

Design and Performance Evaluation of Small-Buffered Optical Packet Switching Networks

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1

Outline

- Problem Statement
- Objective
- Proposals
- Conclusions
- Future Research

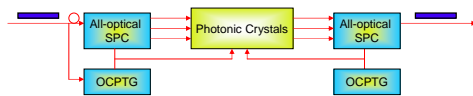
2

Problem Statement

- Major differences between optical packet-switched (OPS) networks and electronic packet-switched (EPS) networks.
- In EPS networks, contention is resolved by
 - Storing the contended packets in a random access memory (RAM)
- Buffering limitations in optical domain,
 - The well-known rule-of-thumb link buffer size requirement ($B = RTT \times BW$) is too big for optical buffering
 - Conversion from optical to electronic domain in order to use electronic RAM is not a feasible solution, because of the processing limitations of EPS, so processing and switching in the optical domain is necessary.
- Buffering in the optical domain
 - Fiber Delay Lines (FDL)
 - FDLs require very long fiber lines, which cause signal attenuation, inside the routers.
 - There can be a very limited number of FDLs in a router due to space considerations, so they can provide a small amount of buffering
 - Optical RAM
 - Still under research
 - Not expected to have a large capacity, soon
- TCP has low throughput due to burstiness, when buffer is very small

3

NTT's All-Optical RAM



- All-Optical RAM is better than Electronic RAM, because
 - Requires much less power
 - Size is smaller
 - Integration is better

4

Objective

- Designing a new OPS network architecture that can achieve high utilization by using small buffers
 - Fiber Delay Lines
 - Optical RAM
- Showing the buffer requirements

Advantages

- Decreasing the buffer requirements in the core
- Realizing all-optical high-speed OPS networks

5

Research

- Proposed and evaluated two different OPS network architectures for very small buffered networks
 - Rate-based XCP controlled edge pacing
 - Buffer occupancy based edge/core node pacing

Outline of Thesis

1. Introduction
2. Rate-based Pacing for Small-buffered Optical Packet Switched Networks
3. Switch Architectures for Small-buffered Optical Packet Switched Networks
4. Pacing for Optical Packet Switched Networks with Very Small Optical RAM
5. Node Pacing for Optical Packet Switching
6. Conclusions

6

Rate-based XCP Pacing for Small-buffered Optical Packet Switched Networks

7

XCP-Based Proposed Solutions 1/2

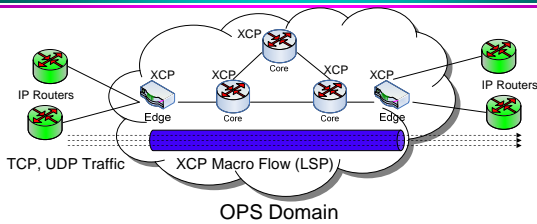
Preventing wavelength over-utilization

- Apply XCP-based congestion control
 - XCP is a new congestion control algorithm specifically designed for high-bandwidth and large-delay networks.
 - Network layer control
 - Nodes exchange probe packets in order to learn link information
 - Uses an efficiency controller for high link utilization and fairness controller for high fairness among flows
- Carefully select XCP parameters
- Control maximum wavelength utilization ratio by XCP

D. Katabi, M. Handley, and C. Rohrs, "Congestion control for high bandwidth-delay product," in *Proceedings of ACM SIGCOMM*, 2002, pp. 42-49.

8

XCP-Based Proposed Solutions 2/2

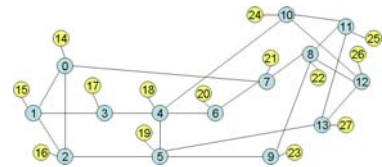


Burstiness

- Establish macro flows between edge nodes
- Assign incoming TCP, UDP traffic to macro flows (similar to XCP-CSFQ, TeXCP)
- Apply leaky bucket pacing to macro flows according to XCP flow rate at edge node
- Possible to use LSPs for controlling macro flows if GMPLS is available

9

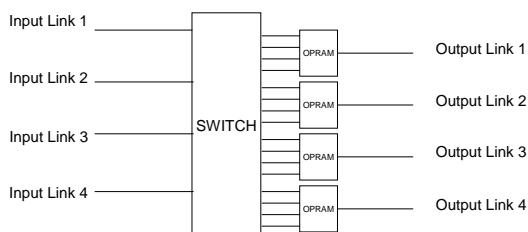
NSFNET Simulations



- 28 nodes (14 edge + 14 core) and 35 links (21 core + 14 edge)
- Wavelength speed 1Gbit/s
- 40 seconds simulation
- Around 1500 TCP flows
- Output buffering with optical RAM
- XCP's alpha, beta and gamma parameters are 0.2, 0.056 and 0.05 respectively

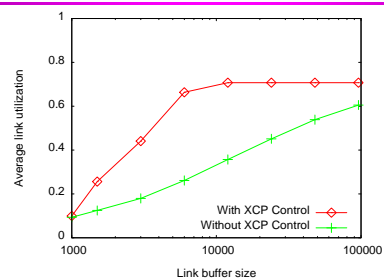
10

Output Optical RAM Buffered Switch



11

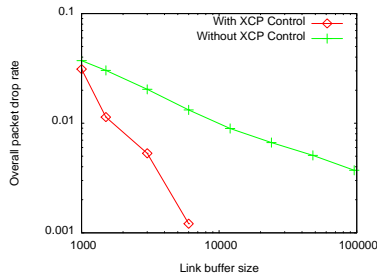
Link Utilization Comparison



- Due to traffic matrix, some links are congested and some links are underutilized, so overall average link utilization converges to around 0.7
- Rule-of-thumb requires around 3 Mbytes buffer per link
- Only 6 Kbytes of buffering is enough for our architecture!

12

Drop rate Comparison



- Only around 6 Kbytes of buffering is enough for achieving very low drop rate in our architecture

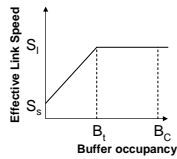
13

Node Pacing for Optical Packet Switching

14

Buffer Occupancy Based Edge/Core Pacing

- No XCP Control, so it is simpler and easier to implement
- Uses part of the node buffer for smoothing the traffic
- Applies pacing at the output link by spacing between packets



$$\text{Rate} = \begin{cases} S_s + B \frac{S_l - S_s}{B_t} & B < B_t \\ S_l & B \geq B_t \end{cases}$$

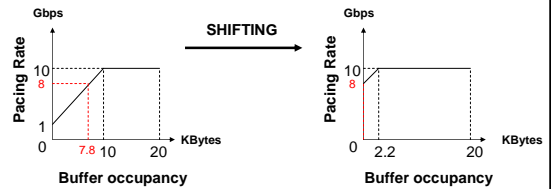
- Updates effective link speed based on buffer occupancy
 - Rate: Effective link speed
 - B: Buffer Occupancy
 - B_t: Buffer Threshold
 - B_c: Buffer Capacity
 - S_s: Initial Pacing Rate
 - S_l: Link Capacity

15

Adaptive Control

- Use both buffer occupancy and average arrival rate for calculating pacing rate in order to decrease average buffer occupancy

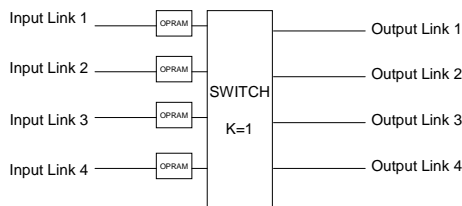
Example



16

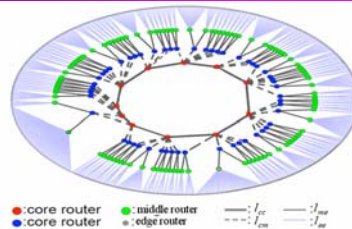
Input Buffered Switch

- Small switch size
 - We need a switch with a size of NxN
- Apply Virtual Output Buffering (VOB) for solving head-of-line blocking



17

Sparse Abilene Topology

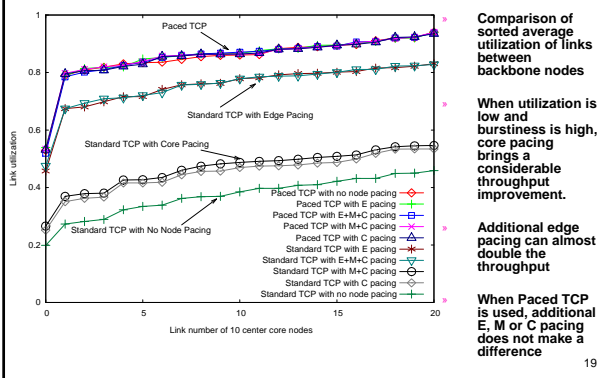


- 1Gbit/s link speed
- Simulate TCP Variants
 - Paced TCP
 - Standard TCP
- Simulate Node Pacing
 - Edge node (E) pacing
 - Middle node (M) pacing
 - Center node (C) pacing

- 698 edge nodes (E)
 - Grey nodes (Traffic enters the network)
- 106 middle core nodes (M)
 - Green nodes (Routers that are connected to edge nodes)
- 65 center core nodes (C)
 - Red and Blue nodes (Routers that are only connected to core nodes)
- 10 center backbone node (C)
 - Red nodes

18

Simulation Results (50Kbits Input buff.)



19

Conclusions

Proposed and simulated two different OPS network architectures for very small buffered networks

- Rate-based XCP Pacing for Small-buffered Optical Packet Switched Networks
 - ▶ Simulations show that our architecture can decrease the buffer requirements by 500 times
 - ▶ High link utilization and low packet drop rate with very small optical buffers
- Node Pacing for Optical Packet Switching
 - ▶ Our node pacing algorithm achieves considerably high link utilization with an easier deployment without requiring XCP control

20

Future Work

- Hybrid OPS/OCS integrated architecture
 - Support of optical circuit switching relaxes the traffic and buffer occupancy
 - ▶ Circuit switching requires no buffering inside the network as there is no multiplexing.
 - ORION architecture can be a good hybrid architecture for further decreasing buffer requirements

21

Thank you

22