Experimental and Theoretical Evaluation of an Ultrafast Multihop Packet-Switched Optical TDM Network Testbed

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Abstract—We discuss some of the physical layer performance issues regarding an experimental multihop transparent optical packet-switched testbed developed recently at Princeton University. Experimental data as well as computer simulation results are presented.

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Recent advances and innovations in ultrafast optical TDM technologies will be able to provide for the basic building blocks required in the next generation of high-speed processor interconnects and computer LANs. One network that has integrated many OTDM technologies such as 100 Gb/s packet compression and ultrafast demultiplexing has recently been demonstrated at Princeton University[1]. The network logical and physical topology is based upon the ShuffleNet architecture[2,3]. This paper briefly presents the experimental results of this demonstration and addresses the physical layer performance issues including scalability, reliability, and channel constraints of such networks.

In the system demonstrations, packet data was first encoded onto a 100 MHz 1 ps pulse stream at 1313 nm and then compressed to a pulse spacing of 10 ps using a 4-stage feed-forward delay line structure[4]. A novel packet header scheme that takes advantage of the regular structure of the ShuffleNet architecture was implemented to allow the network to be easily scalable[5]. The packet header demultiplexing subsystem was constructed using a parallel array of three Terahertz Optical Asymmetric Demultiplexers (TOAD's)[6], and a routing controller routed the incoming packets appropriately through the node's 4x4 routing switch. Since only one physical node of this network was constructed and tested, the entire ShuffleNet was synthesized by using a feedback fiber and allowing the node to dynamically reconfigure its current node address as the packet traversed the network. An example routing path through the ShuffleNet is shown in the inset of Fig. 1 as well as the output of the experimental node 4x4 routing switch. In this demonstration, a new 100 Gb/s packet was regenerated at each virtual node in order to demonstrate functional operation of the demultiplexing subsystem and routing controller. In Fig. 2, the evolution of the packet when the packet is simply looped back to the node input is illustrated. In this setup, one semiconductor optical amplifier was used to compensate as much round-trip loss as possible, but the gain was not adequate to exactly compensate for the loss, which explains the exponential decay of the packet.

The physical layer effects that impact the system performance include the dispersive and nonlinear effects of the fiber links, optical amplifier noise accumulation, adjacent channel crosstalk noise accumulation due to imperfect extinction ratio of lithium niobate routing switches (approximately 22 dB for commercially available devices), and gain dynamics of the SOA used in the TOAD. A computer simulation program was developed to model the physical layer of the network. In Fig. 3, an eye diagram after five hops (inset) and the SNR penalty as a function of the number of hops is illustrated. The simulation takes into account all of the effects described above and assumes the round trip loss can be compensated. The primary source of the SNR degradation is due to crosstalk and can be improved significantly with the development of higher extinction ratio space switches or use of alternative switch topologies.

REFERENCES

1. B. Y. Yu, R. Runser, P. Toliver, K. L. Deng, D. Zhou, I. Glesk, and P. R. Prucnal, "A network demonstration of 100 Gbit/s optical packet switching with self-routing", *Electron. Lett.* **33**, 1401 (1997)

2. M. G. Hluchyj, and M. J. Karol, "Shufflenet: An application of generalized perfect shuffles to multihop lightwave networks", *J. of Lightwave Technol.* **9**, 1386 (1991)

3. A. S. Acampora, "The Scalable Lightwave Network", *IEEE Comm. Mag.* **32**, 36 (1994)

4. K. L. Deng, K. I. Kang, I. Glesk, and P. R. Prucnal, "A 1024-channel fast tunable delay line for ultrafast all-optical TDM networks", *IEEE Photon. Technol. Lett.* **9**, 1496 (1997)

5. S. Seo, B. Y. Yu, and P. R. Prucnal, "Bit-level packet-switching all-optical multihop shuffle networks with deflection routing", *Appl. Opt.* **36**, 3142 (1997)

6. J. P. Sokoloff, P. R. Prucnal, I. Glesk, and M. Kane, "A terahertz optical asymmetric demultiplexer (TOAD)", *IEEE Photon. Technol. Lett.* **5**, 787 (1992)

FIGURE CAPTIONS

- **Figure 1**: Routing path (inset) and 4x4 routing switch outputs for the experimental demonstration
- **Figure 2**: Experimental setup (inset) and evolution of the packet through the ShuffleNet using the fiber loopback and semiconductor optical amplifier
- **Figure 3**: Eye diagram after the fifth hop (inset) and SNR degradation as a function of the number of hops

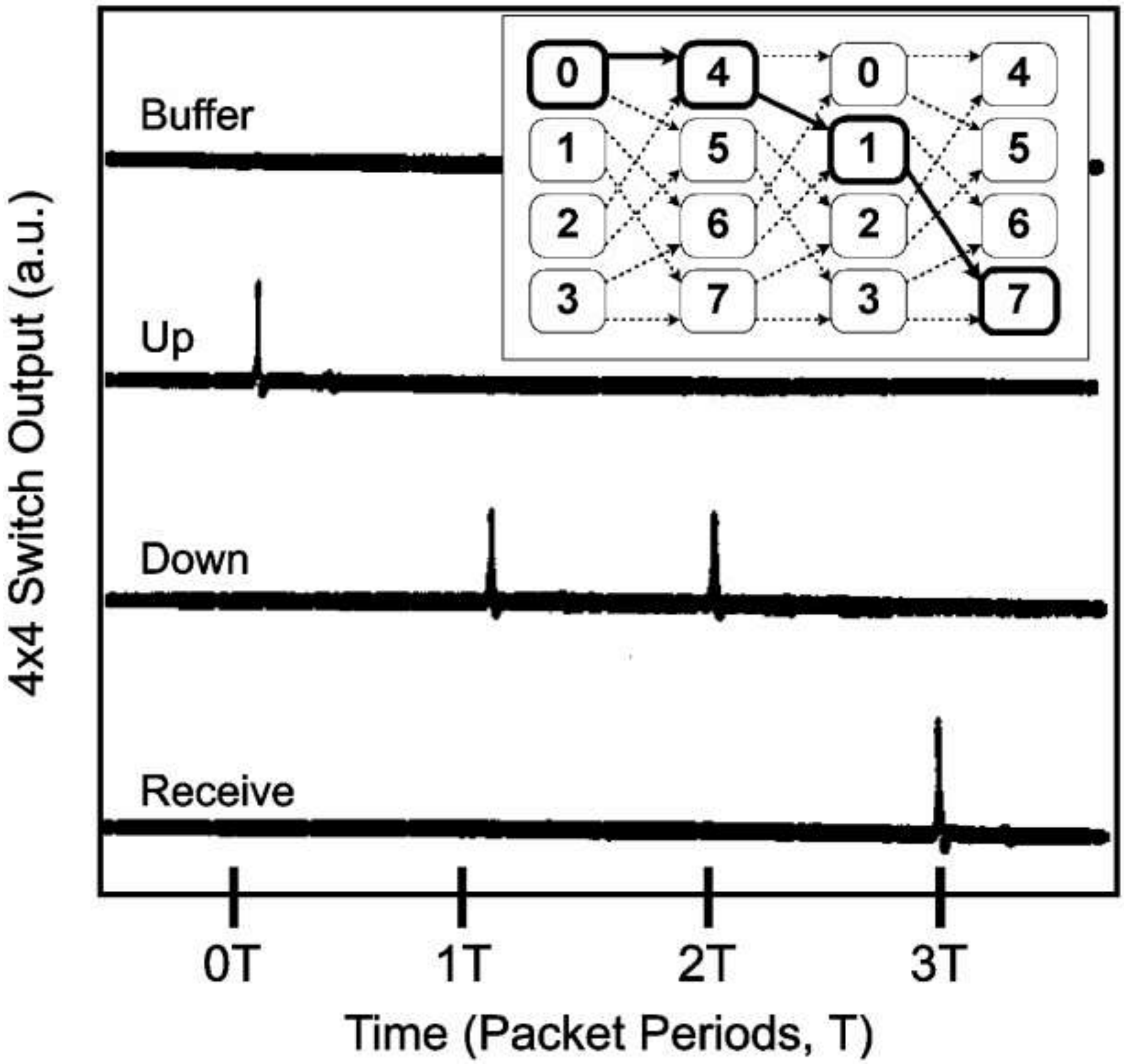

0
4
0
4
1
5
1
5
2
6
2
6
3
7
3
7
Buffer
Up
Down
Receive
4x4 Switch Output (a.u.)
0T
1T
2T
3T
Time (Packet Periods, T)

Fig. 1

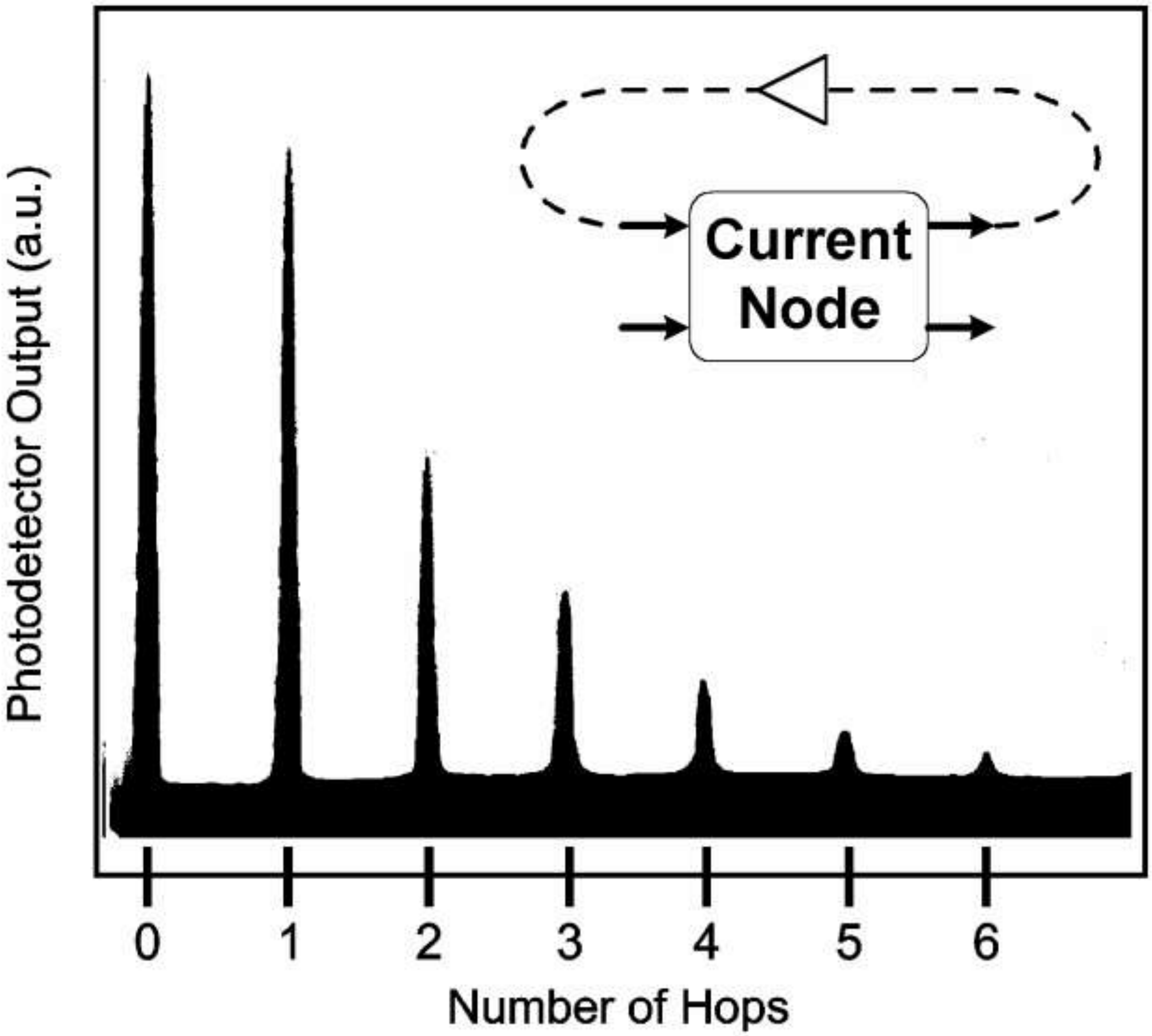
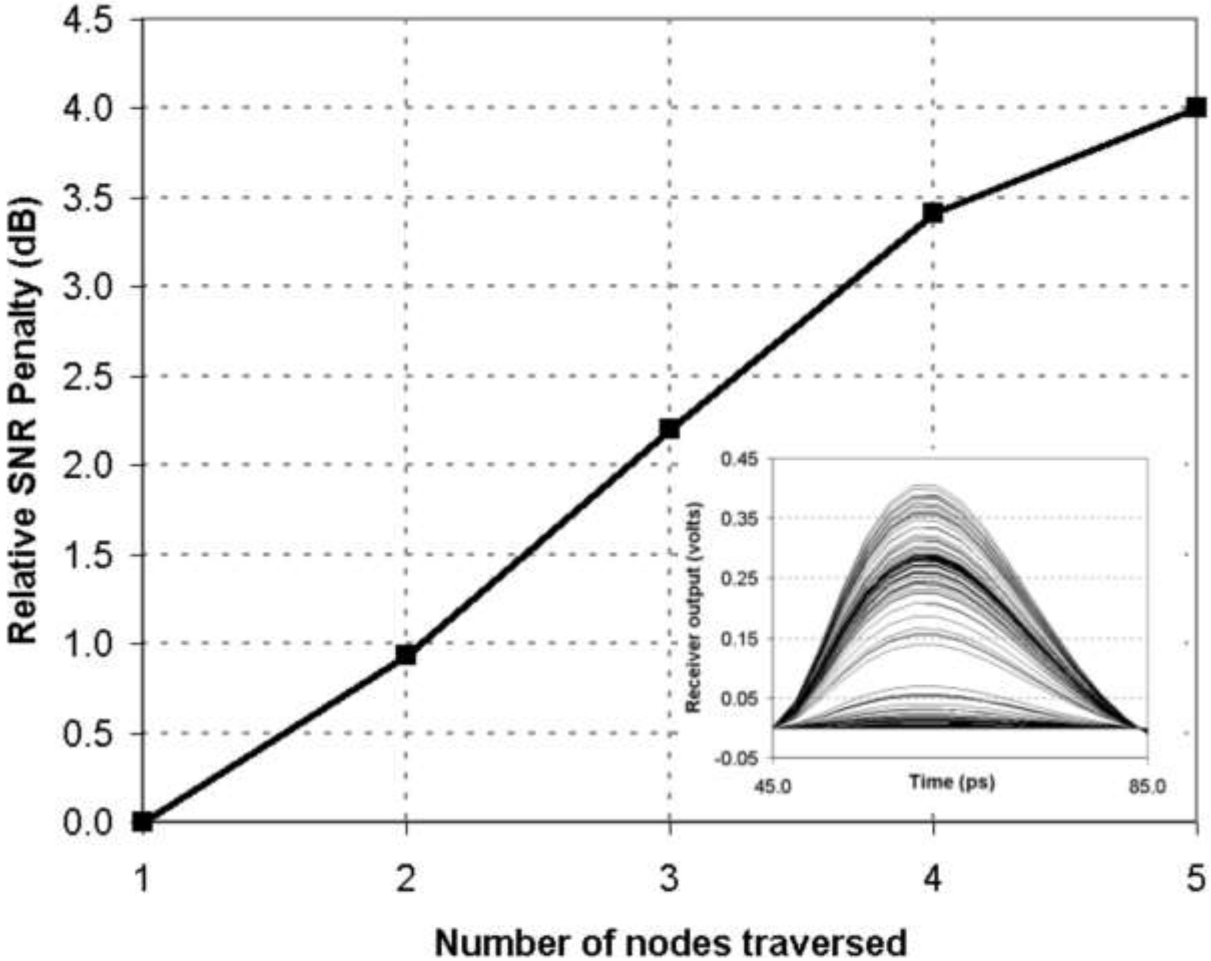

Current
Node
Photodetector Output (a.u.)
0
1
2
3
4
5
6
Number of Hops

Fig. 2



4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Relative SNR Penalty (dB)
1
2
3
4
5
Number of nodes traversed
0.45
0.35
0.25
0.15
0.05
-0.05
Receiver output (volts)
45.0
Time (ps)
85.0

Fig. 3