IST Roadmap for Optical Communications

Generated by the OPTIMIST Thematic Network

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Outline

• Roadmap for Optical Communications
• Network evolution
• System evolution
• Component evolution
• Future and Emerging Technologies
• EU challenges and future issues
• IST OPTIMIST approach
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  • Network evolution
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Photonics enabling **Ambient Intelligence**

**Aml puts PEOPLE in the CENTER**

Making technology invisible, imbedded in natural surroundings, present whenever we need it and making interaction with technology simple and effortless.
Intelligent Optical Network

UoP: Universal Optical Plug

PDA

Wireless Link to Ambient Intelligence

Data Storage

Computing Resources

Networking

Intelligent Optical Network (ION)
Core network for Ambient Intelligence

Making IST services available to all people anywhere anytime in a natural and trustful way requires:

- ultra high capacity optical global network and WAN
- fast and flexible provisioning of optical network resources
- efficient and very reliable management of multi-vendor multi-operator optical networks
Access Network (City)

100 wavelengths
10 Gbit/s/\(\lambda\)
<20 km

N x 10 Gbit/s

UOP: Universal Optical Plug
Main ring: flexible \(\lambda\)-OADM
Secondary ring: fixed fiber OADM

10 Gbit/s

0.1 ... 1 Gbit/s per customer
TDM/TDMA

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MAN (Country / Region)

1000 wavelengths
10 Gbit/s/\(\lambda\)
wavelength conversion
<200 km

Fast Wavelength Switches (FWS) /
Optical Burst Switches (OBS)
+ Gateway to access network
+ Content servers (e.g. streaming media)
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+ Gateway to access network
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1000 wavelengths
10 Gbit/s/λ
fast wavelength conversion
no optical buffers
Wide Area Network (WAN)

WAN:
- Up to 1000 wavelengths
- Up to 80 Gbit/s/\(\lambda\) wavebands (> 10 \(\lambda\))

OXC: Optical Wavelength/Waveband Cross Connect
OPR: High Throughput Optical Packet Routers
Global Network (GN)

GN:
Up to 128 wavelengths
up to 160 Gbit/s/\(\lambda\)
wavebands (> 10 \(\lambda\))
## Global Network (GN) / WANs

### Key Features and Figures 2012

**Networks**
- Mesh topology
- Optical wavelength (waveband) switching / optical packet routing
- End to End Intelligent Optical Networking (ION) (e.g. G-MPLS)
- Ubiquitous network resilience
- Transparent monitoring

**Systems**
- GN: transparent transoceanic distances
- GN: up to 160 Gb/s/λ, up to 128 channels
- WAN: up to 3000 km transparent transmission
- WAN: 2.5 to 80 Gb/s/λ, up to 1000 channels
- Optical Cross-connects, Optical Packet Router
- Optical communication techniques (O-CDMA)

**Components/Subsystems**
- MEMS switch fabrics > 5000 x 5000, < 10ms, < 1dB
- Space switches, 64 x 64, < 1ns
- High speed λ-converters (<1 ns)
- Optical buffers
- Wideband optical amplifier (<200 nm)
- Optical regenerators
- Widely fast-tunable Rx/Tx
- Application engineered fibres
# Regional/Metro Networks - Key Features

## Region/Metro Networks

### Key Features and Figures 2012

#### Networks
- Mesh and ring topology
- Optical wavelength switching
- Optical burst switching (buffer-less)
- End to End ION (seamless interworking with GN/ WAN)
- Optimised network resilience classes

#### Systems
- Distances: 20 - 200 km
- 2.5 to 40 Gb/s/λ, 100 to 1000 channels
- Low cost OADM / OXC
- Intelligent burst mode transmitters / receivers

#### Components/Subsystems
- Low cost planar based optical switches / MUX-DMUX
- Supercontinuum generation
- Low cost wavelength converters
- Tunable Rx / Tx
- Wideband optical amplifiers (<300 nm)
- Switches (μsec)
## Access Networks - key features

### Key Features and Figures 2012

### Networks
- Hybrid technology: fiber + (wireless/cable/ copper)
- Fiber to the business (star and ring)
- PONs for residential and SOHO (FTTB/H)
- Seamless integration with End to End ION
- Network infrastructure and management optimized for AmI

### Systems
- Distance: up to 20 km
- Up to 10 Gb/s per electronics serial transmission channel
- Up to 100 WDM channels
- OLTs (PON)/MUXes: up to 1Tb/s up link capacity
- ONTs (PON): 10 Gb/s up link capacity per wavelength
- Burst mode transmission

### Components/Subsystems
- Plug and play retail components and terminal adapters
- Low-cost 10 Gb/s transmitters/receivers for pt-to-pt transmission
- Low-cost 10 Gb/s burst mode transmitters for PONs
- Low cost (D)WDM components
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Flexibility / Granularity of the OTN

<table>
<thead>
<tr>
<th></th>
<th>Static</th>
<th>Dynamic</th>
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<tbody>
<tr>
<td>Packet</td>
<td>X</td>
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<tr>
<td>Burst</td>
<td>X</td>
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<tr>
<td>Circuit</td>
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</tbody>
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- **OXC**: optical cross connect
- **OADM**: optical add drop mux
- **OPR**: optical packet router
- **OPADM**: optical packet add drop mux
Circuit-switching: data-plane node functionality
Burst-switching: data-plane node functionality

Control packet processing (setup/bandwidth reservation)

Switch Fabric

Control wavelengths

Data wavelengths

Data bursts

Time offset

Control packet
Packet-switching: data-plane node functionality

Node Controller (e.g., MPLS)

OPS Controller

OPS Fabric

Header Insertion

Buffering
Network Evolution – IST projects

FLEXIBILITY

- Static
  - Packet
  - Burst
  - Circuit

- Dynamic
  - DAVID
  - STOLAS
  - LION
  - CAPRICORN

Granularity

Access
  - HARMONICS

Metro
  - METEOR
  - STOLAS

Wide Area
  - LION
  - ATRIUM
  - DAVID
Layer interworking IP/OTN
“A testbed of terabit IP routers running MPLS over DWDM”

- The creation of an international optical research network at 2.5 Gbps based on the Alcatel 7770 RCP terabit router.
“WDM & IP Network Management”

- offer an integrated network management solution which is capable of providing end-to-end IP connectivity services derived from Service Level Agreements (SLAs)

**Service Management**

Single access point for Service Management simplifies creation of services

**Network Management**

**Telecom Infrastructure**

**TELECOMMUNICATIONS INFRASTRUCTURE**
IST LION

“Layers Interworking in Optical Networks”

➢ To design, implement and test an Automatic Switched Optical Network (ASON)

Siemens OXCs with NNI signaling

Tellium OXC with UNI signaling

Siemens Domain

Siemens OXCs with NNI signaling

Tellium Domain

Tellium OXC with UNI signaling

T-Nova NMS

Interdomain NMS interworking via a CORBA-based interface

TILAB Domain

TILAB UNI/NNI signaling G.709 interfaces

Cisco GSRs with UNI signaling

UNI (data)

UNI (data & signaling)

NNI (data & signaling)

LION testbed

To design, implement and test an Automatic Switched Optical Network (ASON)
“Hybrid Access Reconfigurable Multi-Wavelength Optical Networks for IP-based Communication Services”

- convergence of access networks, supporting IP with differentiated QoS.
“Data and Voice Integration over DWDM”

- an approach towards MPLS-based, optical packet switching with QoS support

**DAVID node configuration**

- Wavelength multiplexing and pre-amplification
- Coupler + interconnection shuffler
- Space selection
- Wavelength selection

- : regen.
- : mux.
- : SOAs module
- : EDFA
- : 1:(m.n) coupler
- : n:m star coupler

from/to other WAN nodes
from/to Gateway
from/to memory loop

Control Electronic
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OTDM and WDM Transmission

Scheme of a OTDM Transmission System

- **Pulse Source**
- **Modulators**
- **80 Gbit/s - 1.28 Tbit/s - …**

Scheme of a WDM Transmission System

- **λ-Controlled Laser**
- **Modulators**
- **80 Gbit/s - 10 Tbit/s - …**
Evolution of Transmission Bitrate

Spectral efficiency achievements

![Graph showing spectral efficiency achievements with different markers for OFC 2000, ECOC 2000, OFC 2001, and ECOC 2001.]
“All-optical Terabit per second LAmbda Shifted transmission”

- Nx40 and Nx80 Gbit/s transmission in networks encompassing all-optical wavelength converters.

**Successful demonstration of 4 x 40 Gb/s transmission over 500 km G.655**

Residual dispersion slope effect:

Eye diagrams after 500 km (DM with prechirp map, ch 2 optimized):

- 1550.92 nm
- 1552.52 nm
- 1554.13 nm
- 1555.73 nm

Eye diagrams after per channel dedicated postcompensation:
“Metropolitan Terabit Optical Ring”

- design, develop and demonstrate a terabit optical metropolitan area network.

- High speed (40Gbit/s per channel)
- WDM (up to 40 channels)
- Networking (nodes with add-drop functionality)

Mask layout active OADM
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Component IST projects

- **QD + new material**
  - ULTRABRIGHT
  - WILD
  - POWERPACK
  - High power sources

- **Tunable sources**
  - NEWTON
  - TUNVIC
  - VCSEL

- **Amplifiers**
  - LOBSTER
  - SYNERGIA

- **Photonic Bandgap**
  - PCIC
  - PICCO
  - PHOBOS
  - ANLM-OTDM

- **Polymer and POF**
  - GLAMOROUS
  - Poling in glass

- **Cost Reduction Objectives**
  - ATLAS
  - DOALL
  - ROSA
  - PIANO
  - NAIS
  - HOMEPLANET

- **High speed sources and receivers**
  - TOPRAT
  - FASHION
  - METEOR
  - STOLAS

- **Optical Signal Processing**
  - for OTDM or WDM

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Critical components and subsystems

Sources
- Short pulse: 1ps, 100fs
- Tunable: 100nm, 300nm
- Low cost: VCSELs, Polymer lasers

Switches
- OXC/OADM: SiO$_2$onSi/SOA gates
- OTDM Demux: MZ/EA/FWM
- Space switch: MOEMS

Transmission
- Amplifiers: 100nm, 300nm
- Dispersion management: 40Gb/s, 160Gb/s
- Regeneration: 2R, 3R(40Gb/s), 3R(160Gb/s)

Optical dense integration technology
- Photonic crystals
- Bio-photonics

Time
- 2000
- 2005
- 2010
Optical Amplifiers, Spectral Range

FIBRE

AMPLIFIERS

Rayleigh

1390 nm

- OH

1250  1350  1450  1490  1530  1570  1610  1650

XS band  S+ band  S band  C band  L band  L+ band

EDF(F)A

EDFA + gain equalizing filter

EDF(F)A + gain equalizing filter + Raman amplification

EDFA + gain equalizing filter

EDFA

EDF(F)A

RAMAN

Tm(thullium)DFA

P(praseodymium)DFA

Telluride EDFA

Multi-pump RAMAN

Multi-pump Raman achievable range

SOAs achievable range

http://www.ist-optimist.org
"Large Optical Bandwidth by Amplifier Systems Based on Tellurite Fibres Doped with Rare Earths"

- Ultra large T-OFAs for S, C, and L -bands (1.42-1.50 \( \mu \text{m} \); 1.53-1.62 \( \mu \text{m} \))

Possible configuration of ultra-large bandwidth amplifier
“Micromechanical Widely Tunable VCSEL for WDM Telecommunication Systems”

- Introduction of micro-mechanical actuator in vertical micro-cavities in order to obtain wavelength tunability.

- **AlGaAs micromachined DBR**
- **Hybrid integrated long wavelength VCSEL**

- **Filter**
  - FWHM = 0.13 nm
  - Transmission Loss = 1.4 dB
  - Tuning range = 42 nm
  - Sensitivity = 12 nm / mW
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Potentially disruptive technologies

Emerging component technologies

Molecular photonics

• Polymer optoelectronics
• Bio-photonics

Micro-optics and Nanoelectronics

• MOEMS
• Photonic bandgap devices
• Quantum dot devices
• Carbon nanotubes

Quantum Communication

• Cryptography
• Computing
• Teleportation
“Photonic Integrated Circuits using photonic Crystal Optics”

- demonstrate the fundamental principles of photonic crystal microcircuits and refine the computational and technological tools that are required to design, fabricate and cost-effectively mass-produce them.

GaAs based waveguide

Measured propagation loss 20 dB/mm via “cutback method”. Limited bandwidth due to “mini-stopband”
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EU challenges and future issues

• Ambient Intelligence:
  ➤ Making services available to all people anywhere anytime in a natural and trustful way
  ➤ A mix of ‘last mile’ technologies will be required – broadband – wireless – mobile

➤ “Get all communications into fibre as quickly as possible and keep them there as far as possible”
  (David Kennedy – EURESCOM – IST 2001 event)

• Creation of the Intelligent Optical Network is a pre-requisite
EU challenges / issues for further research

- Research towards the **Intelligent Optical Network**:
  - End-to-end intelligent optical networking (optical control plane)
  - Provide higher bitrate – smaller granularity – higher flexibility in the optical network
  - Get fibre closer to the customer in a cost-effective way
  - Seamless convergence of optical networking technologies and access networking (broadband – wireless – mobile)
  - Bridge between NREN’s and advanced photonic networking
Main Access Technologies

Twisted Pair
Legacy

POTS
ISDN
xDSL
Hybrid Fiber Coax
Satellite
Cable

Broadcast Legacy

New Technologies

Fiber To X
GSM-UMTS
Wireless LAN

New Technologies

Broadband
Interactivity
Mobility
AmI
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IST OPTIMIST roadmap exercise

- Define Technology Trends in the technical area’s under study
- Interaction / discussions at workshops – meetings with key actors
- Dissemination at large of concepts / views (CD-rom, website, newsletter, presentations)
- Interaction with other organisations (OITDA, OIDA, PIF, EURESCOM, COST)
- Generate an ‘IST roadmap view’ on optical communication (ongoing process)