Optical technologies and telecommunication networks: some key drivers and technological breakthrough axes for the next decade

*Parts I, II*

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Outline

- Introduction
- Context and key drivers of optical network evolutions
- Technological breakthrough axes for future optical networks
- Some illustrative examples and network implications
- Concluding remarks
Introduction (1)

Five major challenges for the Integrated Operator

1. IP Everywhere
2. Broadband Everywhere
3. Mobility Everywhere
4. Innovative Multiaccess Terminals and Devices
5. IT Platforms for Open Networks
Introduction (2)

Optical networks or optical pipes?

- Optical fibers were introduced in telecommunication networks only two decades ago.

- Do optical networks really exist?
  - Not yet actually…
  - What we often call "optical networks" are in fact electronic networks the links of which are optical point-to-point transmission systems.
  - Optical network nodes (photonic cross-connects) failed their entrance in operators' networks.

- So, is optics capable of providing other functionalities than huge point-to-point pipes?
  - Hopefully this presentation will convince you that the answer is yes…
Outline

Introduction

Context and key drivers of optical network evolutions
- Which networks do we speak about?
- Context and key drivers in transport networks
- Context and key drivers in access networks
- Context and key drivers in home networks

Technological breakthrough axes for future optical networks

Some illustrative examples and network implications

Concluding remarks
Which networks do we speak about?

- **Transport networks** are medium to ultra-long distance networks
  - Distances between nodes: from **several thousand kilometers** down to **a few hundred kilometers**
    - Submarine and terrestrial core networks (**Wide Area Networks**)
  - Distances between nodes: from **several hundred kilometers** down to **a few tens kilometers**
    - Regional and metropolitan networks (**Metropolitan Area Networks**)

- **Access networks** are short to medium distance networks
  - Distances between access nodes and customer premises: from **a few tens kilometers** down to **a few hundred meters**

- **Home networks** and **Local Area Networks** are very short to short distance networks
  - Distances between terminals and/or gateways: from **several hundred meters** down to **a few meters**
Core networks: example

European Backbone Network

Cities
- System in Service
- Project
- Point of Presence / Landing Station
Key drivers in transport networks

- **Increase of bit rate per wavelength** in core networks (WAN)
  - leads to CAPEX+OPEX reduction
  - Increase of overall capacity per fiber has slowed down during recent years
  - Fewer increase in actual bandwidth needs in core networks

- Main research driver: **cost reductions of each (bit/s).km**
  - In the past 5 years, the cost of a (bit/s).km has been divided by 10

- **More flexibility** in optical transport networks (WAN+MAN)
  - Flexibility leads to OPEX reduction
  - The requirement for flexibility in network resource usage is particularly critical in metropolitan area networks
Optical Moore's law

Overall bit rate per fiber (Gbit/s)

- **TDM**
- **WDM**

- +35 % per year
- +120 % per year

WDM introduction
Evolution of WDM system capacities

![Evolution of WDM system capacities graph](image)

- **Bit rate per wavelength channel (Gbit/s)**
- **Number of wavelength channels per fiber**

**Products**
- Available
- Announced
- R&D

- **> 1 Tbit/s**
- **Available Products**
- **Announced Products**
- **R&D Products**

Research & Development
Access network context

- Backbone
- IP video
- Internet
- VoD Server
- IP telephony

- DSLAM: Digital Subscriber Line Access
  - 40 – 400 km
  - ~ 1,000 subscribers

- FTTB: Fiber To The Business
  - ~ 10,000 subscribers

- 90% of subscribers at less than 5 km

- Access Node
  - ~ 5,000 subscribers

- Optics or copper

- PLC
- WiFi
- UTP5 cable
Key drivers in access networks

- Optics has to face various competitive technologies, benefiting from already installed network infrastructures
  - e.g. xDSL, cable, satellite

- Growth of Fiber-To-The Home (FTTH) deployments in the world
  - Several million subscribers in the world including about 5 million in Japan, 0.6 million in Europe, 0.3 million in USA

- Architecture and resource sharing issues in optical access
  - Point-to-point, Point-to-Multipoint
  - Time/Wavelength/Code Division Multiple Access

- Technology, architecture, and cost issues are strongly related in optical access network design
FTTH subscribers in the world

Source: Cahners In-Stat Group, RHK, Corning
Broadband subscribers in Japan

<table>
<thead>
<tr>
<th>Year</th>
<th>Users (thousand)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>CATV: 100</td>
</tr>
<tr>
<td>2002</td>
<td>CATV: 100,000</td>
</tr>
<tr>
<td>2003</td>
<td>CATV: 1,000</td>
</tr>
<tr>
<td>2004</td>
<td>FTTH: 14,100</td>
</tr>
<tr>
<td>2005</td>
<td>FTTH: 7,700</td>
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<tr>
<td></td>
<td>ADSL: 7,000</td>
</tr>
<tr>
<td></td>
<td>CATV: 4,300</td>
</tr>
</tbody>
</table>

Bit rate increase in optical access networks

- **1986**: T-PON, 51.2 Mbit/s, 4 Mbit/s, 32 users
- **1990**: A-PON, 155/622 Mbit/s, 64 users
- **1996**: B-PON, 155/622/1244 Mbit/s, 64 users
- **1999**: Ethernet MC, 10 Mbit/s
- **2002**: Ethernet MC, 100 Mbit/s
- **2003**: E-PON, 1 Gbit/s
- **2004**: G-PON, 1.25/2.5 Gbit/s

**Standards:** FSAN, ITU-T, IEEE802.3

- **1G**: Pt à Pt
- **10G**: Pt à MPt
Home network context

- High penetration of **wireless networks** (Mobile and Wireless Local Area Networks)
  - 17% of home gateways have IEEE802.11 (Wifi) interface

- Service scenarios in a short term:
  - 30Mbit/s bandwidth requirement (High Definition TV, TV, Internet, Games)

- **FTTH** deployment in access networks
  - Optical gateway

- Development of **very high bit rate radio systems**
  - Ultra Wide Band
Key drivers in home networks

➤ High technological diversity
   ● e.g. radio, Power Line Communication, optical fiber, radio over fiber, …

➤ Some original problematics in optics for home networks
   ● Plastic fibers
   ● Microstructured fibers
   ● Hybrid radio/fiber techniques
   ● Wireless optics
   ● Multimode fiber PON…

➤ Home networks will require network convergence and technology integration
Outline

- Introduction
- Context and key drivers of optical network evolutions
- Technological breakthrough axes for future optical networks
  - Scope
  - Presentation of breakthrough axes
  - Summary
- Some illustrative examples and network implications
- Concluding remarks
Scope of technological breakthrough axes

- Technological breakthrough axes presented hereafter concern optical technologies for telecommunication networks.

- These breakthrough axes may affect various areas of optical network layer design: components, sub-systems, systems, and network architectures.

- They are thought to strongly impact on optical network evolution in the next decade.
Microstructured optical fibers

- Impressive progress during recent years
  - 0.28 dB/km loss for index guiding photonic crystal fibers (Holey Fibers)
    - K. Tajima et al, ECOC 2003, Th4.1.6
  - 1.7 dB/km for photonic bandgap fibers (PBG fibers)
    - B.J. Mangan et al, OFC 2004, PDP24

- Main difficulties related to fabrication process and control of fiber properties over long fiber spans
  - 0.3 dB/km achieved along a 100 km holey fiber span
    - K. Kurokawa et al, OFC 2005, PDP21

- Various breakthrough applications
  - As advanced optical functions
    - Dispersion compensation, optical regeneration, wavelength conversion, ...
  - As the line fiber of future telecommunication infrastructures
    - Potential for very low loss compared to standard single mode fiber

- Potential operational maturity
  - 2010 for use in advanced optical functions
  - 2020 as line fibers
Wavelength agility in optical networks

- Agility is a main driver of research in optical networking
  - Optimisation of optical resource allocation, dynamic resource allocation in transport networks
  - Resource sharing in access networks, e.g. in Passive Optical Networks

- Fast & low cost wavelength tunability could change the vision of future optical and IP networks
  - Compact / high performance IP Terarouters with high speed optical switching core based on high-speed wavelength-agile optical components
    - E.g. DARPA IRIS project: 100 Tbit/s IP router based on an optical switching fabric including fast tunable wavelength converters integrated on a InP chip
  - Wavelength agility could be the key to very flexible optical access / metro networks

- Potential operational maturity: 2015
Photonic crossconnects and intelligent optical networks

- Photonic crossconnects (PXC) failed their entrance!
  - Present need in transport networks is for **sub-wavelength** network granularity
  - WDM system engineering are not yet sufficiently flexible and tolerant for "meshed" engineering instead of "point-to-point" engineering
  - Operation, Administration & Maintenance (OAM) functions in optics are not yet mature, but much progress in control plane (ASON/GMPLS)

- But PXC will be the key to intelligent optical networks
  - **Interface-agnostic PXC ports**: compatibility of PXC ports with short reach client interfaces / long reach network interfaces at any bit rate or formats possible
  - PXC will become an unavoidable flexibility element of future optical networks, either **opaque or translucent**
  - In particular, PXC will be key to **multi bit-rate opaque optical networks** in the near future

- Potential operational maturity: **2008**
Robust optical transmission & transparent optical networking

- Wide band optical amplification was a dramatic breakthrough for the advent of WDM transmission
  - **Wide band optical regeneration** could be a dramatic breakthrough for the advent of transparent optical networking
- Network granularity will shift from VC-4 to "wavelength"
  - Transport network minimum granularity will shift to Gbit/s and more
  - Various bit rates per wavelength channel will be used, even in the same fiber: **wavelength will be the network granularity**
- Transmission systems will become reach- and bitrate- agnostic
  - This will require **robust transmission techniques**, i.e. large tolerance of transmission systems to various impairments and network parameters
  - Wide band optical regeneration or robust modulation formats could be keys to this robustness and to transparent optical networking
- Potential operational maturity: **2012**
Wedding of optics and advanced signal processing

- Unlike radio, the optical channel was nearly perfect without bandwidth limitation
  - Modulation format in optics was very basic (on-off keying amplitude modulation) compared to radio (sophisticated multi-level amplitude/phase modulation formats)
  - No digital pre-/post-processing was used except forward error correction introduced with 10 Gbit/s systems a few years ago
- Cost reduction will require more and more signal processing in optical systems
  - Low cost forward error correction will be used in optical access / home networks
  - Electronic pre-distorsion techniques will be used in medium reach optical systems (MAN)
  - Dynamic equalisation (feed forward equalisation / decision feedback equalisation) will be used in most optical systems
  - Maximum likelihood sequence estimation will be largely used in optical systems
- Potential operational maturity: 2012
New optical technologies for multiplexing and multiple access

- Optics is dominated by time / wavelength division multiplexing
  - TDM / WDM approach dominates optical transport networks
  - TDM (downstream) / TDMA (upstream) approach dominates optical access network standards

- Increase of flexibility over cost ratio will require new approaches for optical multiplexing / multiple access
  - Statistical optical multiplexing will appear in metro networks, e.g. Optical Burst Switching (OBS), using both time and wavelength domains for statistical multiplexing
  - Wavelength Division Multiple Access (WDMA) will be used as alternative to (or together with) TDM/TDMA or point-to-point approaches in optical access networks

- Potential operational maturity: 2012
Hybrid radio over fiber techniques and radio/fiber network convergence

Radio access and fiber access networks are separated
- Different technological / network / operating contexts

Intensive deployments of wireless LAN and increase of radio bitrates will boost optical fiber access / home networks and their convergence with radio networks
- Radio cells shrink with increasing radio frequency: high-performance fiber distribution networks will be needed to an increasing number of smaller radio cells
- Costly radio signal processing / networking equipment will be centralized upper in the network, whereas fibers will feed remote antenna units (RAU)
- **Fiber / radio interfaces** (RAU) will be the key issue: the simpler the better, e.g. the electrical pins of a photodiode used as an antenna (!)...
Optical cryptography

- Security is a main issue for all communication networks
  - This area is dominated by algorithmic or "classical" cryptography
  - No real "absolute" security
- Optical cryptography is looking for "absolute" security
  - **Optical distribution of private cryptographic quantum keys**
    - Transmission of 1-photon bits (quantum bits or qbits) or entangled photon states
    - Intrinsic security due to the laws of quantum physics: impossible to clone a quantum state
    - Quantum key distribution already implemented on ~100 km of fiber @ a few 10 kbit/s
  - **Chaotic optical transmission**
    - Tx laser is used in a forced chaotic mode
    - A "strictly identical" laser is used at Rx so as to "subtract" chaos from received optical signal
    - It works! (2.5 Gbit/s over 100 km, ECOC 2004, Tu4.5.1)
- Potential operational maturity: 2020
## Technological breakthrough axes

### Summary

<table>
<thead>
<tr>
<th>Technological breakthrough axes</th>
<th>Breakthrough: potential / anticipated / perceived</th>
<th>Maturity (estimated)</th>
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<tbody>
<tr>
<td>Microstructured optical fibers for advanced optical network functionalities</td>
<td>Potential</td>
<td>2010</td>
</tr>
<tr>
<td>Microstructured optical fibers for new telecom network fiber infrastructures</td>
<td>Potential</td>
<td>2020</td>
</tr>
<tr>
<td>Wavelength agility in optical networks</td>
<td>Perceived</td>
<td>2015</td>
</tr>
<tr>
<td>Photonic crossconnects and intelligent optical networks</td>
<td>Anticipated</td>
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