TDM 100Gbit/s Packet Switching in An Optical ShuffleNet

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ABSTRACT

In this paper we present an OTDM multihop prototype network developed in the Lightwave Communication Laboratory at Princeton University. Employing a new self-routing scheme with special address coding suitable for optical packet switching, we demonstrate 100 Gbit/s optical packet switching in an 8-node transparent shufflenetwork which offers extremely high bandwidth and low latency. Our design has also made the network highly scalable, the results from the performance studies of this network can be extended to many other multihop network topologies of larger sizes.

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We developed an ultra-fast node controller using a combination of optical and electronic processing. The prototype system includes high-speed packet generation with large-scale optical packet compression. The mode locked laser system, Nd:YLF, operates at 100 MHz repetition rate with a pulse width of about 100 ps and a carrier wavelength at 1.3 μm. We compress the pulses to 1-ps width, and then the pulse trains are modulated with an E/O modulator by the 100 Mb/s electronic data streams generated from a customized packet generation unit before they are compressed into 100 Gb/s optical packets. It is noted that due to the SOA relaxation time in the TOAD, the packet-to-packet time interval should be at least 500 ps to avoid saturation. Once the packets arrive at the destination they are downconverted from 100 Gb/s to an electronically processable 100 Mb/s rate.

Demultiplexing in the OTDM system requires fast temporal synchronization between the clock and data. This can be achieved with a few directional couplers and different lengths of optical fibers. This unit is called a rapidly tunable delay line. Conceptually, the output of the rapidly tunable delay line shifts the optical pulses in time by routing the optical pulses through different optical path lengths. The required number of directional couplers depends on the number of bits in a packet.

In the rapidly tunable delay line, the two outputs of one directional coupler are connected to the inputs of a second directional coupler by two different lengths of optical fibers. The difference in the optical fiber lengths is determined by the amount of optical path length required for an appropriate time delay. The process is repeated a number of times which is dictated by the number of channels in the OTDM system. By using the appropriate optical path length, the data signal can be synchronized with the clock pulse. The tuned data pulse stream is sent to a demultiplexer along with the clock optical pulse train. Ultra-fast routing control requires all-optical demultiplexing of the compressed packet header. We employ our TOAD to perform the required demultiplexing and routing control. If the header contains m address bits, it can be demultiplexed using an array of m TOADs producing a parallel address header.

Based on the destination address recognized by the TOAD, the appropriate state for the main routing switch is determined. The determination of switch states can be done by one of two commonly used methods: the look-up table and self-routing. In the look-up table method, each node contains all the information on the shortest path to the destination in the memory. When a packet arrives, the controller searches through the table for the correct output. In the single-bit self-routing method, the switch setting is accomplished by reading the single bit value in the address, which is known as destination-tag routing scheme (e.g., if bit value is 0 (1), then the packet is sent to upper (lower) output port in the 2×2 switch).

The network topology chosen in our demostration is the ShuffleNet with 8 nodes arranged in two columns. In this network, the self-routing method is more desirable because it reduces system latency and minimizes the hardware required. As shown in the block diagram, a node in the network is configured as a 4x4 switch, which includes a transmittter/receiver unit, and a single-packet delay buffer. Based on the single-bit self-routing method commonly used in Shuffle networks, we devolped a new header-coding scheme which is more suitable for optical networks and our node struture.

At the source node, the routing information required to reach the destination is encoded explicitly in the header of added packet. The routing address is represented in 2k 3-bit groups, with k being the number of columns of the ShuffleNet. Each of the first (2k-1) groups is read sequentially by the node controller at each hop in transition to make a routing decision. The last group is added for absorbing the packet when it reaches its destination. A clock bit carried with the packet is used at each node to synchronize the TOADs and switch controlling electronics. The starting position of the clock is aligned with the (D+1)-th position, where D is the distance from the source to destination with no deflection, and the clock is shifted by one bit-group position at each hop. When a deflection occurs, the clock will be moved back to the position of the first group in the header.

This scheme allows the routing controller to read only partial information in the packet header which leads to very low latency for routing decision making and also keeps the number of demultiplexers required at each node constant independent of the size of the network. Cost-effective design of a node is therefore possible.

One drawback of this scheme is its long address header since each bit in the header is encoded into three bits and the header size is dependent on the longest path length in the shuffle network. However, in a reasonable size network, the advantages of this scheme are enough to offset the longer header problem.

In the experiment we demonstrate the 8-node multihop transparent optical shufflenetwork by using a single node with a loop back. The node transmits and receives packets, and monitors the behavior of the packet along its way to the destination. Packets are generated in the packet generation unit which forms the bit serial data from a workstation located at the node. The experiments can be extended to perform the studies for both MSN and SN multihop topologies with larger sizes. As each packet passes through the node, the controller reads its destination addresses and determines the state of the 4×4 switch. The local address of the node is changed to correspond to the next node to which the transiting packet will hop by feeding back the output to an input. In effect, the entire *N*-node network is simulated by having the one node hop ahead of the packet, so that physically the packet simply loops back to the input of the same node.

By monitoring the path of the hopping node, the workstation can measure the path of the arriving packet through the multihop network. At the second input port contending packet addresses will be randomly generated. We count the number of deflections which occur along the path of the packet. When the packet arrives at its destination, the workstation can determine the number of hops which it has incurred, and the resulting delay. The resulting experimental data will provide information on the throughput-delay performance characteristics of the multihop networks, and will be compared with the theoretical results.

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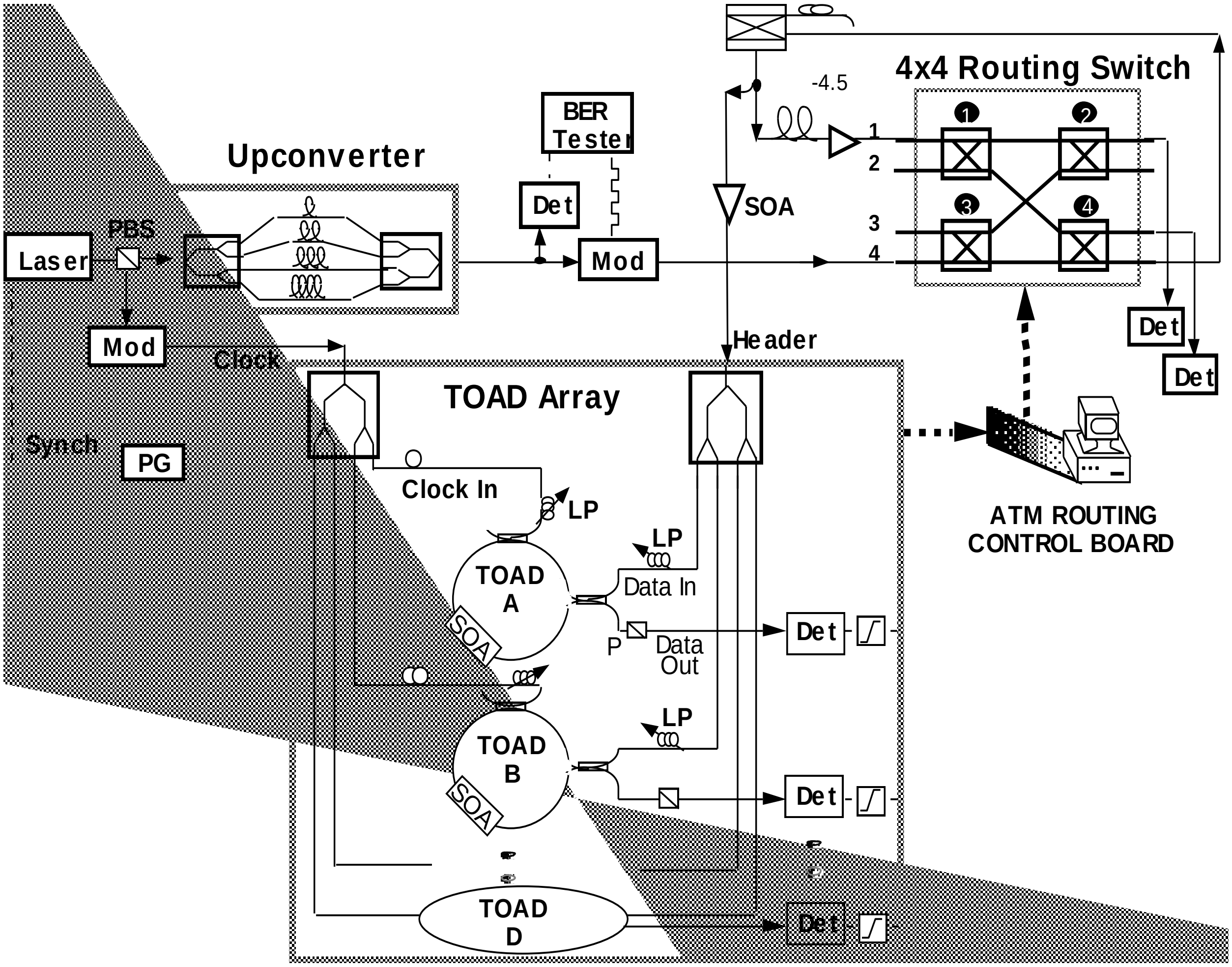

Figure 1: Experiment Setup of the 8-node Transparent ShuffleNet