWDM sistems on **50GHz** ITU-Grid
- Better tollerance to chromatic dispersion and PMD
- Sensitivity to PDL and polarisation crossmodulation.



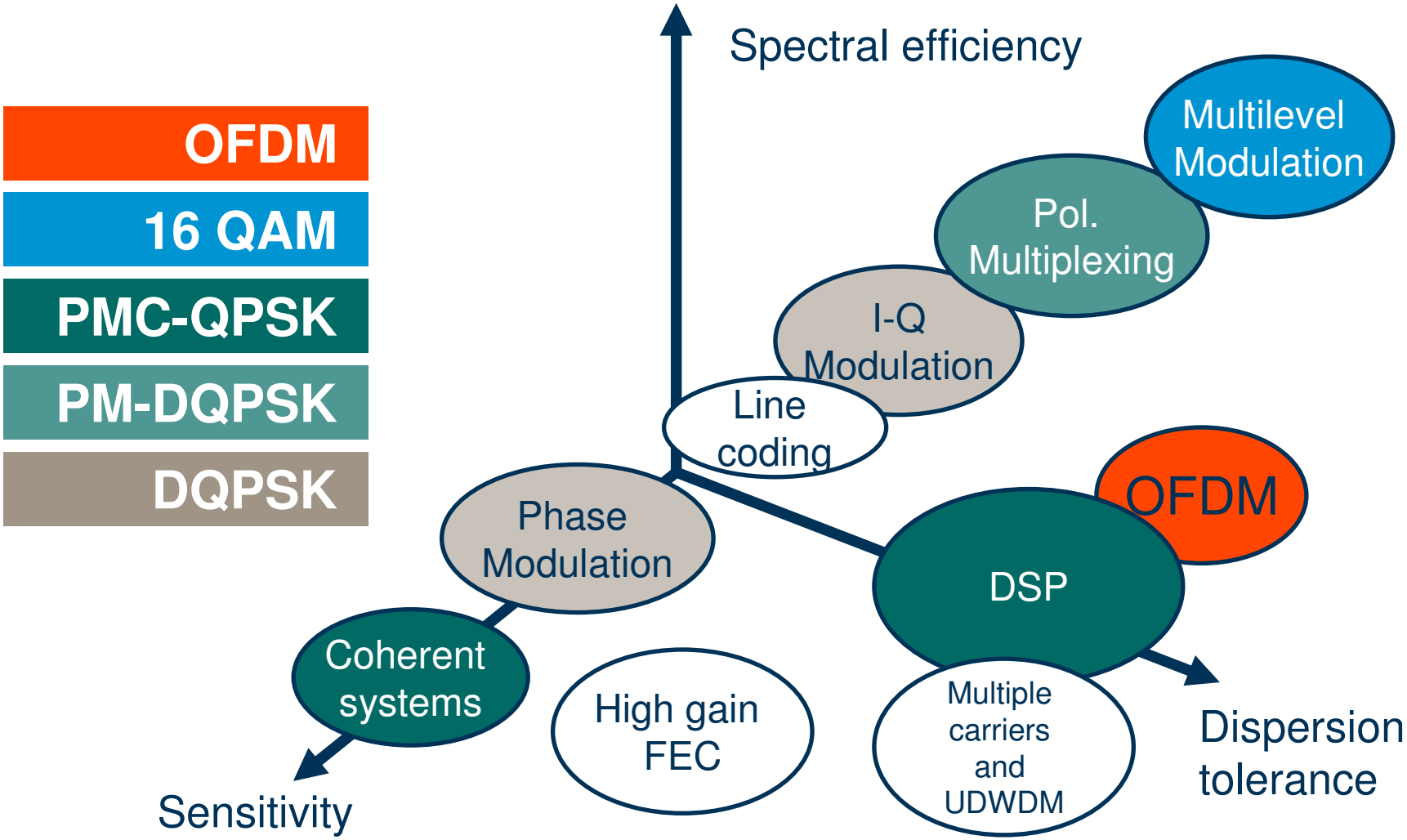
Implementation complexity is blurring

… and the same employing coherent processing

- Key: Coherent & DSP
- Low bit rate at the price of **complex high speed electronics**
- Compatible with DWDM sistems on a **50GHz** ITU grid
- Requires high linearity fornt end (for linear parameters compensation)
- Very sensitive to **non linearities in fibre especially for ULH systems**



Tecnology performance map



Several methods can be joined together

Is there more?

Can we use the optical integration and reborn system concepts to help designing new switching architectures?

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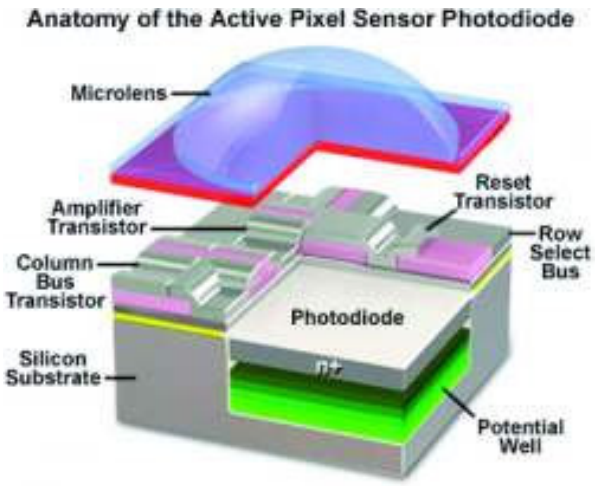
Conclusions

- ICT is a strong catalyst for social changes and a cornerstone for developing low carbon economies
- Novel high bandwidth services are key, but do pose serious constraints to the existing infrastructures
- Efficient use of fiber in access is essential and inevitable to maintain and grow a stable service and value chain business model
- This will stretch further Metro and Core networks, requiring fewer but very powerful and integrated very high speed networks elements
- Power consumption is now a key performance parameter. Integrated photonics technology can allow for integrated opto and electronics functionalities and enabling new efficient digital processing schemes
- New generation coherent system, opto-integration and DSP processing are likely to be key in >100Gb/s transmission systems
- Can this technology offer more?

Impossible?

- Well, never answer a question with another question but…
- …what ever happened to film photography?

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