Fusion Light Testbed

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What is Fusion Light?

Goals
1. Design, develop and rollout a fiber-optic network in Fusionopolis to study next generation metro and access optical networks

2. A platform to integrate, test and evaluate architectures, protocols, optical subsystems, and components

3. To provide infrastructure for bandwidth-intensive applications

Novelty
• Integrated Optical Ethernet Switch (iOPEN)
• 10Gbps WDM PON
• Low cost Radio-over-Fiber transceivers

End user benefits
• End user access speeds: 1.25 to 10Gbit/s
• Can reserve entire wavelength channel
Fusion Light Project (2007-2009)

- $1.5 million in grant from A*STAR SERC
- 18 Researchers and students
- 4 patents filed
- Over 50 publications in journals and conferences
- 5 Industry partnerships formed

Project Focus Areas:
- WDM-PON
- Ethernet-over-WDM
- EPON (Dynamic Bandwidth Allocation)
- mmWave-over-fiber (1Gbit/s transmission @ 60GHz)
Proposed Coverage of Fusion Light Network

A pair of single mode fiber to every desktop in A*STAR

The fibers will also connect labs, resource centers, and classrooms
Fiber-to-the-Desk

1. 2 single mode fibers to every desk in A*STAR

2. Connection to PC via EPON ONU (1.25Gbit/s) or WDM PON ONU (10 Gbit/s)

3. Runs in parallel with copper-based corporate IT network

4. Access to Fusion Light services:
   - SAN-based storage
   - IPTV
   - 3D media/games
   - HD Video Conferencing
Fusion Light Network Architecture

There are now more than active 50 users in Fusion Light.

Internet

router

SingAren

IPTV Video

Storage

Server

SAN

Applications

Control management plane

PC

ONU

[1.25 - 10Gbit/s]

EPO

N

or W

D

M

PO

Optical

Electrical

Data Center (14F North)

IPTV Video Storage Server

SAN Applications

90TB Data Storage Server

MDA 11F Symbiosis

DSI 14F NST Lab

I²R 12F Server Room

I²R 11F Optical Lab

I²R

11F Optical Lab

12F Server Room

Central Station

Base Station

Customer Unit

EPON or WDM PON

25km SMF

ROF

Data Center (14F North)
Fully Functional iOPEN Node

- iOPEN Optical Crossconnect (OXC)
- 10-Layer PCB with OXC, FPGA and SFPs
- CWDM MUX/DEMUX
- Web-based monitoring system
- Control and Management PC
- Uninterruptible Power Supply (UPS)

A total of 4 iOPEN nodes have been deployed in Fusion Light
iOPEN - 2nd Generation (2008)

Electrical OXC and algorithms for cross-layer switching were added

- Automatic Lightpath Provisioning and Dismantling
- 8 CWDM wavelengths using SFP
- 10Gbit/s XFP Transceivers
- Real Time Monitoring for Rapid Fault Detection
- Low-Cost OXC with Optical Signal Regeneration
- Optical Cut-Through for low-latency and low loss performance
- Proprietary Algorithms for Optimizing Cross-Layer Switching Performance

10-layer PCB of the iOPEN node
Selected Publications on iOPEN


- “iOPEN Network: Operation Mechanisms and Experimental Study”, *IEEE ICC* Glasgow, Scotland, UK, June 2007

- “First Experimental Investigation of Adaptive Ethernet Forwarding and Optical Cut-through for Metro Optical Ethernet Networks”, *OFC*, USA, March 2007
Cross-Layer Throughput Optimization

Experimental setup

Ethernet forwarding
Optical cut-through

A sample of the switching between L2 and L1 with time. (Threshold1=12 and Threshold2=1).

Shao Xu et al., OFC 2008, paper JWA92
The proposed differentiated QoP can achieve a good balance between resource utilization efficiency, QoS and survivability.

<table>
<thead>
<tr>
<th>Classification</th>
<th>High bandwidth and critical</th>
<th>Moderate bandwidth and criticalness</th>
<th>Low bandwidth and uncritical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Route</td>
<td>WDM layer</td>
<td>Cross-layer routing</td>
<td>Ethernet layer</td>
</tr>
<tr>
<td>Survivability</td>
<td>path protection</td>
<td>Cross-layer protection</td>
<td>Rerouting</td>
</tr>
</tbody>
</table>

Shao Xu et al., OFC 2009, paper OTHP6
I²R WDM-PON

[Wavelength Division Multiplexed Passive Optical Network]
Low-Cost WDM-PON Optical Networking Units (ONUs)

• 400% Improvement Over Previous Record
• 16 lockable modes with SMSR > 40dB

Z. Xu et al., Opt Express, P2953, 2007

10Gbit/s Injection-Locked Fabry-Perot LD-based ONU

Investigation of a Free-Running 10Gbit/s VCSEL in WDM-PON

• 1550nm
• Low Power, Uncooled Operation
• 80km Error-Free Transmission with DCF

X. Cheng et al., ECOC 2008, P.6.02
Subcarrier Transmission and Carrier Reuse Based on a Shared Interferometer Filter

DI - delay interferometer (can be replaced by interleaver)
MZM - Mach-Zehnder modulator
LO - local oscillator
DI shared by all the ONUs, leading to reduced cost

Z.Xu et al, ECOC2007, post deadline paper, Th4.3.2
Broadcast Capable 40-Gb/s WDM-PON

To be presented in ECOC2009
I^2R 10Gbit/s Broadcast-Capable WDM-PON System

**Achievements:**
- Colourless ONU using a novel wavelength reuse scheme
- Dedicated 10 Gb/s download and upload bandwidth for end users
- Independent 1.25 Gb/s broadcast channel for video and data
- 4 filed patents on architecture, remote node design and ONU
- 18 related publications in top scientific journals and conferences

**Significance**
Fully functional 10-Gbit/s WDM-PON system with a novel remote node capable of routing:

(i) broadcast channels
(ii) downstream data
(iii) upstream data, and
(iv) optical carriers for upstream transmission
10Gbit/s Broadcast-Capable WDM-PON System
Summary

Competency Development

- **WDM-PON**
  - 10G FP-LD Based ONU
  - Broadcast-capable
  - Novel architectures

- **Ethernet-over-WDM**
  - iOPEN architecture
  - L1/L2 traffic optimization

Test-Bedding

**Fusion Light**

- 4 iOPEN Nodes
- 50 Users
- EPON
- Radio-over-fiber
- WDM-PON

Supporting Services & Partners

- **IPTV (I²R)**
- **SAN-Based Storage (DSI)**
- **Fiber-to-the-Desk**
- **IMS-Based Services (I²R)**
- **Cloud Computing (IHPC)**

I²R Proprietary