Optical Coarse Packet Switched IP-over-WDM Network (OPSINET): Technologies and Experiments

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Outline

- Optical Networking- Introduction
- A New Paradigm- Optical Coarse Packet Switching (OCPS)
- OPSINET- An Overview
- System and Network Technologies
- Conclusions
Why Optical Networking?

- Flexibility
- Distance
- Reliability
- Economics
- Capacity
- New Services
- All Optical Switching
- O/E/O Grooming Switch
- O/O/O Switch
- ULH
- SONET/SDH
- DWDM
- UNI
- IP Router

Source: Dr. N. Patel Talk on NGN2002
Optical Networking Evolution

1st Generation
- Wavelength Transport
  - Optical Transmission
  - OEO Switching
  - IP-over-ATM-over-SONET

2nd Generation
- Wavelength Switching
  - Optical Transmission
  - OOO Switching
  - Circuit Switc. IP-over-WDM

3rd Generation
- Wavelength Routing/Sharing
  - Optical Transmission
  - OOO Switching
  - IP-over-WDM
    - Optical Packet Switching
    - Optical Burst Switching
    - Optical Coarse Packet Switching
    - Photonic Slot Routing
Optical Networking Evolution (cont.)

- Optical Circuit Switching (OCS)
  - Static utilization of WDM channels
  - Good to support stream traffic
- Optical Packet Switching (OPS)
  - All optical: transport, processing, and buffering
  - Fine-grained WDM channel allocation
  - An ultimate solution for data-centric Internet
- Current dilemma for OPS
  - Lack of optical signaling processing and optical RAM
  - Large switching overhead

Alternatives?
**OPS Alternatives**

- **Optical Burst Switching (OBS)**
  - Supports per-burst (rather than per-packet) switching
  - Focuses on out-of-band, one-way wavelength allocation
    + A control packet for each burst payload is first transmitted out-of-band, allowing each switch to perform just-in-time configuration before the burst arrives
    + Wavelength is reserved only for the duration of the burst
    + The burst payload follows its control packet immediately after a predetermined *offset time*
- **OBS** can be viewed as a more efficient variant of OCS

Our approach: **Optical Coarse Packet Switching (OCPS)**
A New Paradigm - OCPS

- By “Coarse”
  - Per-burst switching (rather than per-packet switching)
  - Header is electronically processed while the payload remains in the optical domain

- By “Packet Switching”
  - Header is in-band modulated with payload and sent via one \( \lambda \)
  - Wavelengths are shared via wavelength converters
  - Enforcement of traffic control and traffic engineering to maximize wavelength-dimension statistical multiplexing gain

- OCPS can be considered as a less stringent variant of OPS

- Based on OCPS, we have constructed an IP-over-WDM network, called OPSINET (Optical coarse Packet Switched IP-over-WDM Network)
**Project at a Glance**

- **CSEE, Univ. of Maryland**
  - Prof. Y. J. Chen
- **NCTU/IEO**
  - Prof. J. H. Chen
- **NCTU/EE**
  - Prof. W. Z. Chen

**NCTU/CSIE/Excel. Proj.**
- Prof. Maria Yuang
  - Res. Assist. Prof. : 2
  - PhD : 4
  - MS : 4
- Prof. Winston Way
  - PhD : 1
  - MS : 1

**ITRI/CCL**
- Director Dr. S. C. Jeng
  - PhD researchers: 1
  - MS researchers: 9

- Propose a new OCPS paradigm
- Support 2.5 Gb/s with basic QoS

**Phase- I**

**Phase- II**

- New Technologies
  - New optical switch architecture
  - New header/payload multiplexing
  - 10Gbps Burst Mode Receiver
- Support 10 Gb/s with full-grown QoS
OPSINET: All-Optical Experimental Network

Legend:
- L2SC: Layer 2 Switch Capable
- L3SC: Layer 3 Switch Capable
- λSC: λ- Switch Capable
- FSC: Fiber Switch Capable
OPSINET- Phase I

- Ingress and Egress Edge routers
- Optical Label Switched Routers (OLSRs)
- Fiber/Lambda Switches
Ingress Edge Router Architecture

GMPLS Control Plane

Traffic Engineering
Routing and Wavelength Assignment, Constraint Based Routing, Call Admission Control

OSPF
RSVP-TE
LMP

Routing Signaling Control Channel Mgmt

Digital Comm. Network

FPGA

Configuration
Interrupt
ON/OFF

1G (GE)

Header + Payload Generation

$\psi, \tau$-Sched./Shaper

G-Ethernet Controller

32

Payload Generator

8B/10B Encoder

8

Header/Payload Generator

Fixed Optical LD

8

Optical Gating

MUX

Optical Line

Electronic Line

Legend:

$\lambda_1, \lambda_2$

$\lambda_1$

$\lambda_2$

MUX

1G

(.Multiline)

1G

(ManyToOne)

1G

(ManyToOne)

1G

(ManyToOne)
Optical Label Switched Router Architecture

GMPLS Control Plane
- GMPLS
- PC Linux
- OSPF
- RSVP-TE
- LMP
- Traffic Engineering
- Routing and Wavelength Assignment, Constraint Based Routing, Call Admission Control
- Routing Signaling
- Control Channel Mgmt

Digital Comm. Network
- Label Update
- F1
- F2
- F3
- F4
- Cyclic Frequency (CF)
- AWG

FPGA
- CAM
- μ-processor
- Tuning Signal
- Burst Mode CDR
- Header Generator
- Header/Payload Synchronizer (SCM-based)

Burst Mode Receiver
- O/E
- Limiting Amp.
- TH Stb.
- (1R)

Digital Splitter
- Header
- Payload
- Payload Regenerator (1R)
- EPDL

Optical Filter (FFP)
- Optical Filter
- Payload
- (CF)

Header Generator
- Header
- Payload
- Payload Regenerator (1R)
- EPDL

Legends:
- Optical Line
- Electronic Line
System and Network Technologies

- Label multiplexing and swapping
- Traffic control at edge routers
- Traffic control at core switch routers: $\lambda$ contention resolution
- Traffic engineering: Optical Tunnel Allocation
- Optical switch architecture with partial $\lambda$-sharing and limited optical buffers
Label Multiplexing and Swapping

- Existing Method: Sub-Carrier Multiplexing (SCM)
  - Payload and label are carried at different frequencies
  - Payload is carried at low band
  - Label is carried around 7.9 GHz
  - Advantage: Simple
  - Disadvantage: Fail to support 10Gbps payload transport

- Our Innovative Method: Superimposed ASK-based Label Multiplexing and Swapping
All optical label swapping technique - Superimposed ASK label

**Optical Transmitter**
- 10Gbps Payload
- 8B10B coder
- 100Mbps Header
- CW laser
- MZM

**Label swapping**
- Fixed Fiber delay line
- AM modulator
- LPF
- Limiting amp.
- Coreswitch controller

Label bit stream: 1 0 1 1 0 1 0 0 1

High speed payload data

Eye diagram of Transmitted signal → After header eraser

Received Header waveform
Traffic Control at Edge: \((\psi, \tau)\)-Scheduler/Shaper

- For a \((\psi, \tau)\)-Scheduler/Shaper\(_K\)
  - It is a scheduler for packets of different delay classes
  - It is a shaper for bursts of the same loss class

Legend:
- \(F_{d,y}\): Packet flow of destination/loss class \(d\) and of delay class \(y\);
- OLSP: Optical Label Switched Path;
- TLS: Tunable Laser Source;
**(ψ, τ)-Scheduler: Concept**

- **FCFS-based burstification**

  \[ A_4 \rightarrow A_4A_3C_4B_8C_3A_2B_7A_1C_2B_6; B_5C_1B_4B_3B_2B_1 \]

- **(ψ, τ)-Scheduler (ψ = 6, τ = ∞)**

  \[ A_4 \rightarrow C_4B_8B_7; C_3B_6B_5; A_4C_2B_4B_3; A_3A_2A_1C_1B_2B_1 \]
$(\psi, \tau)$-Scheduler: Delay Guarantee

Mean Burstification Delay

- $\psi = 25$
- $\tau = 10$

$w_{F1}:w_{F2}:w_{F3}:w_{F4} = 10:6:5:4$

Offered service

Legend:
- $G$: Bandwidth granularity;
- $I$: Incremental Interval;
(ψ, τ)-Shaper: Concept

- Departure Process contains burst inter-departure time (T) and burst size (S) distribution.
Effectiveness of \((\psi, \tau)\)-Shaper \((\psi=25)\)

Packet loss probability

W = 50
\[\psi = 25\]
\[\tau = 80\]
Performance Comparison: OCPS and OBS

\[ \psi_H = \psi_M = \psi_L = 25, \ \delta = 48 \mu s \]

\[ \psi_H = \psi_M = \psi_L = 100, \ \delta = 48 \mu s \]

\[ \psi_H = \psi_M = \psi_L = 25, \ \delta = 9.6 \mu s \]

\[ \psi_H = \psi_M = \psi_L = 100, \ \delta = 9.6 \mu s \]
Conclusions

- OCPS is a relaxed OPS paradigm by exploiting coarse switching granularity (burst vs packet)
- OCPS is a viable paradigm making all-optical networks a cost-effective reality within three to five years
- OCPS can be applied to metro core networks
  - Mesh topology: wavelength contention resolution
  - Ring/Bus topology: Medium Access Control