An Optical-Header Processing and Access Control System for a Packet-Switched WDM Metro Ring Network

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Outline

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- Optical-Header Processing and Access Control System (OPACS)
  - System Architecture
  - MAC Scheme: Distributed Queue with Multi-Granularity and Multi-Window (DQMGW)
  - Performance Comparisons
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Introduction

- Future optical metro networks are expected to cost-effectively satisfy a wide range of heterogeneous traffic with different time-varying and high bandwidth demand
- **Optical Packet-Switching (OPS)** employs statistical multiplexing to share wavelengths among multiple users
- Our work focuses on OPS-based access control system under slotted-ring-based optical WDM networks
- The OPS-based access control system includes:
  - Header processing/control (**in-band-based**)
  - Medium Access Control
- **In-band-based header control** differs from out-of-band header control
**In-Band vs. Out-of-Band Header Control**

- **Out-of-Band Header Control**
  - Requires an additional control channel
  - Drawbacks
    - Inefficiency
    - Low reliability
    - Low scalability

- **In-Band Header Control**
  - High efficiency and scalability
  - Prevailing approach: SubCarrier Multiplexed (SCM)
  - SCM drawbacks
    - Baseband expanding may overlap subcarrier frequency
    - Needs large # of O/E/O devices
Our Goal

To propose a system:

**Optical-Header Processing and Access Control System (OPACS)**

Achieving:
- Efficient In-band header control
  - Header and payload are time division multiplexed
  - Optical headers are in parallel efficiently received, modified, and re-transmitted by wavelength/time conversion techniques
- High-performance MAC
  - Dynamic bandwidth allocation
  - High performance on delay, throughput, and fairness
    + Low load $\rightarrow$ random access, low delay and jitter
    + High load $\rightarrow$ guaranteed per-user bandwidth
  - High scalability and modularity
System Architecture

- Operates at nodes interconnected via dual unidirectional fiber ring
- Each node is equipped with one tunable transmitter and one tunable receiver for each ring
- System architecture

Legend:
- OGS: Optical Gate (1x2 Switch)
- OC: Optical Coupler
- EA: Electro-Absorption
EA Modulator

- MAC processor determines certain bits to be updated
- MAC is specially designed so that header bits are always changed from 1 to 0
- EA Modulator simply attenuates those optical pulses to be updated

RZ encoded bits

Bit Index: 1 2 3 4 5 6 7 8

1 1 1 1 1 1 1 1

1 1 1 0 1 1 0 1

Erase 4th and 7th bits
**MAC Scheme - DQMGW**

- **DQMGW** = Distributed Queue with Multi-Granularity and Multi-Window
- **DQMGW** enables dynamic bandwidth reservation in space (granularity) and in time (window)
  - Multi-Granularity: allows to reserve different # of slots in a request
  - Multi-Window: permits multiple reservation requests

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**Slot Format**

<table>
<thead>
<tr>
<th>Payload</th>
<th>DA (6)</th>
<th>B (1)</th>
<th>R (3)</th>
</tr>
</thead>
</table>

**Multiple Window**

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**Legend:**
- **R:** Request;
- **B:** Busy;
- **DA:** Destination Address;
- **PR:** Prior Reservation counter;
- **RQ:** ReQuest counter;
**Performance on Normalized Throughput**

- DQBR & WDMA: poor statistical multiplexing gain (throughput deterioration)
- DQMGW achieves the same degree of bandwidth efficiency irrespective of the wavelength number and load

Simulation parameters:
- Number of nodes = 48
- Inter node distance
- \(D\) = 10 slots
Performance on Access Fairness

- Under different burstiness settings
  - Delay unfairness is manifested in both DQBR and WDMA
  - DQMGW guarantees delay fairness due to the multi-window design

Simulation parameters:
- Number of nodes = 48
- Number of wavelengths = 4
- Load (L) = 0.85
The Impact of Multi-Window Design

- Single Window Multiple Granularity (SWMG): DQMGW with window size=1
- SWMG suffers throughput unfairness as the load is above 0.8, DQMGW guarantees fairness under all loads

Simulation parameters:
- Number of nodes = 48
- Number of wavelengths = 4
- Inter node distance = 10 slots
Experimental Setup

- Header: RZ-encoded and 26 bits long at a data rate of 1 Gb/s
  - Includes 8-bit preamble, 4-bit header control and 6-bit address
- Payload: NRZ-encoded and 250 bytes long at a data rate of 10 Gb/s

Legend:
TL: Tunable Laser;
EA: Electro-Absorbtion;
OADM: Optical Add/Drop Multiplexer;
Experimental Results- Header & Payload

(i) Initial packet signal trace

(ii) Payload

(iii) Time slot

(iv) 111111111111111101

(v) 111111111111111101

(vi) 111111111111111101

(vii) 111111111111111101
Conclusions

- We have proposed a novel system, OPACS, encompassing an efficient in-band header control and high-performance MAC.
- By making use of wavelength/time conversion techniques, optical headers are efficiently received, modified, and re-transmitted.
- OPACS uses the DQMGW to enable dynamically bandwidth allocation on space (granularity) and on time (window).
- Compared with two existing approaches (HORNET DQBR and WDMA), OPACS achieves higher throughput, lower packet delay, and exceptional fairness under various traffic settings.
- Experimental testbed demonstrates the viability of OPACS.