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

Fiber-optic transmission systems to provide high capacity - Basics
• Guided, isolated from ext. interferences
• Very low attenuation:
  - 0.188 km @ 1550nm (down to ~0.148km)
• Huge available bandwidth ➔ high capacities /
• Virtually 50THz
• In practice, operate w/ ~4THz bandwidth
  all-optical Erbium Doped Fiber Amplifiers

Optical Networks in Telecommunications ? Everywhere
Optical network to support the continuous increase of multimedia traffic
• From subnanosecond to sub-second to second - to multi-second to multi-point - reconfigurable networks

Trends in Telecommunications - from Capacity explosion ...
Greater capacity into a single fiber
Per channel bit rate
2.5 Gb/s 10 Gb/s 40 Gb/s 100 Gb/s
Year
1990 2000 2010
Trend #1: greater capacity ➔ exponential growth, driven today by video traffic

Trends in Telecommunications - ... to Operational Automation
Transparent, reconfigurable mesh networks

Trend #2: Higher transparency ➔ photonic pass-through, eliminates regeneration
Key points:
• Bridge larger distances
• Mix bit rates over the same fiber
• Mix several fiber types across full fiber path

Trend #3: Full remote reconfigurability ➔ remotely configures 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 handles of electronic convergence

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

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TREND 1: GREATER CAPACITY

Signal spaces in optical communications

System Evolution in metro/core terrestrial networks

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

<table>
<thead>
<tr>
<th>Year</th>
<th>Technology</th>
<th>Capacity</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990s</td>
<td>2.5-10 Gb/s</td>
<td>8, 16, 40 channels</td>
<td>0.025-0.05</td>
</tr>
<tr>
<td>2000</td>
<td>10 Gb/s, channel rate</td>
<td>100 channels</td>
<td>0.2</td>
</tr>
<tr>
<td>2010</td>
<td>100 Gb/s, channel rate</td>
<td>100 channels</td>
<td>2.0</td>
</tr>
<tr>
<td>2020</td>
<td>1 Tb/s, channel rate</td>
<td>100 channels</td>
<td>20</td>
</tr>
</tbody>
</table>

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

Coherent detection vs today’s system reception scheme

Coherent detection and signal processing
Record experiments and the non-linear Shannon limit

- Efficiency per polarization (bits/s/Hz)
- Nonlinear Shannon limit
- Distance = 500 km
- Signal to Noise Ratio (dB)
- Spectral efficiency

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)

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

Beyond Shannon?
Polarization and space mux

Evolution of Ethernet rates

TREND 2: OPTICAL TRANSPARENCY

Towards transparent meshed backbone networks

Past Installed Photonic Networks mostly opaque
- Electrical-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 ...

Towards transparent meshed backbone networks

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

⇒ CAPEX and energy consumption reduction
Towards dynamic mesh backbone networks

Currently proposed solutions:

- **TUNABLE ROADMAP FOR DYNAMIC NETWORKS**
  - Possibility to have connection from any port to any part of the nodes
  - Dynamic margin allocation
  - Physical parameters monitoring

Opportunity for advanced functionalities managed by the control plane (GMPLS)
- Network reconfiguration on demand
- Optical Restoration

But dynamity reduces the transparency radius:
- Incremental G.8032
- Physical parameters monitoring

TREND 3: FLEXIBILITY

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: 400Gb/s per channel
- Research lab records: Capacity x distance product: CxD = 112Pbit/s·km
  - 155x100Gb/s over 7,200km (G.Charlet et al, ECOC, September 2009)
  - Based on 0.166W/km fiber from Sumitomo
  - Coherent-PDM-QPSK
  - Raman-Erbium amplification
  - Bit Error Rate better than 4.10^-3 before Error Correction

High bit rate, long distance WDM transmission

- 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 resources dimensioning requires
- A fine tool to predict quality of transmission, accounting for:
  - And a planning tool to align 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 x 10^9 with 7% overhead
  - 10Gb/s useful data rate - e = 10^-3 is effective bit rate in optical systems
  - Lab experiment: 160x30Gb/s over 3150km (OFC, 2008): 40 Petabit/s · km

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Research trend: Optical Packet Switching

Packet Optical Add/Drop Multiplexer (POADM)

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

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 challenge 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

Hypothesis:
- mix of 10G, 40G & 100G interface
- with 3 tendencys: evolutions from higher speed
- OEO-XC config based 10/75 add/drop
- Assumes that Network Capacity trend roughly increases, depending on actual network traffic

Need to shift as much capacity as possible from routers down to XC and Photonic domain to sustain the IP traffic growth
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, interconnection of supercomputers, Data-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): 10GE 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 drivers: transport of 100GGE client signals (between routers, video servers or computers)
VoD:
- High Speed Data Center Interconnections
- Ethernet
- Transport drivers: concentration of several client signals + 100G and transport via 100G
Transport Optimizations:
Basic technologies: Reconfigurable and dynamic Optical Networks

Challenges in Optical transport network management: flexibility and transparency

Network Transformation

It’s all about … Transport Innovations

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Thank you