An OPTIMIST’s view on emerging component technologies for photonic networks

Torino - 16th Oct. 2002

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The OPTIMIST project

• OPTIMIST = “Optical Technologies in Motion for the IST Program”
  - IST Thematic Network project

• R&D on photonic technologies in IST
  - Concertation: Ensure collaboration between projects
  - Convergence and collaboration between different platforms
  - Dissemination of results and strategies of the IST projects
  - Analyse Technology Trends and create Roadmap to the future
  - Interaction with actions outside IST
    - workshops/ meetings/ interactions with society
    - web server
      • Information on the IST projects
      • Technology Trends views
      • Extraction of the Roadmap

http://www.ist-optimist.org
Outline

• Roadmap for Optical Communications
• Network scenario
• Network evolution
• Component requirements in the future
• Emerging Technologies
• Examples from current IST projects
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 effortless

Personal communication
Multimedia
E-commerce
Advanced Photonic (Sub)Systems
Telework
Advanced Photonic Components
Advanced Photonic Networks
Virtual presence
Teleeducation
Entertainment

IST- OPTIMIST
http://www.ist-optimist.org
Approach for the roadmap

• Top-Down approach from « Networks » towards « Components »

• All timescales refer to deployed technology

• Main scenario estimates the 10 year prospects
Access Network (City)

UOP: Universal Optical Plug
Main ring: flexible λ-OADM
Secondary ring: fixed fiber OADM

100 wavelengths
10 Gbit/s/λ
<20 km

N x 10 Gbit/s

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

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MAN (Country / Region)

Short Term Scenario

100-1000 wavelengths
2.5-40Gbit/s/λ
wavelength conversion
<200 km

Fast Wavelength Routing (FWR) / Optical Burst Switches (OBS)
+ Gateway to access network
+ Content servers (e.g. streaming media)
MAN (Country / Region)

Long Term Scenario

10-1000 wavelengths
10-640Gbit/s/λ
fast wavelength conversion

Fast Wavelength Switches (FWS) / Optical Burst/Packet Switches (OBS/OPS)
+ Gateway to access network
+ Content servers (e.g. streaming media)
Wide Area Network (WAN)

GAN links

WAN:
- Up to 200-500 wavelengths
- 40-160 Gbit/s/\(\lambda\)
- Wavebands (> 10 \(\lambda\))

OXC: Optical Wavelength/Waveband Cross Connect

IST- OPTIMIST

http://www.ist-optimist.org
Global Area Network (GAN)

GAN:
Up to 200 wavelengths
up to 80-100 Gbit/s/λ
Outline

• Roadmap for Optical Communications
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  • Emerging Technologies
• Examples from current IST projects
Component IST projects

- QD + new material
- Polymer and POF
- Cost Reduction Objectives
- High power sources
- Amplifiers
- High speed sources and receivers
- Tunable sources
- Photonic Bandgap
- Optical Signal Processing for OTDM or WDM

Projects:
- ULTRABRIGHT
- POWERPACK WILD
- DOTCOM GSQ
- BigBand
- TUNVIC
- VCSEL
- GLAMOROUS Poling in glass
- GLAMOROUS
- VCSEL
- PCIC PICCO PHOBOS
- ANLM-OTDM
- ATLAS DOALL ROSA PIANO
- TOPRATE FASHION METEOR STOLAS
- NAIS
- APPTECH HOMEPLANET
- AGETHA
- ULTRABRIGHT
Component requirements for Access

**Transmitters**
- Very low cost
- Plug and play
- Burst mode transmission
- 10Gbit/s
- Transmission/modulation of microwave signals

**Fibres**
- Robust
- Low cost installation and maintenance
- Fibre to the home/curb
- Secured distribution process (e.g. CDMA)

**Regenerators**
- In-line amplification-free transmission
- Low cost amplifiers for boosting and preamplification

**Switches**
- Low cost
- Waveband switching
- Space switches (up to 256x256, ≤ 1 ms)
- Packet switching?

**Receivers**
- Very low cost
- Plug and play
- 10Gbit/s
- Interface with wireless network for efficient signal distribution
## Component requirements for Metro

<table>
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<tr>
<th>Transmitters</th>
<th>Fibres</th>
<th>Regenerators</th>
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<tr>
<td>• Low cost</td>
<td>• Wideband (≤300nm)</td>
<td>• 2R regeneration (retiming too costly at this level of network)</td>
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<td>• Tuneable</td>
<td>• High spectral efficiency</td>
<td>• Wideband amplifiers (200-300nm)</td>
<td>• High throughput</td>
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<tr>
<td>• Bit rate 40 Gb/s</td>
<td>• Fast tuneable (&lt;1 μs) for OBS</td>
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<td>• Time division multiplexing to higher bit rates</td>
<td>• Low cost 40Gb/s (up to 160 Gb/s over 10-20 years)</td>
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# Component requirements for GAN/WANs

**Transmitters**
- ITU-grid locking
- Fast tuneable: $\mu$s (5-10 years) ns (10-20 years)
- Controllable chirp
- High repetition rates (40 Gb/s) (via high speed modulation or OTDM)
- Multi channel (<200 λ) transmission via high quality single channel lasers
- Higher order dispersion monitoring and compensation
- Low polarization mode dispersion through fibre design or active compensation
- Low non-linearity (large area)

**Fibres**
- Full 3R (reamplification, reshaping, and retiming) necessary due to large transmission distance
- Wideband amplification (200-300nm, Hybrid Raman/EDFA)
- High cascadability

**Regenerators**
- Circuit switching
- Relatively low reconfiguration speed
- Transparent
- MPLS compatible
- λ conversion
- Evolution from electrical over optoelectronic to all optical clock recovery
- Efficient demultiplexing in both time and wavelength domain for high speed operation
- Low inter-channel crosstalk
- Highly integrated and compact

**Switches**

** Receivers **
Transmitter technology

**5-10 years**

- **DFB laser**
  - Accurate ITU grid locking
  - External modulator
  - EA-DFB laser

- **Short-pulse-laser**
  - Repetition rate: 80-160 Gb/s
  - Transform limited pulses
  - Mode-locked lasers
  - Fibre ring lasers

- **Directly modulated/EA-DFB laser**
  - Modulation speed: 10-40 Gb/s
  - Limited chirp acceptable

- **Directly modulated VCSEL**
  - Modulation speed 10 Gb/s
  - Cheap and compact unit

**10-20 years**

- **Quantum dot laser**
  - Widely tuneable (300 nm)
  - Low chirp
  - High power

- **New modulation formats**
  - Duobinary
  - High spectral efficiency

- **Tunable laser**
  - DBR, SG-DBR
    - Rapid tuning (100 ns)
  - External cavity laser
    - 300 nm tuning range
    - 45 dB SMSR

- **Integrated transmitter array**
  - Compact module w. multiple wavelength channel emission and modulation

- **Polymer transmitters**
  - Cheap production & testing

- **Supercontinuum generation**
  - High speed modulator for pulse carving
  - Crystal fibre based

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“Micromechanical Widely Tuneable VCSEL for WDM Telecommunication Systems”

Surface micromachined optically pumped VCSEL

Bulk micromachined tunable VCSEL
Tunable and multiwavelength lasers
From ECOC’02

Wavelength Tunable DFB Laser Array for WDM Applications
Yuki Kotaki and Ken Minto
Fujitsu Laboratories Ltd.
10-1 Morinosato-Wakamiya, Atsugi 243-0197, Japan
Tel: +81-46-250-8183, Fax: +81-46-218-5193, e-mail: kotaki.yuki@jp.fujitsu.com

Abstract We report a wavelength tunable laser with tight emission characteristics compatible with high-quality DFB lasers by monolithic integration of a DFB laser array, an optical combiner, and a semiconductor optical amplifier.

Figure 3. Temperature tuning characteristics

A widely tunable Digital Supermode DBR laser with high SMSR
G Busico, N D Whitbread, P J Williams, D J Robbins, A J Ward and D C J Reid.
Bookham Technology, Caswell, Towcester, Northants, NN12 8EQ, UK
gladino.busico@bookham.com; TEL: +44 (0)1327 356773; FAX: +44 (0)1327 356389

Abstract: A novel, monolithic, tunable digital supermode (DS) DBR laser for DWDM applications is described. A continuous tuning range of over 50nm with SMSR of 50dB is demonstrated.

Figure 4: DS-DBR power variation for constant gain section current, with SMSR > 35dB.
Fibre technology

- **Dispersion compensation**
  - Dispersion monitoring
  - Wide band compensation (multi-channel)

- **PMD compensation**
  - Active compensation
  - New fibre designs

- **Large area fibers**
  - Low nonlinearity
  - High power

- **Dispersion managed fibres**
  - Low accumulated dispersion
  - Soliton-like transmission

- **Photonic crystal fibres**
  - Detailed control of:
    - Dispersion
    - Nonlinearity

- **Standard fibre**
  - Pre chirp modulation for short distances

- **Polymer fibres**
  - Cheap production
  - Easy maintenance
  - Low loss necessary

5-10 years

10-20 years
Photonic crystal fibres

- Unprecedented control over propagation properties
  - Dispersion
  - Polarization Mode Dispersion
  - Losses
  - Nonlinearities

- Difficult to produce

- High losses

N. Venkataraman et al. (Corning), ECOC 2002, post deadline PD1.1

L. Farr et al. (Blaze photonics), ECOC 2002, post deadline PD1.3
Regenerator technology

- **Fibre amplifiers**
  - Hybrid Raman & EDFA
  - Distributed amplification
  - Wide band, flat gain
  - Low noise and cross talk
  - High power pump sources

- **Electro absorption modulators**
  - High speed (40 Gb/s)
  - Reshaping, gating
  - Controllable chirp

- **Linear semiconductor amplifiers**
  - 10 Gb/s operation
  - Cheap and compact unit

- **Optoelectronic 3R regeneration**
  - 80-160Gb/s operation
  - Clock recovery
    - Self-pulsating lasers
    - Heterojunction Bipolar Transistors

- **2R regenerators**
  - Interferometric structures (reshaping)
  - Saturable absorber
  - Wideband amplifiers (300nm)

- **Quantum dot amplifiers**
  - Low noise
  - WDM amplification
  - High bit rate operation

- **All optical 3R regenerators**
  - Multiple WDM channels
  - High cascadeability

- **Photonic crystals**
  Integrated components combining:
  - Splitters/Filters
  - Regenerators
  - Monitoring

- **Integrated components combining:**
  - Splitters/Filters
  - Regenerators
  - Monitoring

**Access**

**Metro**

**Global**

**5-10 years**

**10-20 years**
Quantum dots

- **Potential advantages:**
  - Low threshold/transparency current density
  - Low temperature sensitivity
  - High power operation
  - High quantum efficiency
  - Low chirp
  - Broad gain spectrum
  - Low noise figure
  - High linearity
  - Low linearity (depending on regime of operation)

- **Potential disadvantages**
  - Difficult to reach $\lambda=1.55\mu$m operation
  - Difficult to control production
Main Objective: development of ultra wide band InP based quantum dot devices and their applications covering the 1.4 – 1.65 µm wavelength range
• Realization of
  ‣ External cavity lasers (300nm tunability)
  ‣ Multi-wavelength Broad band amplifiers (300 nm)
  ‣ Low chirp directly modulated lasers

- High output power (15dBm)
- Efficient four wave mixing
- CW lasing
Switching technology

- **Large MEMS arrays**
  - µs switching
  - MPLS compatible

- **Arrayed Waveguide Gratings**
  - WDM (de)multiplexing
  - Low cross-talk filters

- **Optical Add /Drop Multiplexers**
  - WDM operation
  - AWG +switch
  - OTDM operation
  - NOLM,
  - SOA/MZI,
  - EA modulator

- **Wavelength conversion**
  - DISC structure:
    - Transparent
    - High speed (160Gb/s)

- **Waveband switching**
  - FWM in SOA

- **Electrical switching**
  - G-MPLS compatible
  - 10 Gb/s operation
  - Low cost

- **All optical switching**
  - Interferometer based
  - High speed (160Gb/s)
  - Packet switching (G-MPLS)

- **Optical logic gates**
  - Header recognition and processing

- **Multiple channel λ conversion**
  - Based on four wave mixing
  - Transparent
  - High speed (160Gb/s)

- **Photonic crystals**
  - Integrated, compact units:
    - OADMs
    - OXCs

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**5-10 years**

**10-20 years**
Switching Technologies for Optically Labelled Signals

• Optical labelling by orthogonal modulation formats for payload (IM) and label (DPSK)

**Partners:** Eindhoven University of Technology (NL), ADC Altitun (S), IMEC (B), Kymata (UK), Lucent Technologies Nederland (NL), Telenor R&D (N), COM (DK), University College Dublin (IRL)
MOEMS - Optical Networks applications

ON-OFF Switch

[Diagram showing ON-OFF Switch components: Optical fiber, "Self-assembling" shutter, Mirror, Sliding plate, Optical fibers, Hinges, Fiber alignment rails, Gold mirror.]
MOEMS - Optical Networks applications

2x2 Switch

- Sliding plate
- Beam
- Mirror
- Optical fibers
Optical Cross-Connect (OXC) Design

- 2D
- 3D

- Imaging lenses
- Input beams
- Movable micromirrors

MOEMS - Optical Networks applications
Receiver technology

**Ultrafast receivers**
- 160Gb/s operation
- Travelling wave /carrier photodetectors
- Grating enhanced field photo detectors,
- Fast waveguide avalanche photodiodes

**Single channel receivers**
- 40Gb/s operation
- Low cost
  - Alignment tolerant

**Arrayed Waveguide Gratings**
- WDM (de)multiplexing
- Temperature compensated
- Low attenuation
- Flat top transfer function

**Electrical clock recovery**
- Low cost

**Electro Optic clock recovery**
- Photo HBT,
- Optically locked oscillators (80-160 Gb/s)
- Electro Absorption Modulators
- Demultiplexing (160⇒40Gb/s)

**All optical clock recovery**
- Self pulsating lasers
- High speed (160Gb/s)

**Integrated receiver and transmitter**
- Compact module for the end user

**Integrated receiver module**
- Integrated Mux and diode
- Compact and efficient
- Multi-channel WDM receiver

**Access | Metro | Global**

5-10 years

10-20 years
Photonic Crystals

• Workhorse for large scale integration of photonic components

• Potential advantages
  - Control over optical density of states
  - Combination of active and passive devices possible
  - WDM capabilities
  - Compact

• Potential disadvantages:
  - Tight production constraints
    - Mass production difficult
  - High losses
“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”
Conclusions

• A lot of interesting proposals for new devices

• Some priorities
  ➤ Low cost for access
  ➤ High-level integration
  ➤ Tuneable sources
  ➤ Wideband amplifiers
  ➤ Compensation and regeneration
  ➤ Switching, Optical Buffer/Memory ???

• Components research very dynamic and complex: many solutions for the future

• Focus on improving existing functionality/technology than making new