



Institute for  
Infocomm Research

# Fusion Light Testbed

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# What is Fusion Light?

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## 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)

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- \$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)

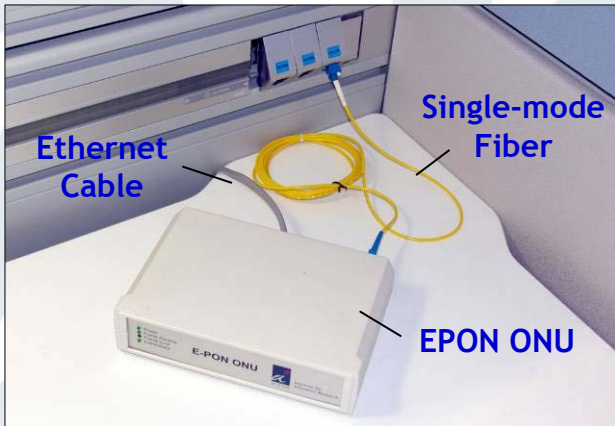
# Proposed Coverage of Fusion Light Network



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

***The fibers will also connect labs, resource centers, and classrooms***

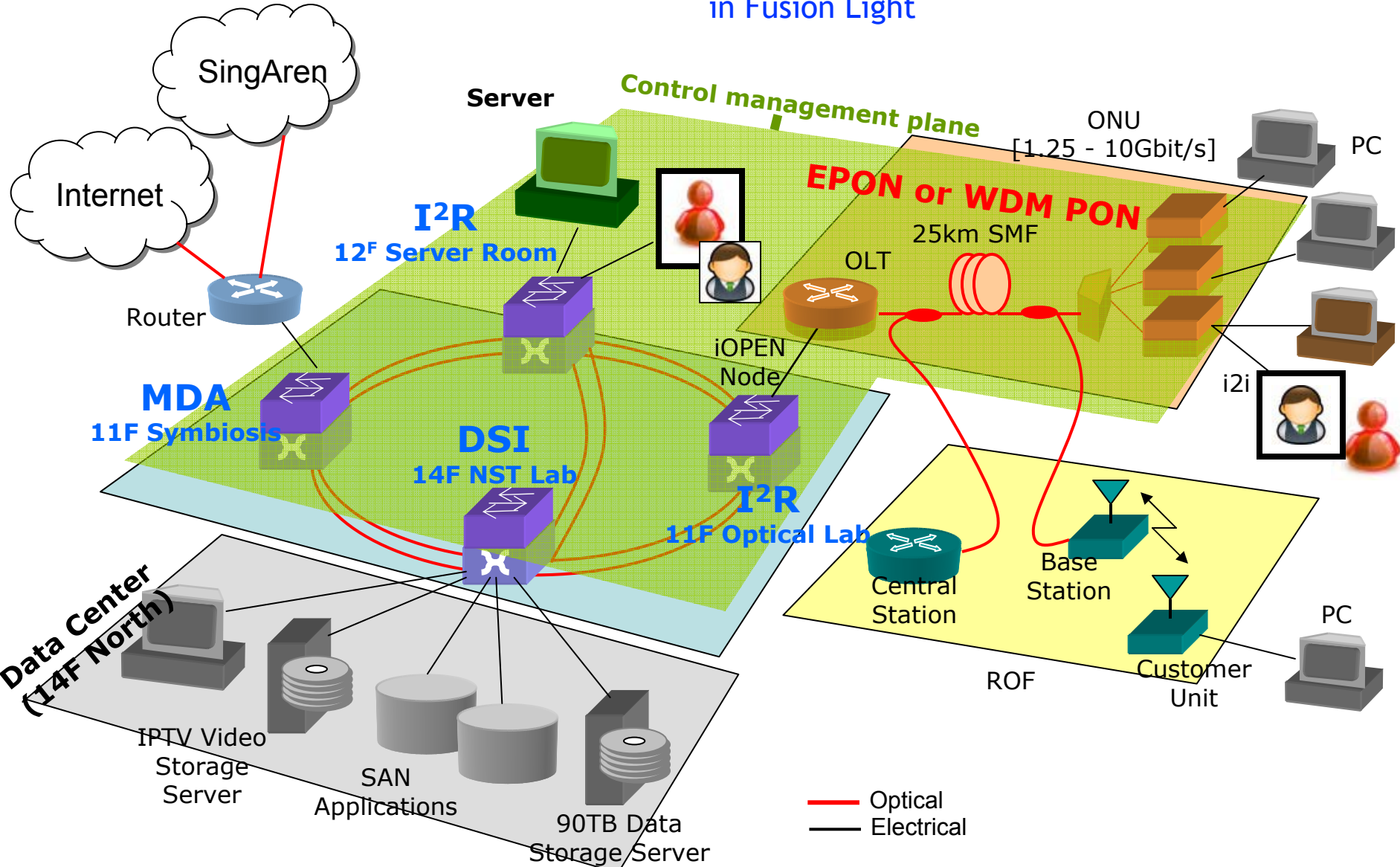
# Fiber-to-the-Desk



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

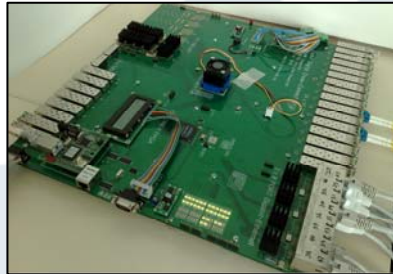
# Fusion Light Network Architecture

There are now more than active 50 users in Fusion Light



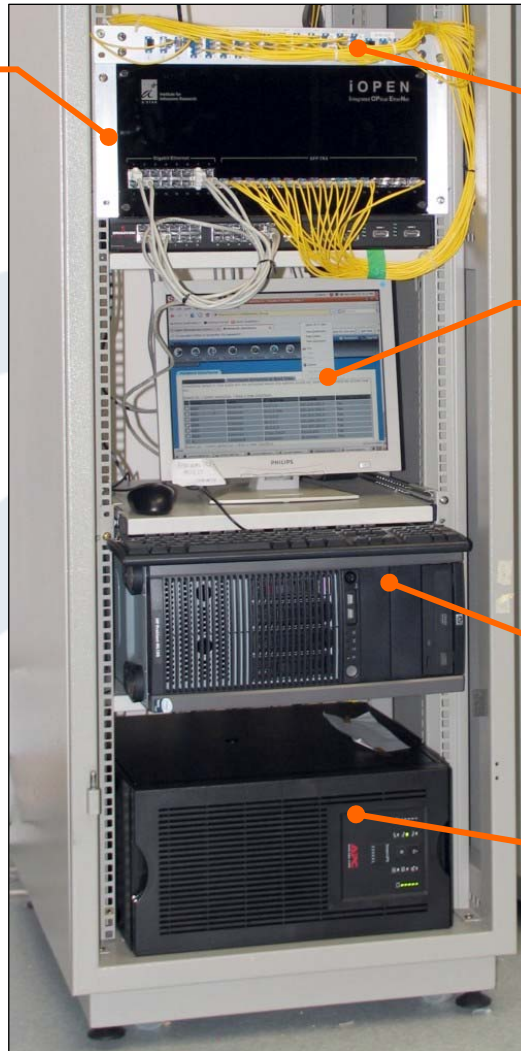
# Fully Functional iOPEN Node

iOPEN  
Optical Crossconnect (OXC)



10-Layer PCB with  
OXC, FPGA and SFPs

**A total of 4 iOPEN  
nodes have been deployed  
in Fusion Light**



CWDM  
MUX/DEMUX

Web-based  
monitoring system

Control and  
Management PC

Uninterruptible  
Power Supply  
(UPS)

# iOPEN - 2<sup>nd</sup> Generation (2008)

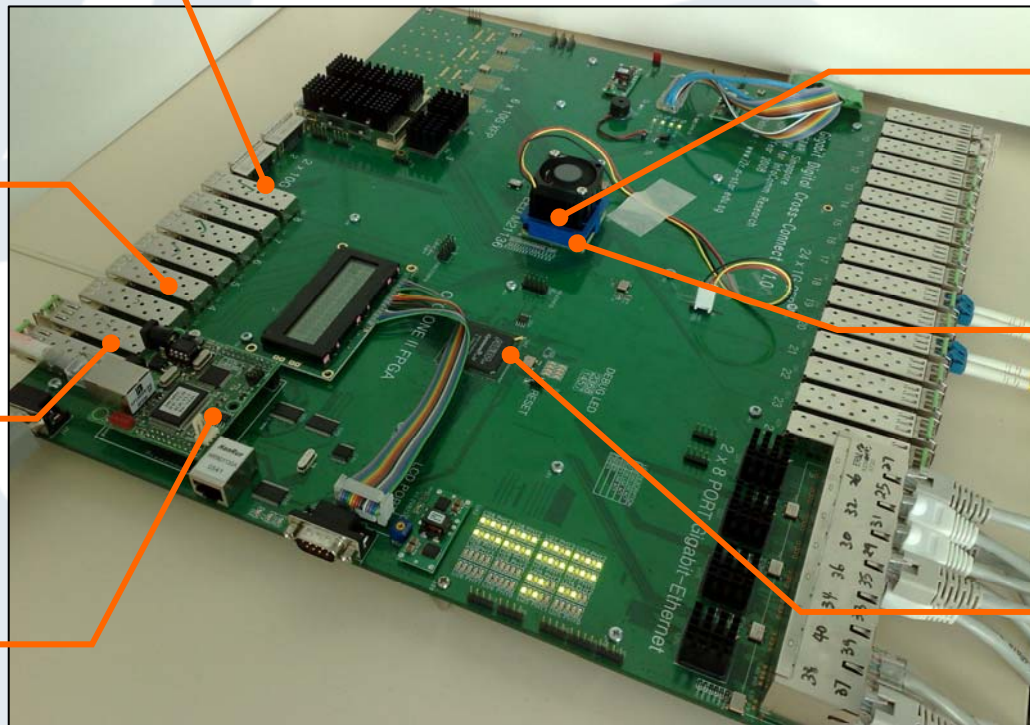
Electrical OXC and algorithms for cross-layer switching were added

Automatic Lightpath Provisioning and Dismantling

8 CWDM wavelengths using SFP

10Gbit/s XFP Transceivers

Real Time Monitoring for Rapid Fault Detection



10-layer PCB of the iOPEN node

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

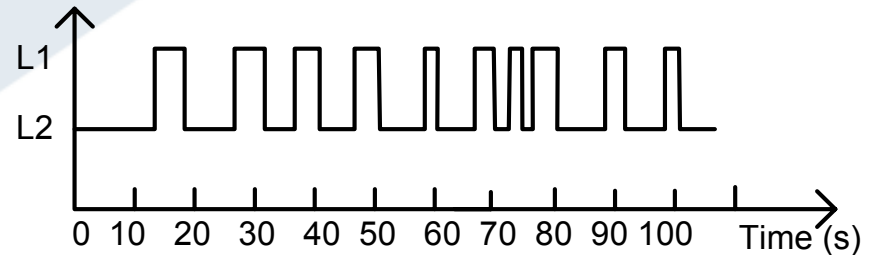
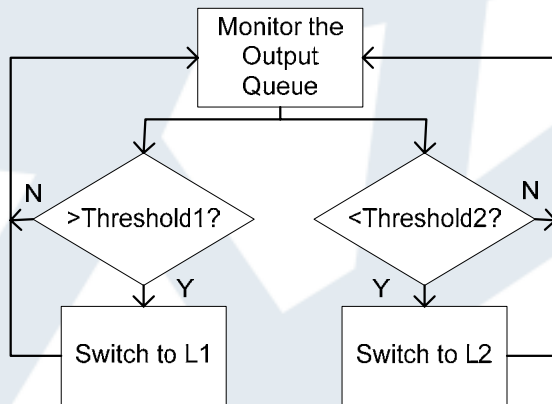
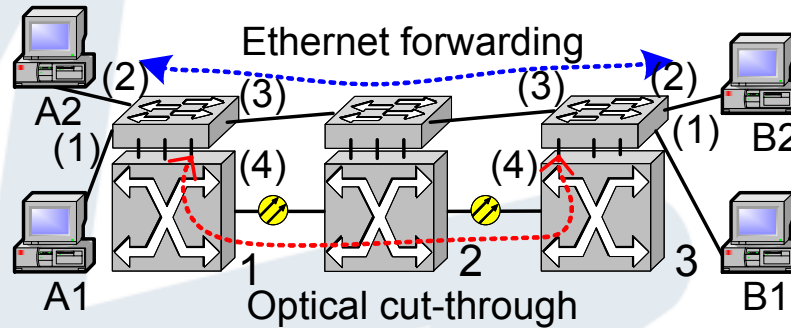


# Selected Publications on iOPEN

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- “iOPEN Testbed for Dynamic Resource Provisioning in Metro Ethernet Networks” **IEEE TridentCOM**, Spain, March 2006
- “iOPEN: Integrated Optical Ethernet Network for Efficient Dynamically Reconfigurable Service Provisioning”, **OFC**, California, USA, March 2006
- “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

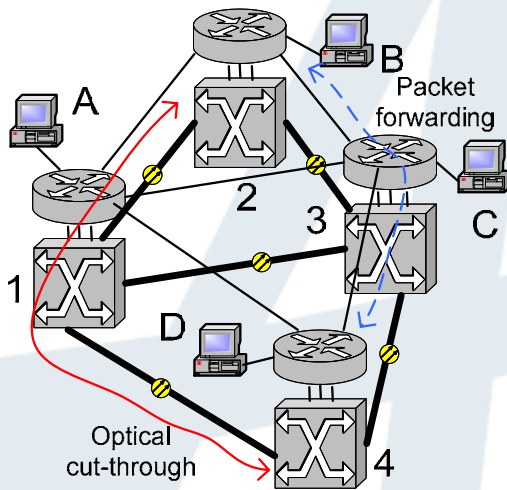
# Cross-Layer Throughput Optimization



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

Shao Xu et al., OFC 2008, paper JWA92

# Cross-Layer Protection for Differentiated Quality of Protection (QoP)



The proposed differentiated QoP can achieve a good balance between resource utilization efficiency, QoS and survivability.

	High bandwidth and critical	Moderate bandwidth and criticalness	Low bandwidth and uncritical
Classification	Class 1	Class 2	Class 3
Route	WDM layer	Cross-layer routing	Ethernet layer
Survivability	path protection	Cross-layer protection	Rerouting

Shao Xu et al., OFC 2009, paper OTHP6

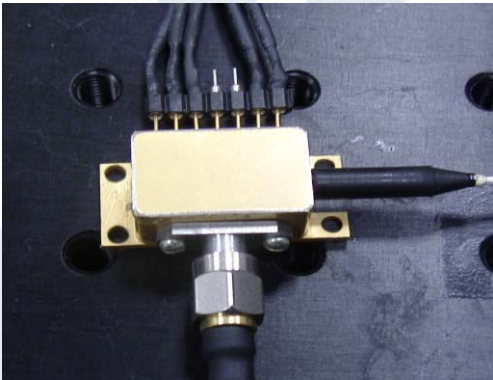
# I<sup>2</sup>R WDM-PON

[Wavelength Division Multiplexed  
Passive Optical Network]

# Low-Cost WDM-PON Optical Networking Units (ONUs)

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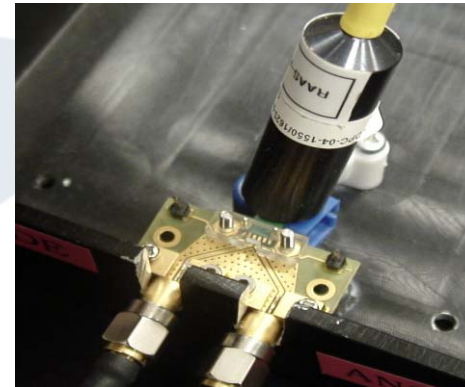
## 10Gbit/s Injection-Locked Fabry-Perot LD-based ONU



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

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

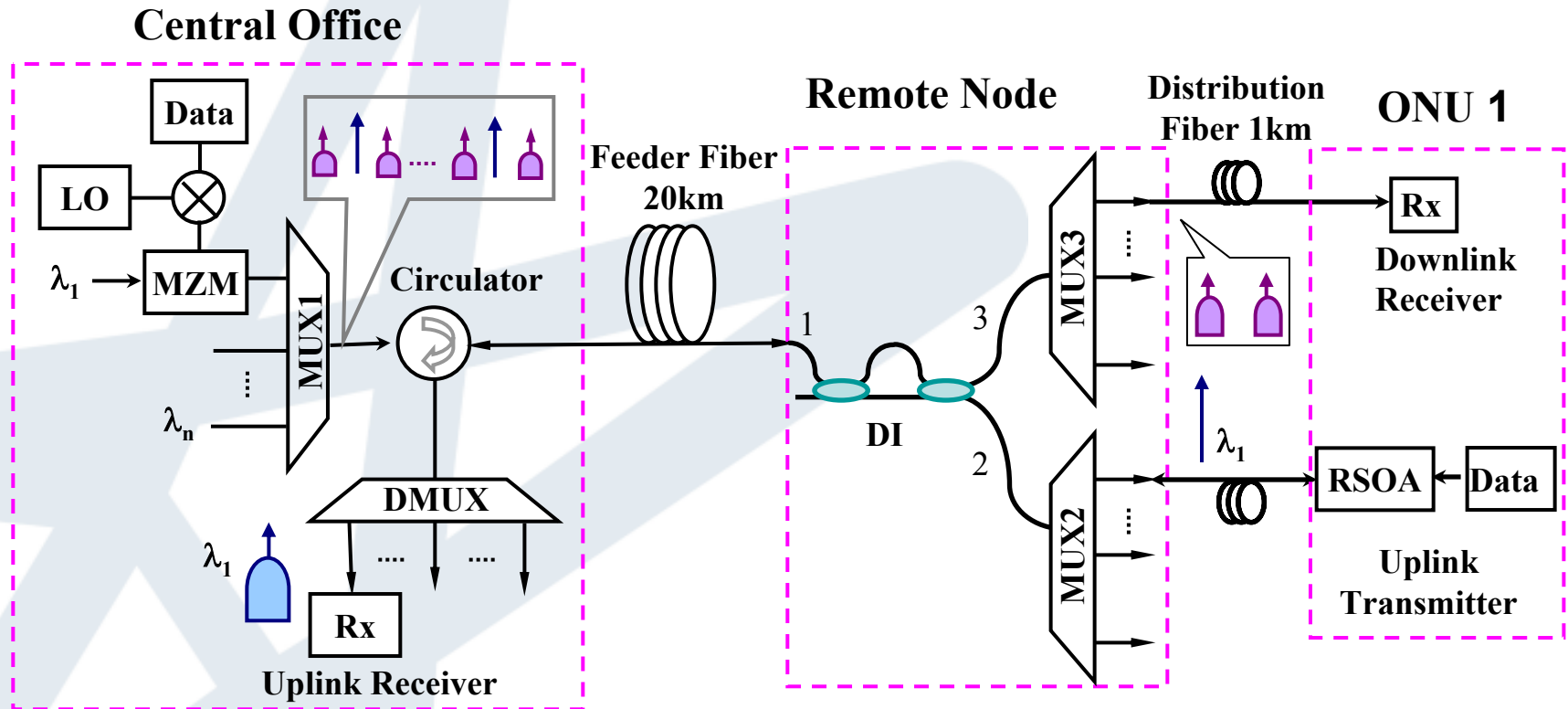
## Investigation of a Free-Running 10Gbit/s VCSEL in WDM-PON



- 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)

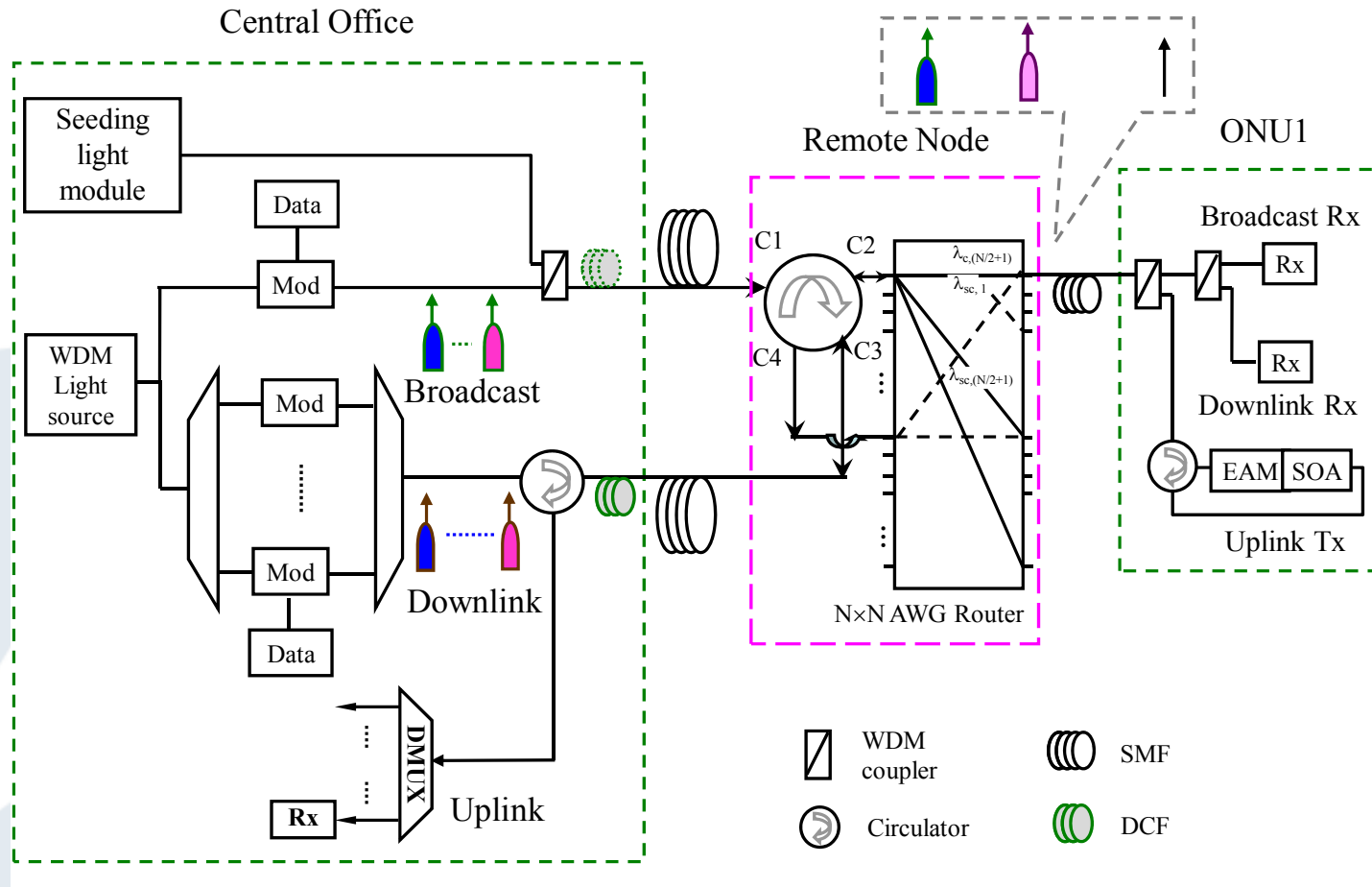
MZM - Mach-Zehnder modulator

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



# I<sup>2</sup>R 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

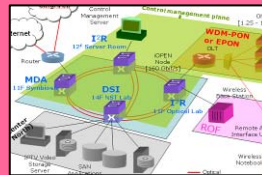
- 10G FP-LD Based ONU
- Broadcast-capable
- Novel architectures

### 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 (I<sup>2</sup>R)



SAN-Based Storage (DSI)

Fiber-to-the-Desk

IMS-Based Services (I<sup>2</sup>R)

Cloud Computing (IHPC)

