Packet Switch Architectures for Very Small Optical RAM

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30 January 2009

Outline

- **Problem Statement**
- **Objective**
- **Proposed Solutions**
- **Switch Architecture**
- **Simulations**
- **Conclusions**
- **Future Research**

Problem Statement

- **Major differences and limitations 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)

- **Limitations in optical domain,**
  - Optical to electronic domain in order to use electronic RAM is not a feasible solution, because of the processing limitations of EPS.
  - 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**

Objective

- **Designing an all-optical OPS network architecture that can achieve high utilization and low packet drop ratio by using very small Optical RAM buffers**
- **Show and compare the buffer requirements**

Advantages

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

TCP Pacing

- Evenly spacing transmission of a window of TCP packets over a round-trip time (RTT)
  - **Packets are injected into the network at the desired rate of W/RTT when W is congestion window size.**
  - **Smoothing the traffic**
- It is shown that O(logW) router output buffer size is enough for high utilization when Paced TCP is used
  - **Aggregate paced TCP traffic converges to poisson**
- Requires changing the TCP senders
  - **Migration is hard**

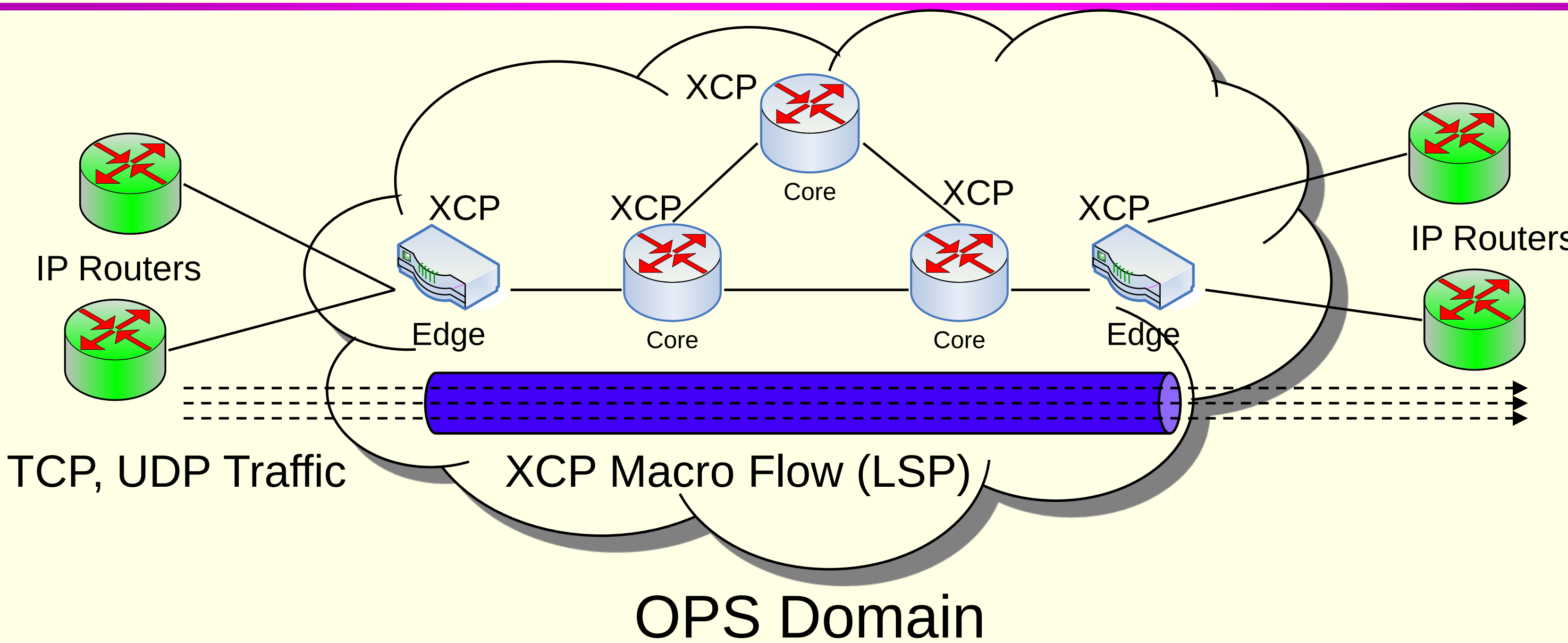
M. Enachescu, Y. Ganjali, A. Goel, N. McKeown, and T. Roughgarden, "Part III: Routers with very small buffers," ACM SIGCOMM Computer Communication Review, vol. 35, pp. 83–90, 2005.

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.

XCP-Based Proposed Solutions 2/2

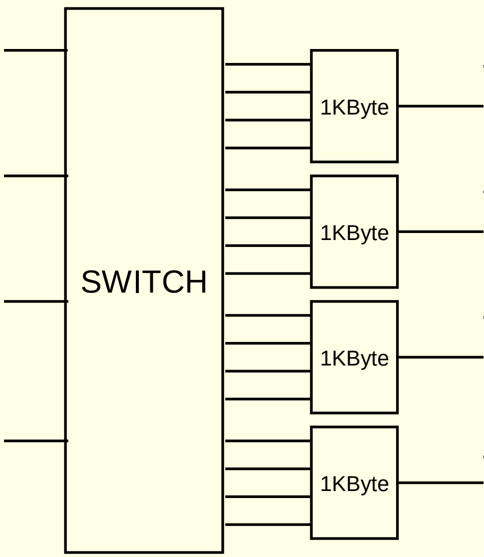


- **Burstiness**
  - Establish macro flows between edge nodes
  - Assign incoming TCP, UDP traffic to macro flows (similar to XCP-CSFQ, TeXCP)
  - Apply leaky bucket pacing to macro flows according to XCP flow rate at edge node
  - Possible to use LSPs for controlling macro flows if GMPLS is available

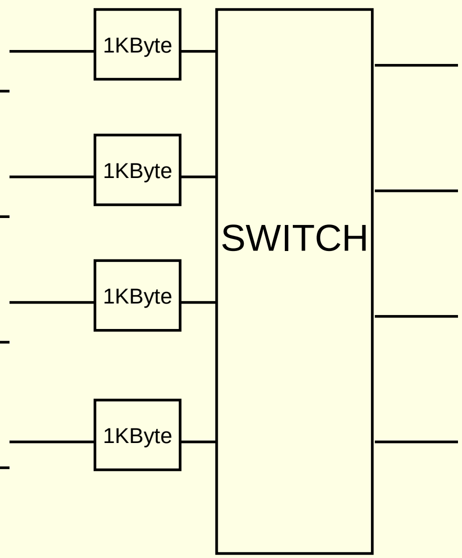
Buffer and Switch Architectures

- Shared Buffering
  - Total buffer size in a node increases linearly with the number of links
  - For example, when buffer size per link is 1KByte, a node with 4 links has 4Kbytes Shared Buffer
  - Total buffer size inside the switch is the same as OB and IB. Only buffer
  - placement is different

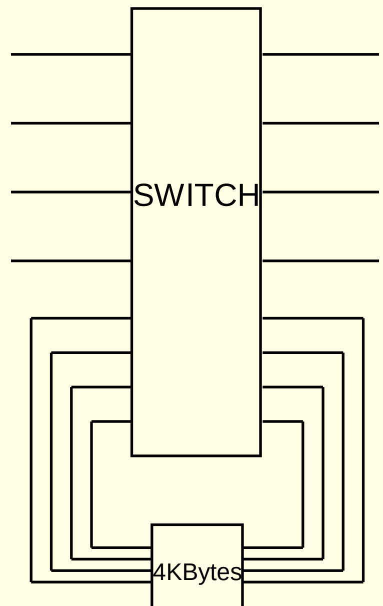
- Worst Case Shared Buffering
  - Total buffer size is constant (equal to buffer capacity of a single OB or IB link)



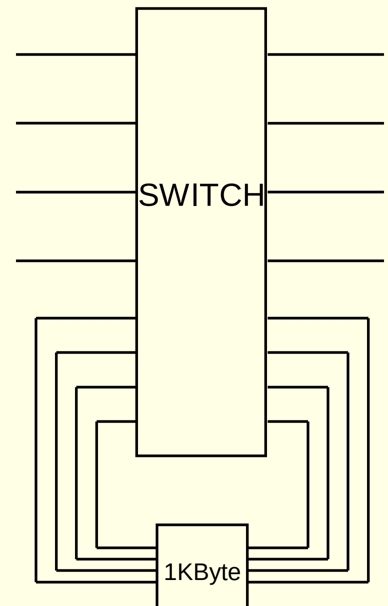
Output Buffering (OB)



Input Buffering (IB)

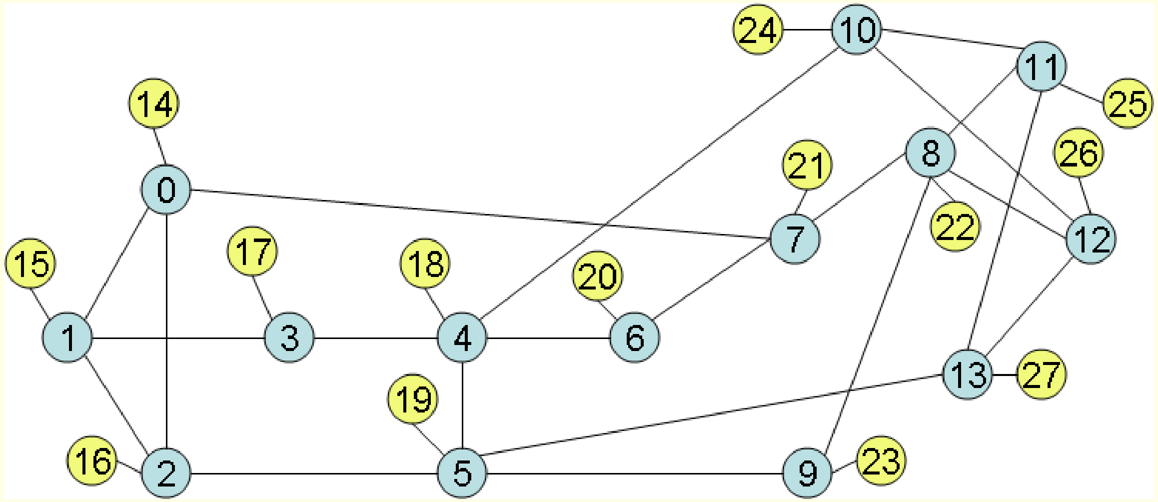


Shared Buffering (SB)



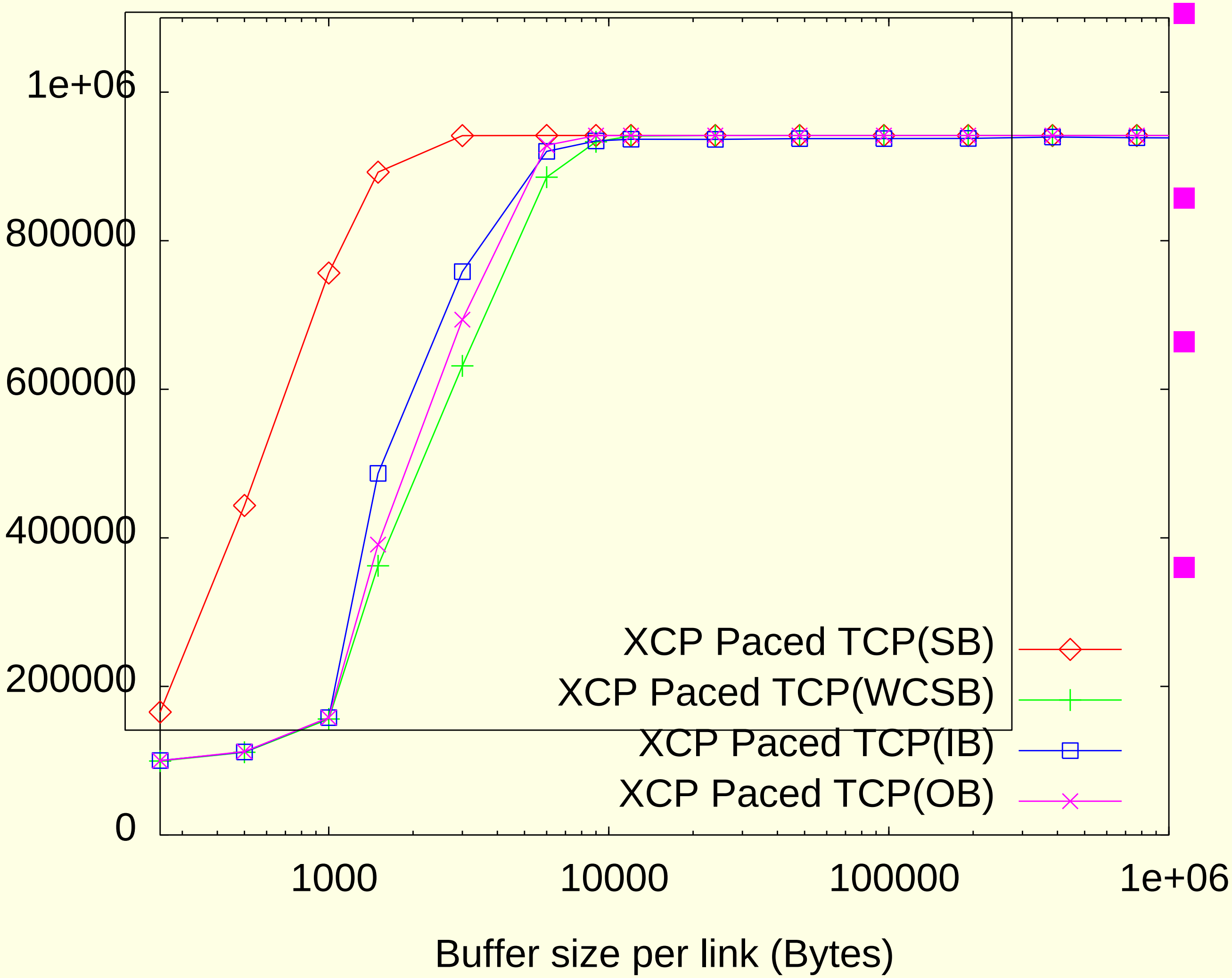
Worst Case Shared Buffering (WCSB)

NSFNET Simulations



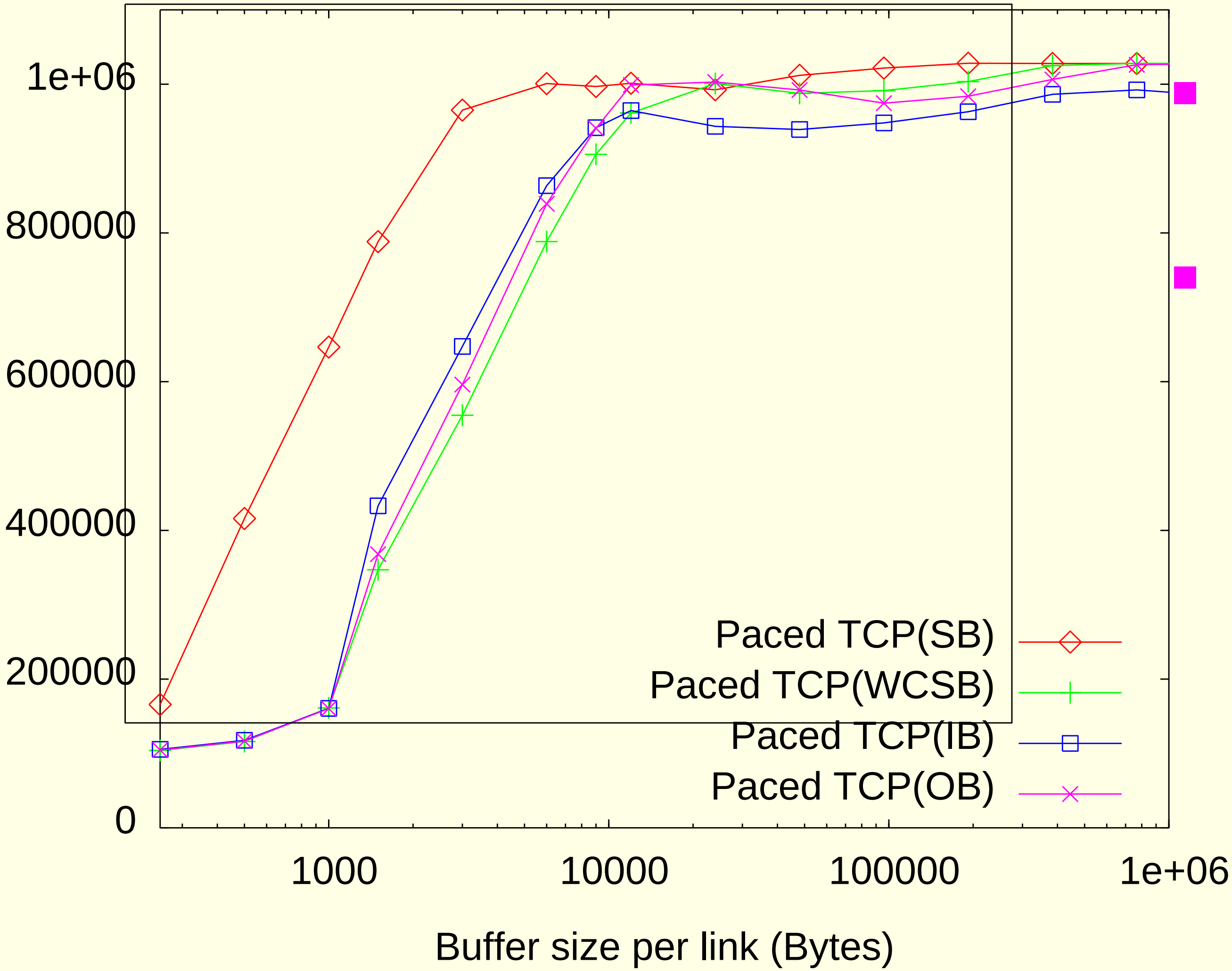
- 28 nodes (14 edge + 14 core) and 35 links (21 core + 14 edge)
- Wavelength speed 1Gbit/s
- 40 seconds simulation (use last 5 seconds for results)
- 1587 TCP Reno flows (Poisson flow arrival)
- TCP maximum congestion window size is 20 packets
- Data packet size (MSS) is 1500 Bytes
- Optical RAM
- Cut-through optical packet switching and buffering
- Evaluate average goodput of TCP flows

XCP Pacing (separate ACK macro wavelength)



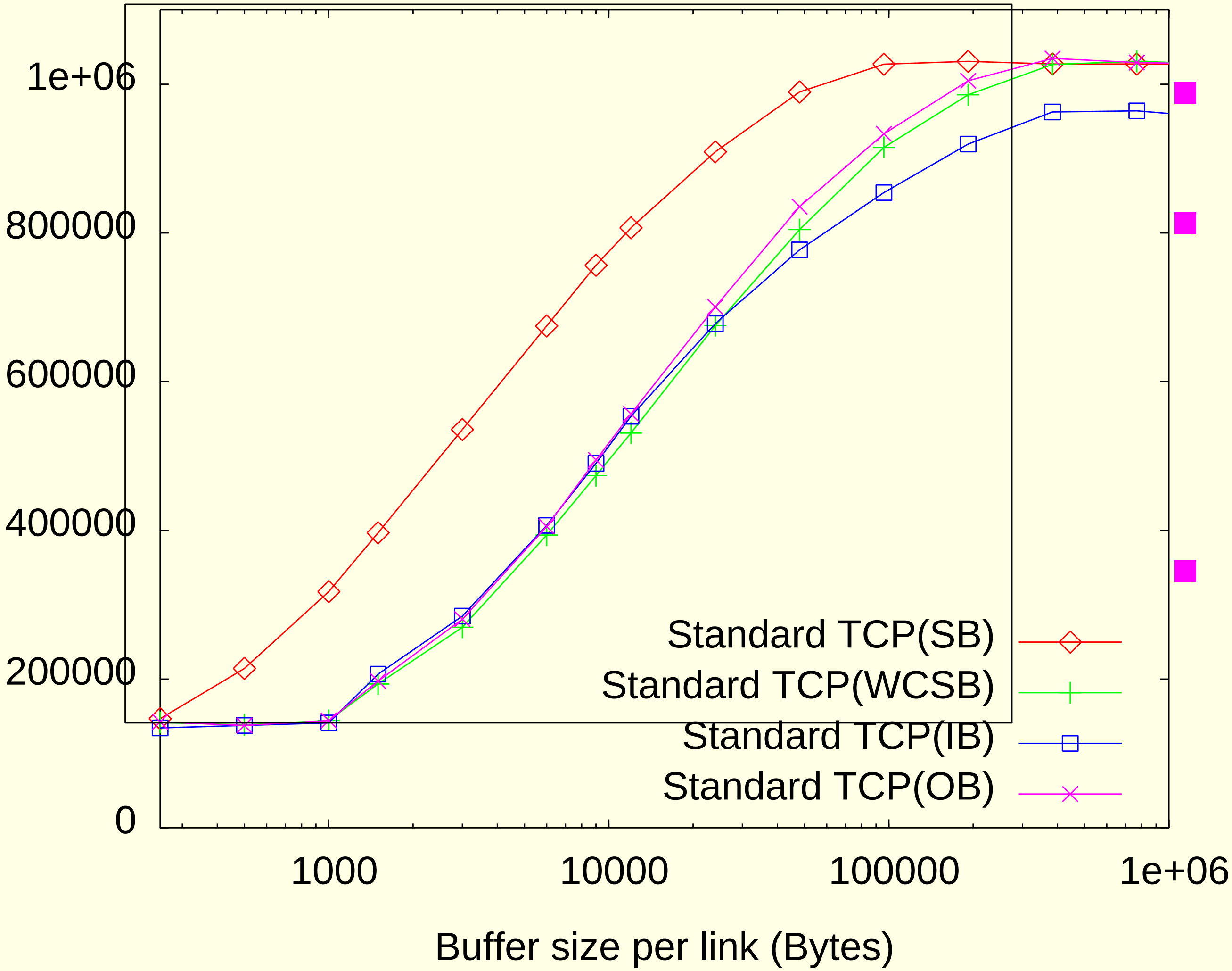
- **More than 3 times higher goodput with SB**
- **IB has higher goodput than OB**
- **WCSB goodput is close to OB with a much smaller buffer**
- **IB, OB, WCSB have the same goodput when buffer size is less than MSS**

TCP Pacing



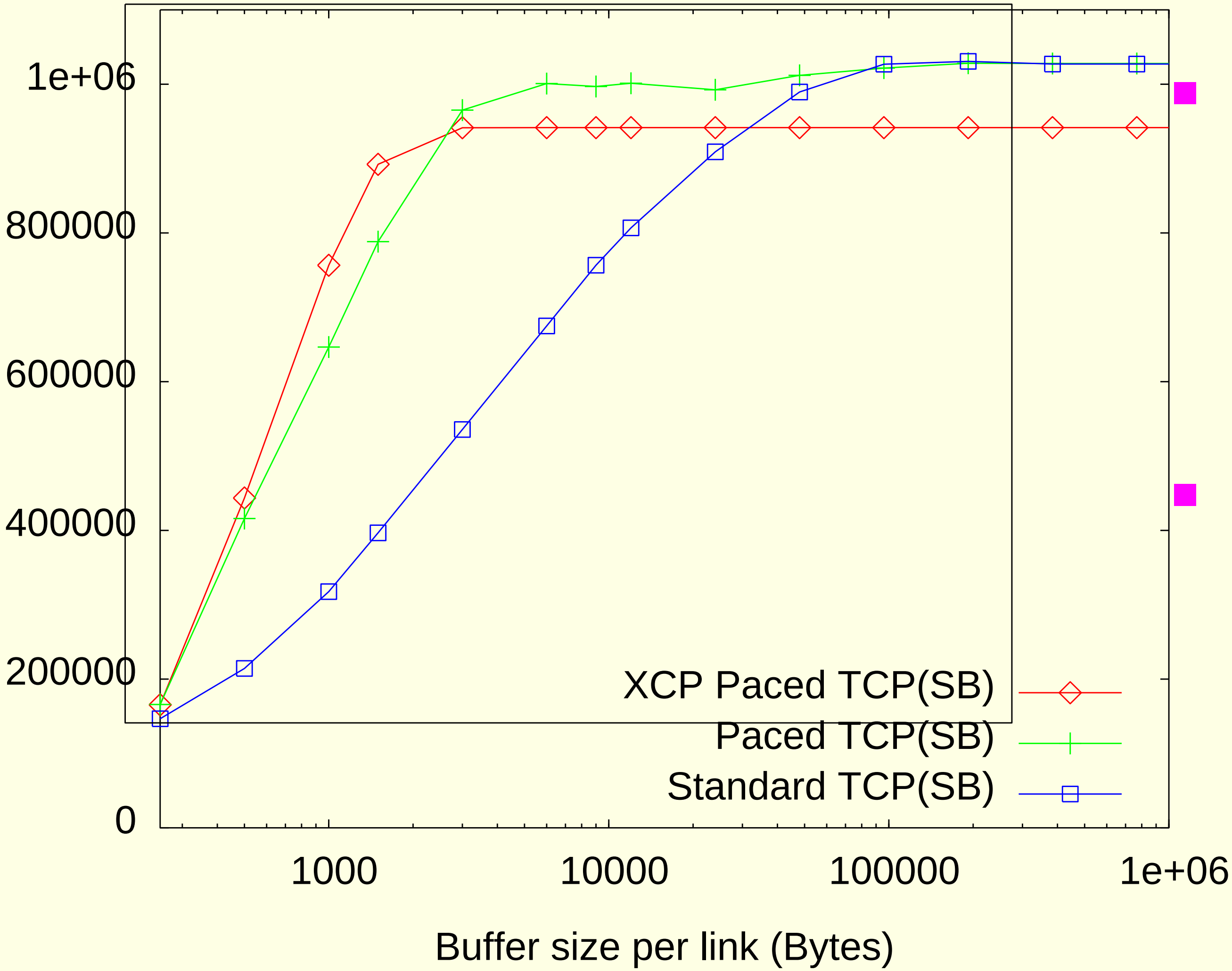
- **Similar to XCP Paced TCP**
- **When buffer is large, IB has the lowest goodput due to head of line blocking**

Standard TCP



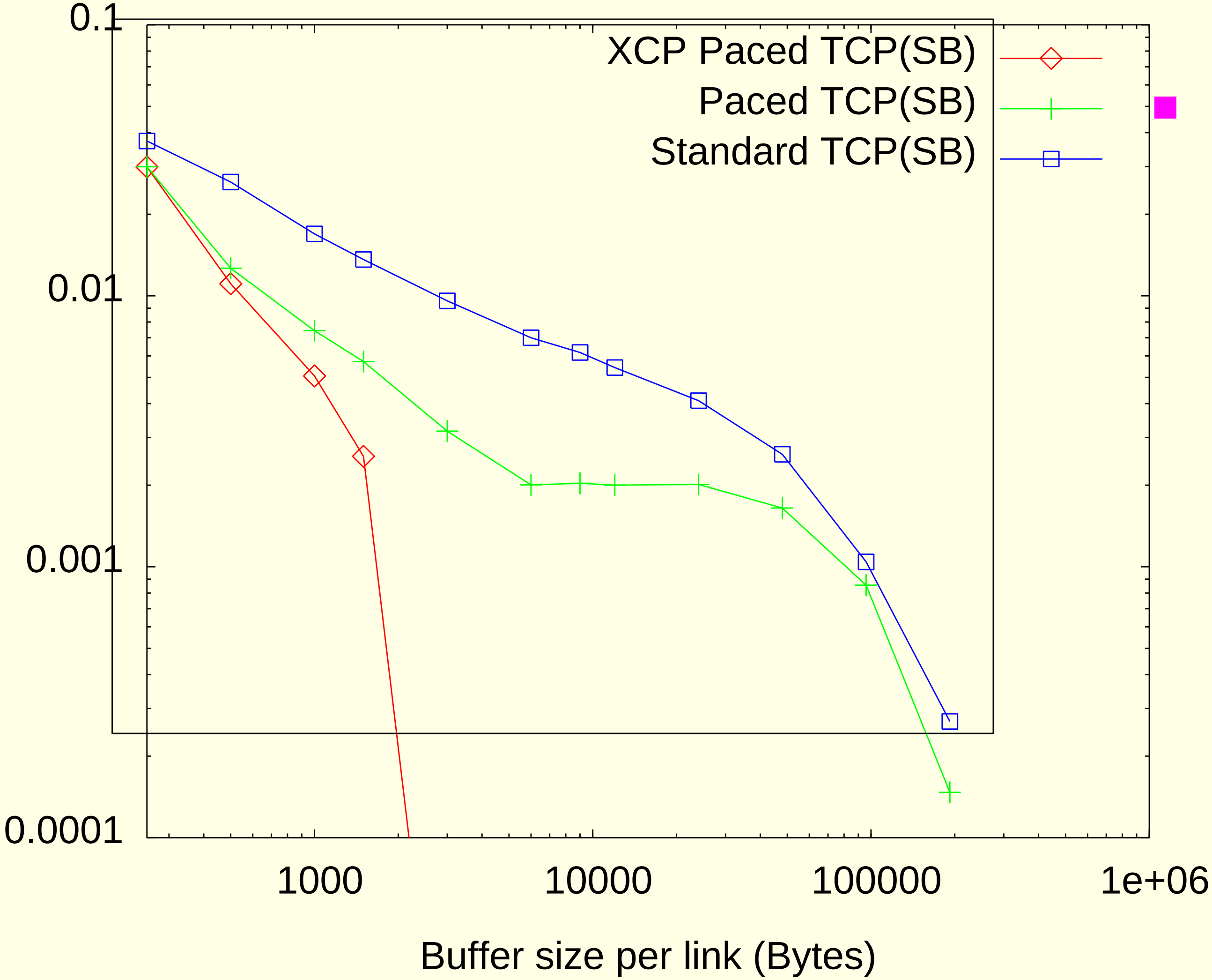
- **Lowest goodput**
- **OB, IB and WCSB give almost the same throughtput when buffer is small**
- **When buffer is large, IB has the lowest goodput due to head of line blocking**

Goodput Comparison of Pacing Methods



- **XCP Pacing gives the highest goodput when buffer size is very small (less than MSS)**
- **XCP Pacing has a better fairness, so maximum average goodput is lower**

Packet Drop Rate inside Core Network



- **XCP Pacing has a much lower packet drop rate**

Conclusions

- When buffers are very small, XCP-based paced standard TCP flows can achieve higher goodput and lower packet drop rate than TCP Pacing
  - XCP based pacing does not require changing TCP senders.
  - Pass the performance of Paced TCP with standard TCP
- When the total buffer capacity in a node is the same, shared buffering with XCP pacing has much better performance than input and output buffering
- Performance of worst case shared buffering is close to output buffering even though worst case shared buffering uses much less buffering per node

Future Work

- NSFNET nodes mostly have a small nodal degree of 3 to 4, so worst case buffering shows good performance
  - Simulate topologies with a higher nodal degree like Abilene topology
- Buffer requirements of multi-wavelength WDM

Thank you