Optical Networks: recent breakthroughs and future challenges

Jean-Pierre Hamaide, Alcatel-Lucent Bell Labs

ComInLabs Days, Rennes– March 2015

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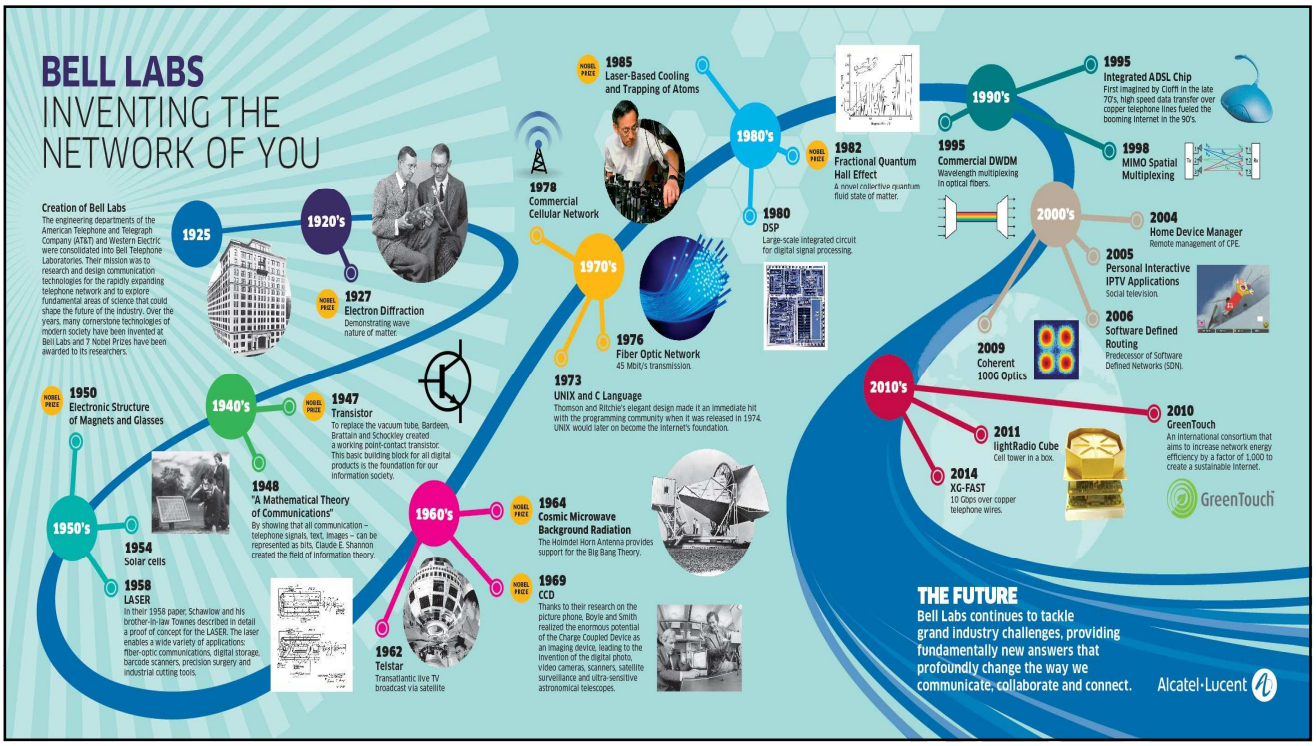

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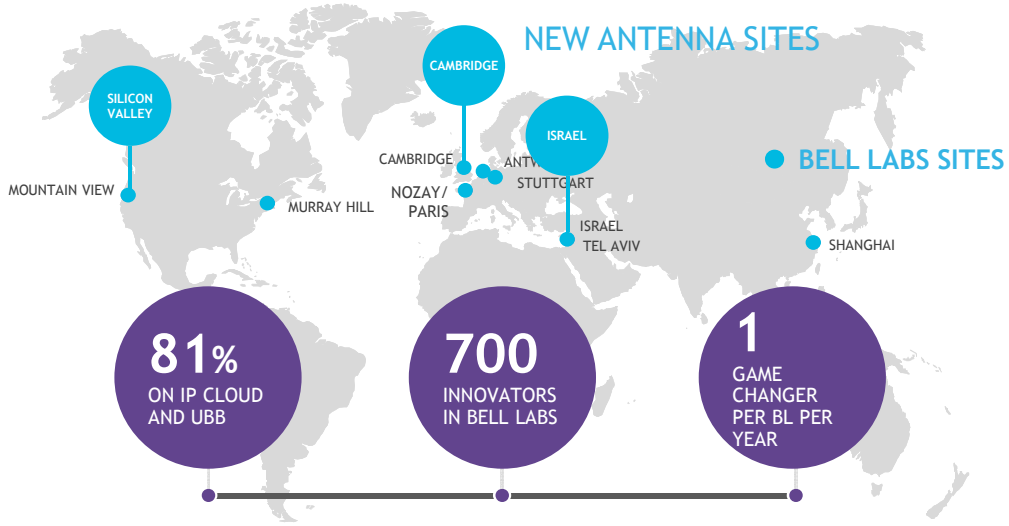
The Network of You



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Market trends

3.9Bn People connected to the Internet in 2017

720% Increase in video traffic 2012-2017

320M More tablets sold in 2014 than laptops and desktop computers combined

>50Bn Enterprise networking market revenue in 2017 (US $)

>70Bn Things connected to the Internet in 2020

440% Increase in cloud and data center traffic 2012-2017

3X Increase in average broadband speed 2012-2017

2X Increase in cloud computing market 2013-2017

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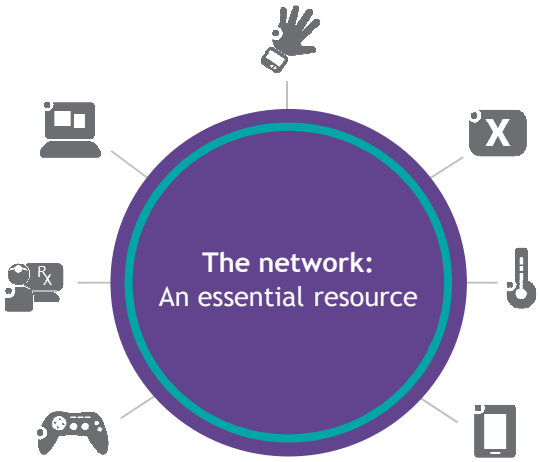
Key resulting market forces

Disruptive scaling in usage

Mobility
Video
Things



Highest performance
Lowest cost per bit
Most personalized

Massive move to the cloud

@ Enterprise
@ Home
@ Providers

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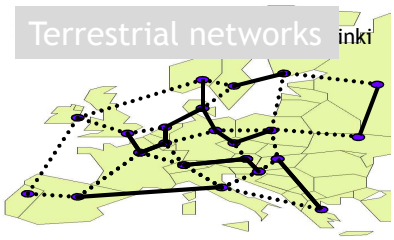
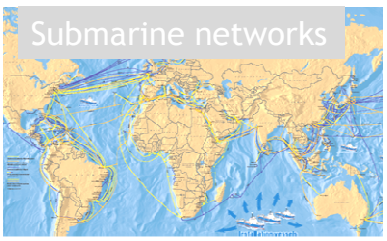
Introduction
Optical networks to provide the transport Infrastructure





- Key questions and challenges for Optical Infrastructures:
  - Provide capacity: Bandwidth efficiency is approaching fundamental limit
  - Provide networking functions: Intelligence is spreading in the optical layer
  - Provide economical and energy efficient solutions

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High-speed fiber optics, all around the World

- Long distance optical networks support the majority of the traffic (>99%).
- Successors of telegraph technology and of the first submarine cables
- All-in-one networks: data, video, internet, voice données, video, internet, voice,
- More than 40 years of research & development and … still active field of research!

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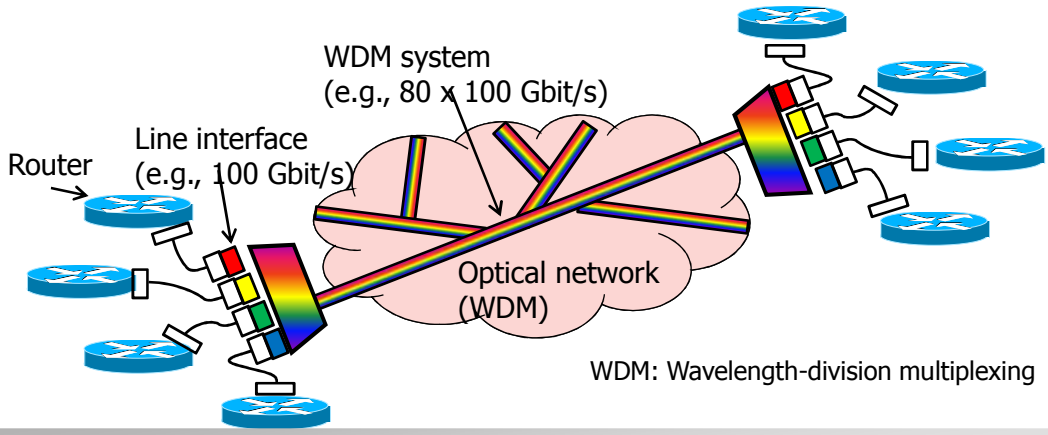
High-speed fiber optics has enabled this network growth



WDM: Wavelength-division multiplexing

Key Technology #1: WDM = solution to reach multiterabit/s capacity
Key Technology #2: Reconfigurable Nodes = Flexible Networking
Key Technology #3: Format, Coding, DSP and Coherent technologies

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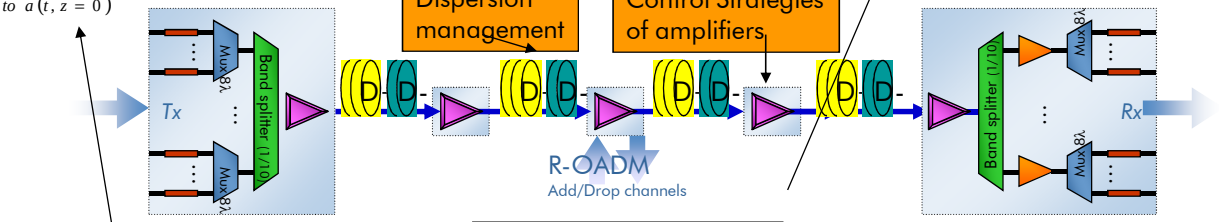
WDM transmission
Some key investigations

Optical field | Dispersion | Kerr NL | Attenuation | Higher Order Disp | Raman Scattering

$$i\frac{\partial a(t,z)}{\partial z}-\frac{1}{2}\beta_2\frac{\partial^2 a(t,z)}{\partial t^2}+\frac{\omega_0 n_2}{cS_{eff}}|a(t,z)|^2 a(t,z)=-i\frac{\alpha}{2}a(t,z)+i\frac{1}{6}\beta_3\frac{\partial^3 a(t,z)}{\partial t^3}+\left(\frac{\omega_0 n_2}{cS_{eff}}\right)h(\tau)t_R\frac{\partial|a|(t,z)^2}{\partial t}a(t,z)$$
$$+\ Gain\ (z)+\ Noise\ (z)+\ Filter\ (z)+\ldots$$

$\beta_2=\beta_2(z)$

from Initial Informatio n to $a(t,z=0)$



Advanced transmitters & modulation formats

Planification rules & Dynamic reconfiguration

Electr. & Opt. processing

from $|a(t,z=L)|^2$ to reCovered Informatio n

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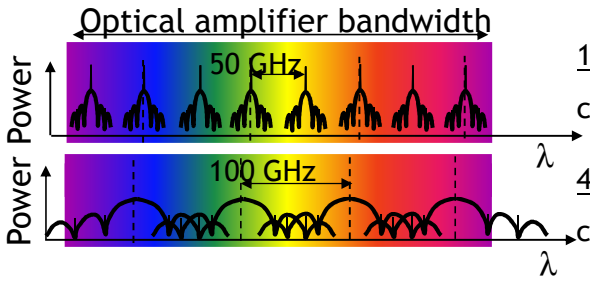
WDM transmission
Increasing the information spectral density

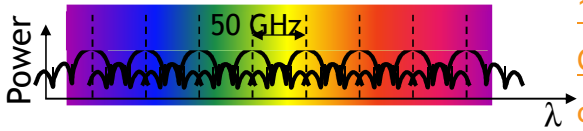


10 Gbit/s NRZ
capacity = x 1

40 Gbit/s DPSK
capacity = x 2

Efficiency	Bit/symbol
20%	0 +1
40%	-1 +1

Revolution: coherent technology



100 Gbit/s
Coherent PDM-QPSK
capacity = x 10

200%

T.E.
T.M.

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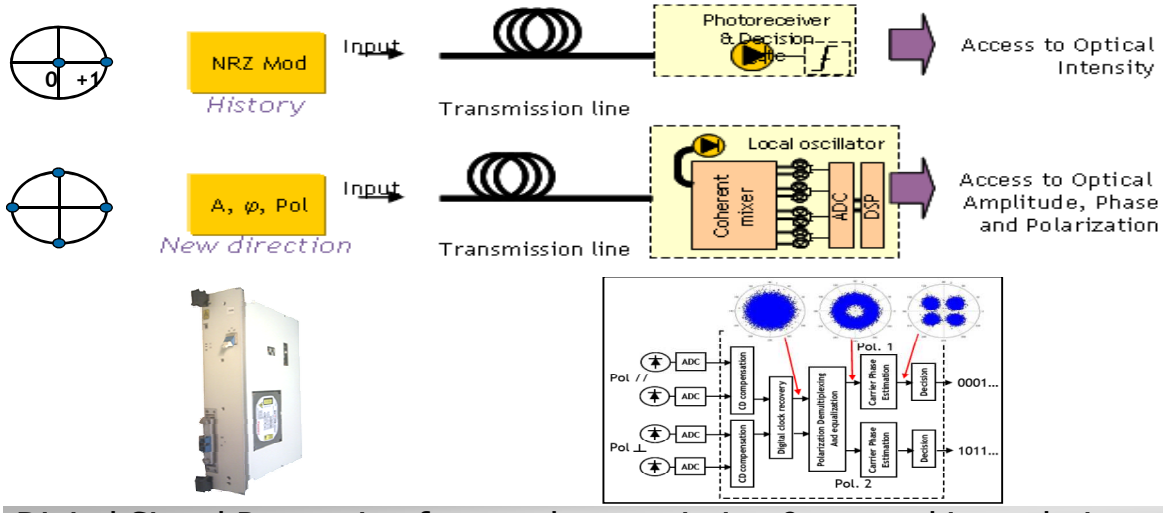
WDM transmission
The Coherent/DSP-based systems breakthrough



Digital Signal Processing for novel transmission & networking solutions

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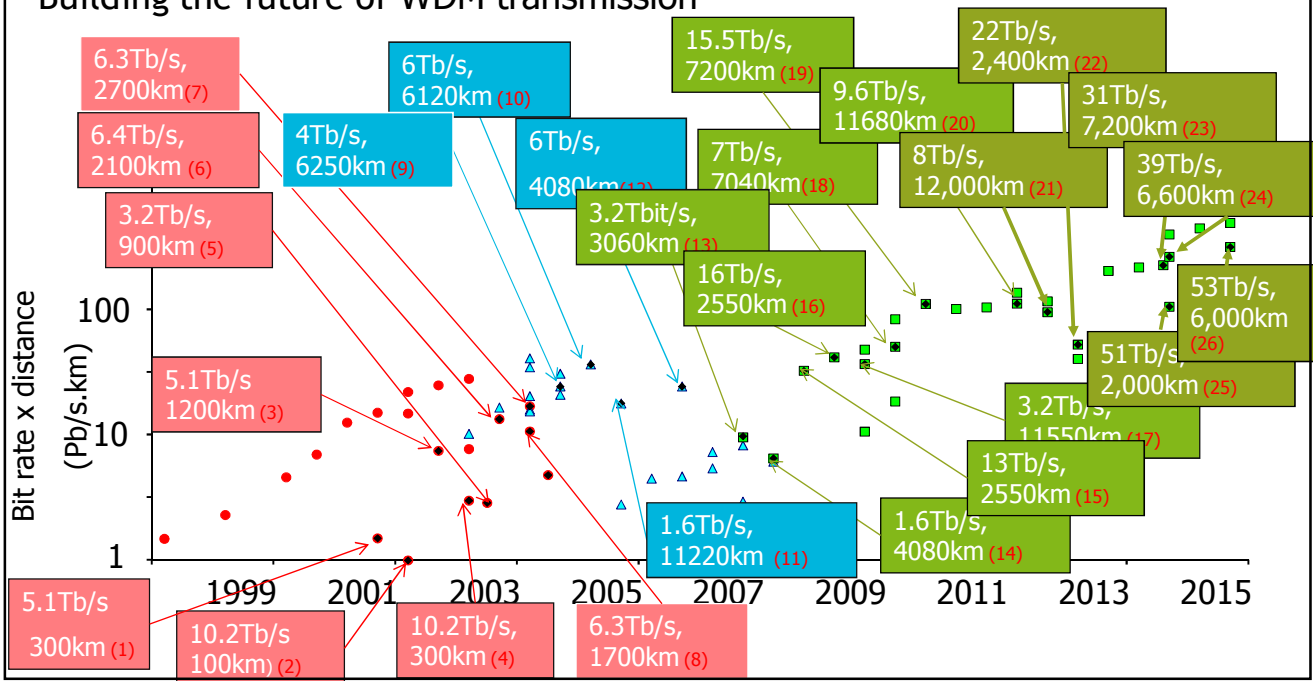
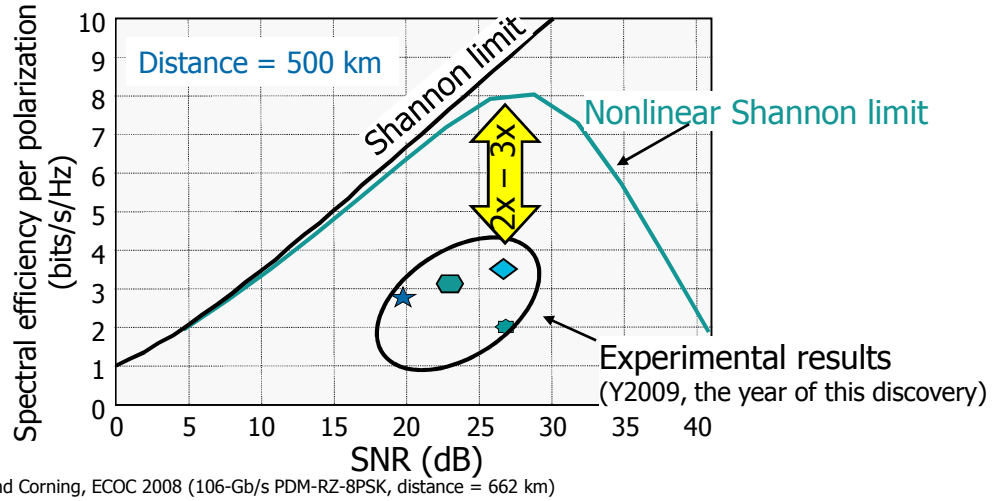
Building the future of WDM transmission



The wall: the non-linear Shannon limit



- 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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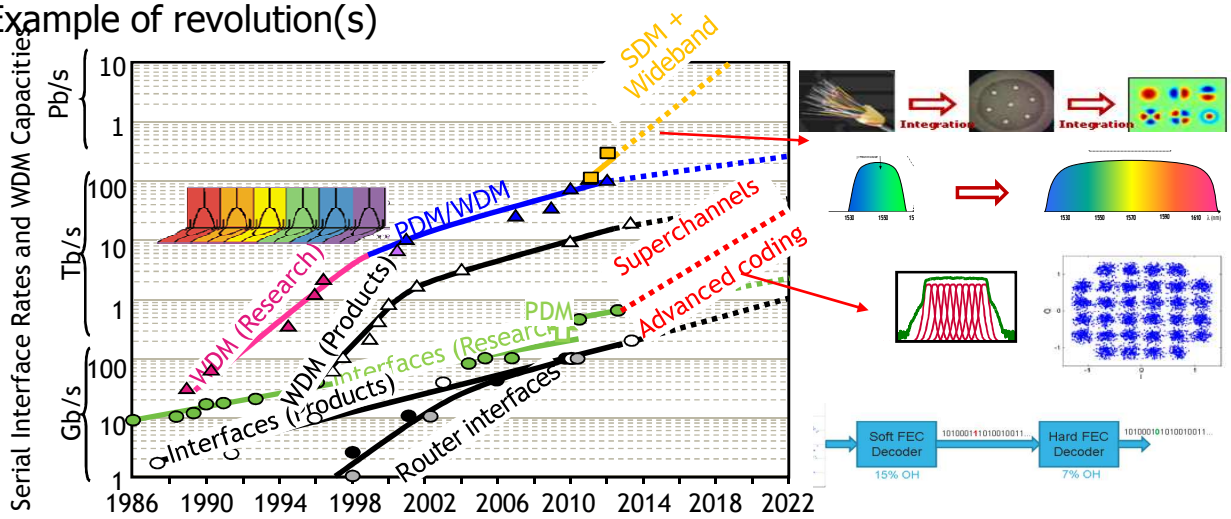
WDM transmission: Breaking the wall with SDM
Example of revolution(s)



- The dream: 10Tbit/s optical interface and 10Pbit/s transport capacity
- Combination of Hardware – Systems – Networks - Mathematics research

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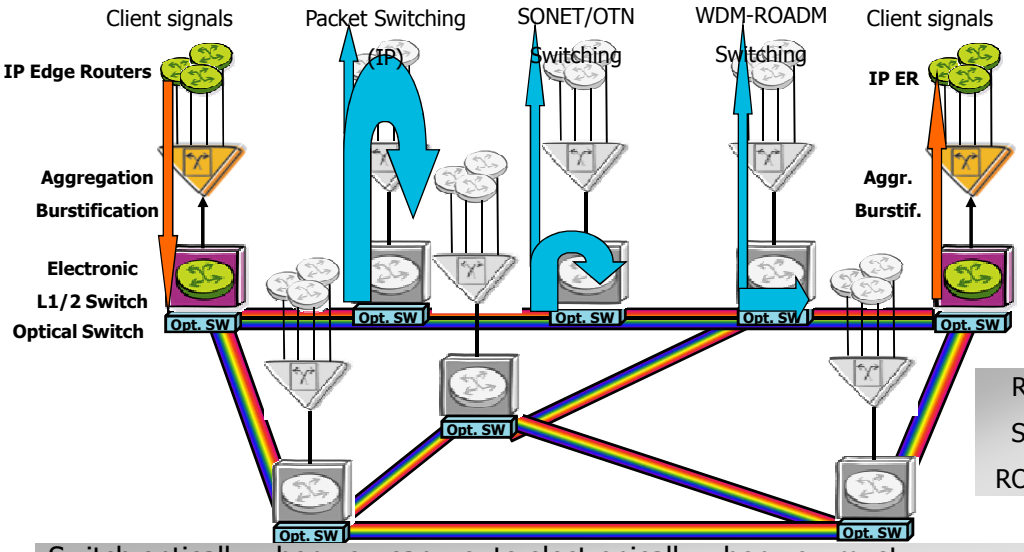
Intelligent Optical Networks



Router: 12 mW/Mb/s,
Switch: 2-8 mW/Mb/s
ROADM: < 2 mW/Mb/s

Switch optically when you can, route electronically when you must
IP – Optics integration for reduced transport cost and operational complexity

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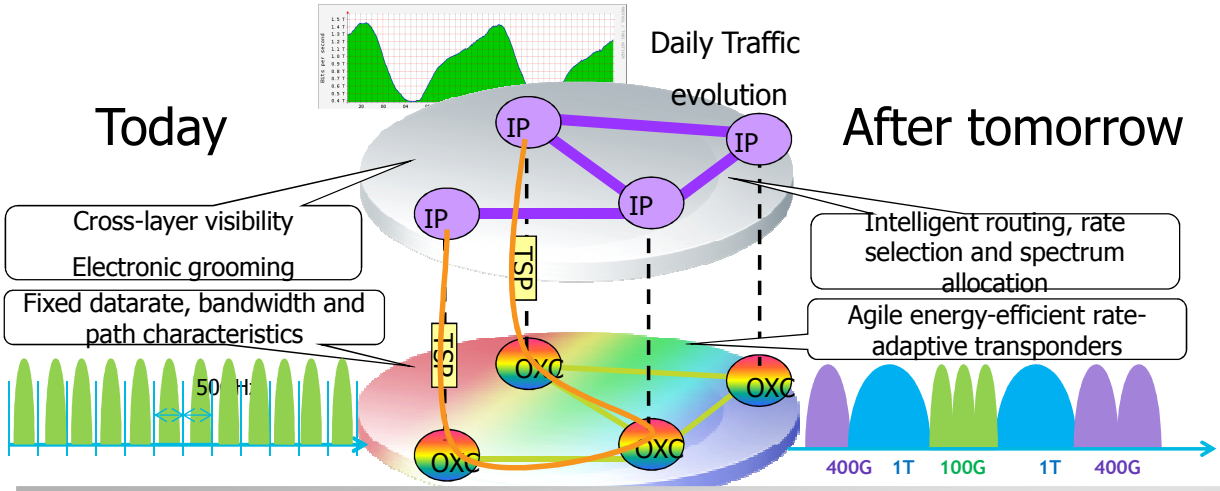
Intelligent Optical Networks
Example of revolution: Elastic Optical Networks



•The dream: Transponder which adapts traffic and infrastructure
•Combination of Hardware – Systems – Networks – Mathematics research

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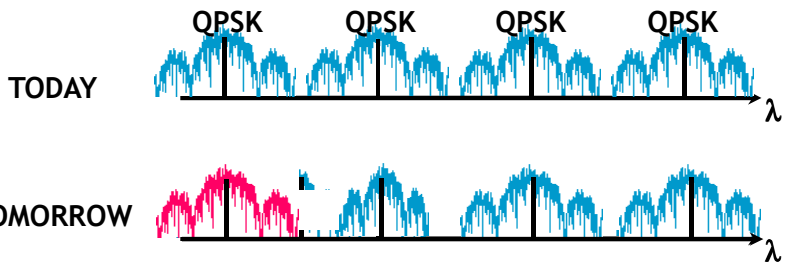
Intelligent Optical Networks
Example of revolution: Elastic Optical Networks



Fixed format
Fixed symbol rate
Fixed channel spacing
Variable format
Variable symbol rate
Variable channel spacing

- **Expected benefits of elastic optical networks:**
  - Better use of available fiber bandwidth → Increased network capacity
  - Adaptation of resources to actual demand → Better energy efficiency
  - Pro-active operation and decision

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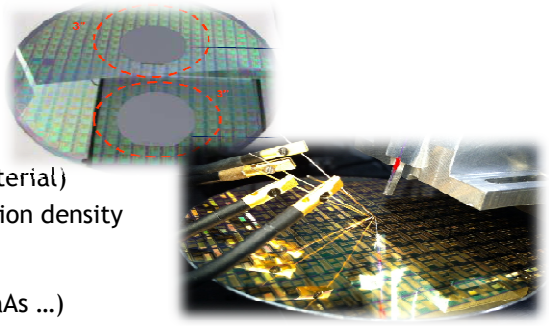
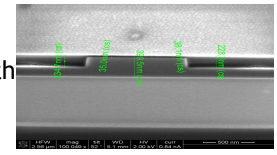
Hardware technology
Example of revolution: Silicon Photonics



- Electronics everywhere
  - Mature CMOS fabrication process (based on Silicon material)
  - Cost reduction through mass production, high integration density
- Current optical communication technology:
  - Based on a dedicated III-V platform (material : InP, GaAs …)
  - High bit rate, transmission over long distance, immunity to electromagnetic interference, high energy efficiency

- **New paradigm : New III-V/Si integration platform combining best of both worlds**
  - III-V : providing optical gain (Silicon can't compete for light emission)
  - Silicon : Available key building blocks (low loss passive waveguides, wavelength multiplexers/demultiplexers, detectors, modulators)
  - Key point : molecular bonding of III-V wafers to 200/300mm SOI wafers



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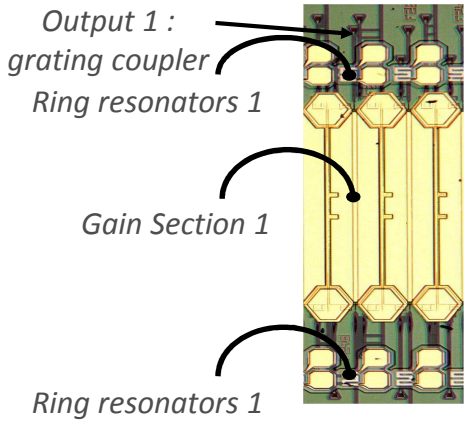
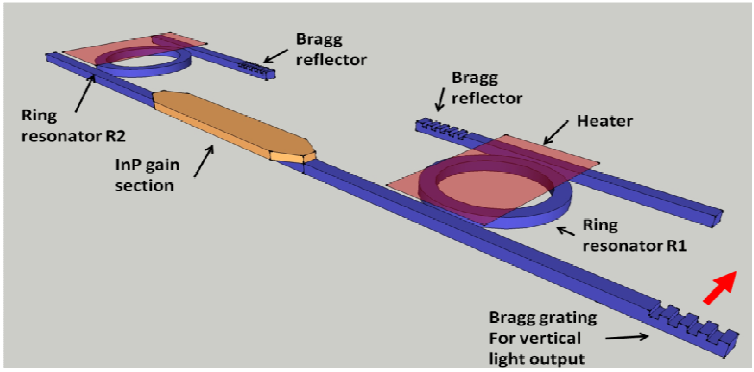
Silicon Photonics revolution
From a hybrid SOA structure to a tuneable laser





[8] A. Lelievpre et al., GFP'12, WC3 (2012).

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Video – Transoceanic cable installation
meeting point of many sciences, technologies and knowledge

- From research
- To Innovation
- To Product
- To Installation

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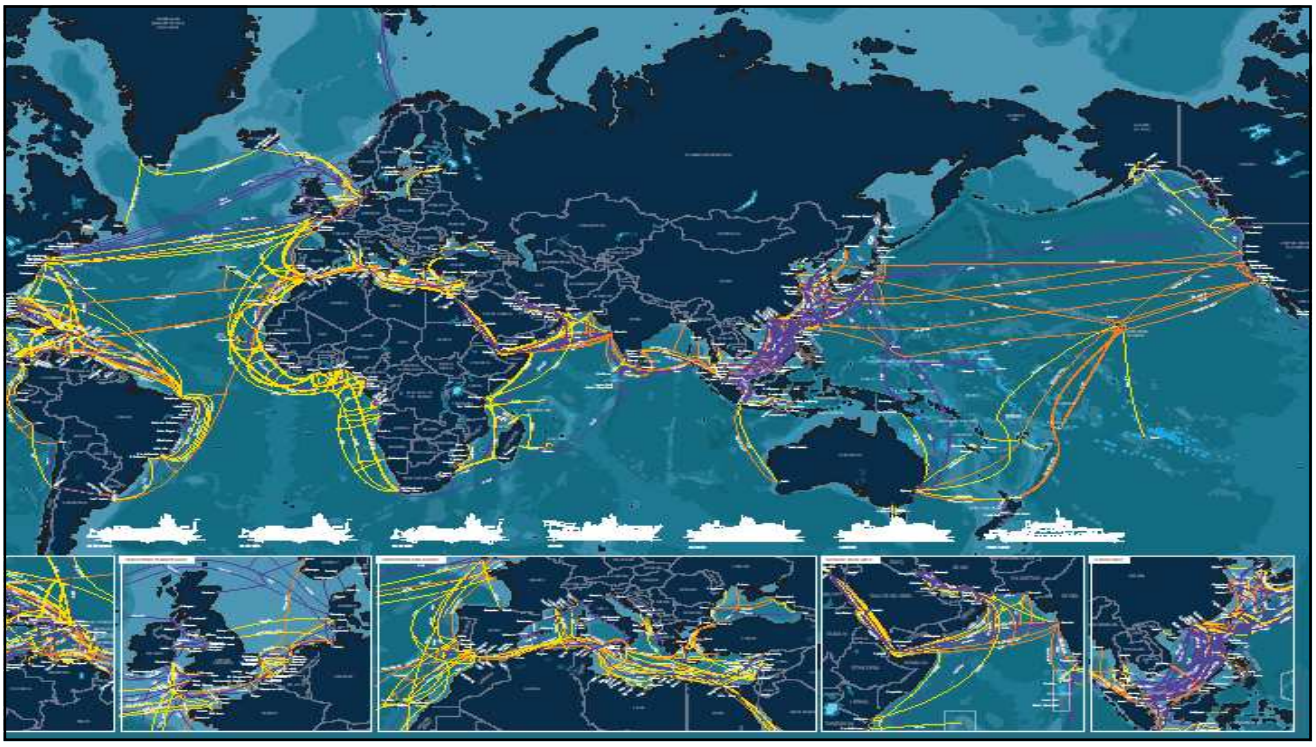
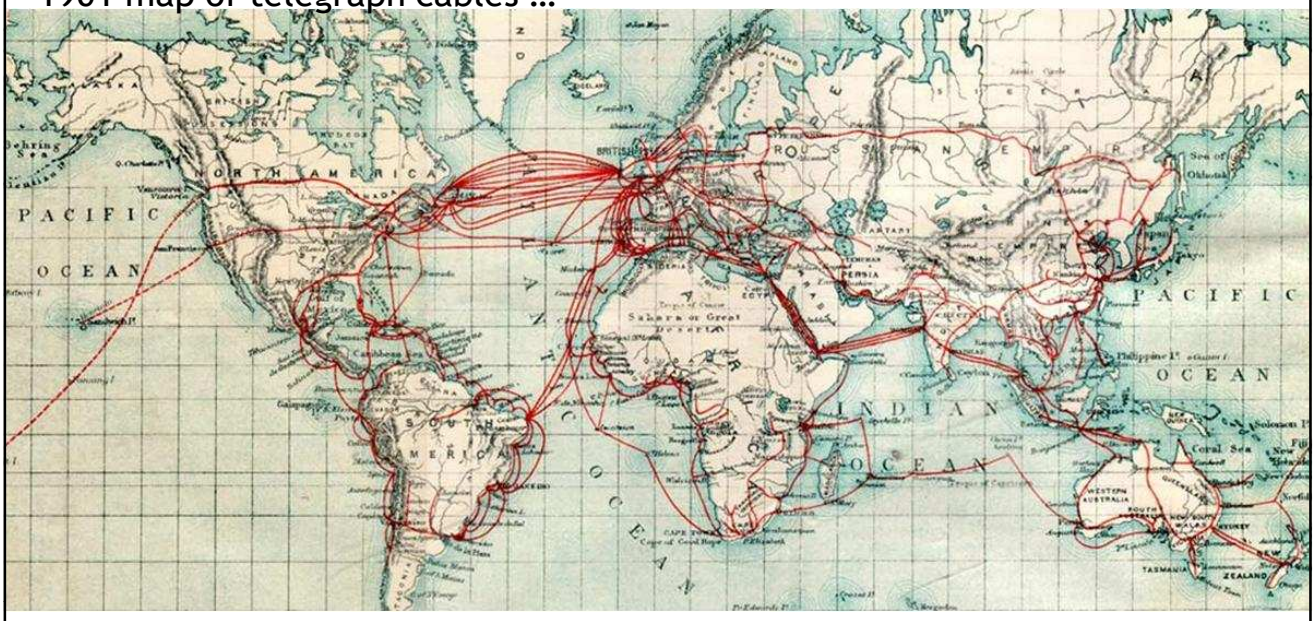


1901 map of telegraph cables …



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Summary

- Data services are still fueling an exponential traffic growth & energy consumption
  - Human-generated traffic; Machine-generated traffic
  - Impact of video, cloud computing, wireless services & backhauling, new applications, etc...
- Optical Technologies has enabled traffic growth over the last 40 years
  - 100-Gb/s and 400-Gb/s research translated into innovation and is product-ready
  - Physical limits are approaching, Bandwidth should no longer be taken for granted
- Four evolutionary questions; revolutionary answers needed
  - Large space for innovation find the ideal Routing / Switching / Transport configuration
  - Physics, optics, information theory, digital signal processing, communication protocols and trans-layer networking

Optical Transport is an active part of the full Network
Exciting challenges in front of the research community !

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Additional information
YouTube – BL Prize

- https://www.youtube.com/watch?v=Wq1-Iq9Vm28
  - **The Shannon Limit - Bell Labs**
- A nice paper on a earth quake in 1929 along the Canadian coasts : what an adventure
  - http://www.slate.fr/story/94779/tremblement-terre-cables-1929

- Bell Labs Prize: https://www.bell-labs.com/prize/
  - **Win the 2015 Bell Labs Prize - Deadline April 22nd, 2015**
  - The Bell Labs Prize is a competition for innovators from participating countries around the globe that seeks to recognize proposals that 'change the game' in the field of information and communications technologies by a factor of 10, and provides selected innovators the unique opportunity to collaborate with Bell Labs researchers to help realize their vision.

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Every success has its network

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