MUSE Advanced Optical Architectures & Technologies for High-Speed Broadband Access

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Outline

> Introduction
  • MUSE Project Objectives
  • Optical access challenges

> MUSE Studies
  • 1. VDSLoO
  • 2. CWDM Access Rings
  • 3. RoF
  • 4. Advanced P2P Ethernet
  • 5. AsPON

> Conclusions & outlook
Low cost, full service access and edge network for ubiquitous delivery of broadband services to all European users
MUSE Optical Access objectives

> Challenges
  - New services will require High speed (>100 Mbps) access
  - Broadband market requires Low cost solutions

> Focus shift
  - From enabling technologies to optimal implementations
  - From low CAPEX to low OPEX

> Key aspects
  - Cheap & reliable components
  - Zero maintenance
  - Low management

> Open issues
  - Central vs. Distributed architectures
  - PON vs. AON technologies
1. DSL over Optics - Overview

- VDSL over Fibre to the Curb architecture featuring...
- DP (or SAI) based ONU
- Retains DSLAMs at the CO
- Low cost, low power interfacing hardware at Curb, possibly power fed from
- Optical hardware consists of single transmitter for the (potentially) 25 CPEs
- Signals multiplexed using SCM
Seeking to achieve a **practical solution** to a ubiquitous VDSL based network with 100+ Mbps bandwidth per user.

- **Subcarrier multiplexing** to combine/split multiple DSL signals at the distribution point and CO.

- Direct modulation of **low cost laser transmitters** (ultimately aiming towards VCSEL devices).

- Developed **high speed stream splitting circuits** for separating upstream and downstream channels of each signal.

- Developing both **local carrier** based and **carrier-less** configurations.
Carrier based ONU configuration - demonstrator

CP

CPE modem
100BASE-T

106m UTP

OLT/CO

DFB-LD
HPF
LO
Photodiode
Directional Coupler

Internet

CPE modem
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Internet
Carrierless RSOA based ONU

- RSOA (Reflective Semiconductor Optical amplifier) = Carrierless and Colourless for wavelength assignment and routing in WDM based networks
- Demonstrated performance over unamplified 20 km SMF fibre section with transmission efficiencies of ~60% (c.f. full rate for modems)
Status:

- Developed low profile (low power and cost) electronics to combine multiple VDSL signals onto optical carrier using technique of SCM
- Demonstrated single channel transmission over up to 45 km of unamplified single mode fibre with ~60% transmission efficiency
- Further ONU constructed using RSOA as transmitter
  - Carrierless hardware design - potentially reduces hardware costs
  - Colourless ONUs could increase network functionality (wavelength routing)
  - Experimental performance very similar to fixed carrier design
2. CWDM Ring Architecture

- CWDM dual-fibre double-ring access network
- Passive outside plant
- Exploitation of fibre capacity by means of CWDM (18 channels)
- ~20km ring circumference
- Gigabit Ethernet technology
- Shared bandwidth of 100 Mb/s (peak) and 25 Mb/s (mean) per customer
- Inherent resilience, disjoint protection path
Innovations

- Double ring network covers large distribution area with few fibres
- Disjoint path to every ONU enables layer 2 protection (on demand)
- Supports ~600 customers with guaranteed 25 Mb/s mean bandwidth
- Deploys cost-efficient CWDM technology using up to 18 channels per fibre
- Gigabit Ethernet technology to utilise cost-efficient components
Access network consists of:

> Central Office
  - Ethernet switch with CWDM interfaces as central instance and connection to metro domain
  - CWDM MUX/DMUX with low insertion loss (TFF technology)

> Feeder Area (two counter-propagating fibre rings)
  - RN connects feeder and distribution ring by means of fixed wavelength OADM (e.g. 2 adjacent channels)

> Distribution Area (chained ONUs)
  - ONU with: optical interfaces for ring connection and electrical interfaces to connect to customers
  - Data processing for protection, bandwidth (service) classes, etc.
Final demonstrator

Central Office (Hub)

Feeder area

Distribution area

MUX
DMUX

RN (OADM)

RN (OADM)

ONU

ONU (GbE, RSTP,...)

to custumer(s)

Optional interface to other distribution networks

to Metro domain

Standard path

Protection path

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Recent results

- Hardware setup completed (Q1/05)
  - 18 CWDM channel system (1270-1610nm) running
  - bitrate up to 2.67 Gb/s
  - OLT based on GbE switch
  - ONU platform Linux PC

- Software development running “full steam”
  - Click-Router development platform (PC / linux 2.6.11)
  - RSTP code* integrated, first test performed (switching time 1…8 sec)
  - Integration of bandwidth limiter function started, 1st tests successful
  - Switch throughput for GbE using click kernel interfaces up to 900 Mb/s

*) by courtesy of IMEC
3. RoF: Transporting microwave signals over a fibre link

- sweeping laser wavelength across multiple passbands of optical periodic filter
- sweep frequency $<<$ microwave frequency
- shared high-Q sweep freq. generator

$$f_{\text{min}} = 2N \cdot f_{\text{sw}}$$
Innovations applied

> Novel approach Radio over Fibre: OFM (suitable for SMF and MMF)
> WiMaX over Fibre
> Remote LO delivery
> Signal processing at headend (Software Radio for multi-standard support)
FWA demonstrator

- 134Mb/s (WiMAX)
- QPSK
- QAM-16
- QAM-64
- Down-conversion with adjustable carrier (via f1)
- Results in adaptively deployable carrier in RAP
## FWA RoF target specifications (draft)

<table>
<thead>
<tr>
<th></th>
<th>Downlink</th>
<th>Uplink</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Optical wavelength</strong></td>
<td>1316 nm</td>
<td>1310</td>
</tr>
<tr>
<td><strong>Optical power</strong></td>
<td>-3 – -10 dBm</td>
<td>TBD</td>
</tr>
<tr>
<td><strong>RF Frequency</strong></td>
<td>17 GHz</td>
<td>NA</td>
</tr>
<tr>
<td><strong>RF Power</strong></td>
<td>20 dBm&lt;sup&gt;1a&lt;/sup&gt;</td>
<td>NA (23 dBm&lt;sup&gt;1b&lt;/sup&gt;)</td>
</tr>
<tr>
<td><strong>Modulation</strong></td>
<td>QPSK, 4 QAM</td>
<td>QPSK, 4 and 16 QAM</td>
</tr>
<tr>
<td><strong>Roll Off</strong></td>
<td></td>
<td>0.25</td>
</tr>
<tr>
<td><strong>Error control</strong></td>
<td></td>
<td>FEC&lt;sup&gt;3&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Carrier capacity</strong></td>
<td>1 GHz</td>
<td>1 GHz</td>
</tr>
<tr>
<td><strong>Max capacity per sector</strong></td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td><strong>Multiple Access</strong></td>
<td>TDM</td>
<td>TDMA&lt;sup&gt;4&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Duplexing</strong></td>
<td></td>
<td>TDD&lt;sup&gt;5&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>BER</strong></td>
<td></td>
<td>&lt; 10&lt;sup&gt;-5&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Transmission range</strong></td>
<td></td>
<td>5 km</td>
</tr>
<tr>
<td><strong>MAC</strong></td>
<td></td>
<td>TBD</td>
</tr>
</tbody>
</table>

1) IEEE802.16 definition at BS<sup>1a</sup>/CPE<sup>1b</sup>
2) Adaptive; optional 16 and 64 QAM for DL and 64 QAM for UL.
3) Reed Solomon GF or Block Turbo Code
4) SCM at BS to prevent data collision in upstream
5) Frequency available at both BS and CS
Current FWA results

- Review of wireless standards (completed)
  - 802.11/802.16 & ETSI BRAN
- Review of FWA (completed)
- Option for centralized processing functions (completed)
- High level component analysis (WiMaX reqs.) (ongoing)
  - Purchase of WiMaX test equipment (Phy layer)
- Protocol evaluations (ongoing)
- Network design & testing (ongoing)
  - Point to point configuration
  - Lab test
  - Integrated trial
4. Ethernet based Point to Point (P2P) solution with single mode fibre

Can be implemented with a dedicated fibre from the central office (CO) to each customer – a fully passive network - or can include aggregating switches in the network.
Ethernet based Point to point solution with single mode fibre - Characteristics

- Future proof, easy upgradeable, versatile, secure, supporting symmetric traffic
- Single mode fibres cheap & compatible with metro/core networks
- Comparatively simple (low cost) transceivers at both CPE and CO:
  - None or simple wavelength filtering, no DWDM, no burst mode electronics, no TDM
  - No optical power splitter in the network, thus moderate requirements on laser power and detector sensitivity
- Supported by Ethernet standardisation 802.3ah-2004
- For fully centralised solution: no active equipment in the network, (that is: no electrical powering, minimum maintenance outside CO)
Central Office (CO) in P2P solution

Potential P2P bottleneck: large number of fibres and related optoelectronic equipment need to be handled in a large scale CO

- An overall solution as compact as existing copper based solutions is crucial when migrating to large scale fibre access
- One key issue to solve the bottleneck: a transceiver solution allowing high port density
- In MUSE a specific solution for a novel Small Form Factor (SFF) transceiver is demonstrated – based on existing compact optical bidirectional units

Small Form Factor transceivers commonly incorporate lasers and detectors mounted in separate, hermetically sealed TO-cans
Infineon / EZconn compact TO BIDI® unit

Infineon / EZconn TO BIDI® unit with laser, monitor detector, and detector – all mounted in the same TO-can

Concept

Wafer level assembly for cost-effective production

TO BIDI unit with pre-aligned sleeve for the fibre connector ferrule

When assembling the transceiver, mechanical alignment for single mode precision is not required

Karstensen et al, IEEE 50th ECTC Conf, Proc pp 479-486)
Dual Bidirectional Transceiver Prototype

- **Aim:** two bidirectional ports within SFF sized housing
- Prototype has been designed and built based on existing optical and electrical parts
- Two TO BIDI units, 1550/1310 nm
- Receptacles for LC single mode fibre connectors
- Double port density achieved

Compact transceivers increasingly important when more and more fibre access systems are being deployed.
Results: Dual Bidirectional Transceiver Prototype

- Functionality confirmed by measuring eye-diagrams and BER
- Crosstalk is not an issue
- Improvement in customer port density by a factor of two compared to conventional transceivers
- Yields a CO fibre access P2P solution at least as compact as existing POTS solutions

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EZconn has by end of August acquired the related FTTH BIDI technology and business from Infineon Technologies
5. Asymmetric PON

> FttX: How to combine the benefits of P2P & PON solutions?
  • (without inheriting the disadvantages)

<table>
<thead>
<tr>
<th></th>
<th>PON</th>
<th>P2P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outside plant</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Downstream Optics</td>
<td>+ (single OLT Tx)</td>
<td>- (2N TRx)</td>
</tr>
<tr>
<td>Upstream Optics</td>
<td>- (BMT @ ONU)</td>
<td>- (2N TRx)</td>
</tr>
<tr>
<td>Upstream Electronics</td>
<td>- (BMR @ OLT)</td>
<td>+ (P2P)</td>
</tr>
<tr>
<td>MAC Complexity &amp; Overhead</td>
<td>-</td>
<td>+ (synchronous)</td>
</tr>
</tbody>
</table>
Asymmetric PON (TDM/SDM version)

> Features

- **Downstream PON**
  - broadcast and select GbE

- **Upstream P2P** (no shared media, no BMR, no BMT)

- **Standard IEEE 802.3 compliant**
  - 1000Base SX or LX
  - cheap ONU and OLT transceivers
AsPON TDM/WDM version
Access Multiplexer efficiency

> Central Office and Remote Office deployment

> Low
  • Cost
  • Footprint
  • Power dissipation

> High
  • Port density: 48 -> 96 per AM blade
  • Flexibility/Upgradeability (20.. 100+ Mb/s)

> Planning
  • Phase I: L1+2
  • Phase II: L3+
Electro-optics: Downlink Transceivers

- 48 downlinks @ 100 Mb/s Optics
- Dissipation
  - P2P: 48 SFF FE
    - 48 W
    - 67 cm
  - AsPON: 5 SFP GbE + 4 PORx
    - 7 W
    - 15 cm
- Footprint (width)
- 12 ports
- Saving
  - 86%
  - 77%
Electronics: MUX scheduler

> Low Cost & Complexity WFQ Scheduler
  - Based on Golestani fairness
  - Packets are served based on an estimation of the service difference received between backlogged flows
  - Reduced computational complexity
  - Feasible within Gigabit network devices
  - Simulation show that the LC2WFQ scheduler has characteristics comparable to WFQ.

- Throughput:
  - Virtex 4
  - 10 ports x 4 CoS:
    - >8 Gb/s (10 kb)
    - >2 Gb/s (64 b)
Conclusions & Outlook

- Broadband Access markets will demand high speed services at very low costs.
- Fibre optics will provide the core technology for the Access Network of the future.
- FttX technologies are maturing, focusing on efficient implementations.
- Different studies are being performed in the MUSE project:
  - Phase I: 2004-2005
  - Phase II: 2006-2007
Acknowledgements

- MUSE
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