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Self-Routing in a Photonic Packet Switched Manhattan Street Network based on all-optical label recognition

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Abstract: An all-optically addressed self-routing optical packet switched network scheme based on the Manhattan Street Network is presented. This scheme simplifies the optical processing that is required in the optical core. The resulting network provides a high-bandwidth flexible transmission path that is completely transparent to the data payload. The all-optical addressing is based on optical pattern recognition using matching filtering. Experimental results using all-optical recognition of a 20 Gchip/s four bit adddress label using super structured fibre Bragg gratings are presented.

Keywords: Packet Switching, All-optical Networks, Self-Routing Networks, Fibre Bragg Gratings, OCDMA.

Introduction

Packet switched networks provide a flexible core that is well suited to the bursty nature of IP traffic whilst providing the QoS required for voice and high-definition video [1, 2]. Conventional packet switching schemes utilise routing nodes that contain a considerable amount of intelligence. In addition to label recognition, packet contention resolution and switching of packets they also carry out packet buffering, address lookup, packet relabelling and numerous other network management functions. Although it is relatively straightforward to implement these operations in the electrical domain, it is extremely difficult to implement them optically. However the network flexibility offered by a packet switched protocol is still extremely attractive for high-bandwidth all optical networks. All optical packet switched networks provide a high bandwidth flexible transmission path by keeping the payload in optical form throughout the optical core, providing format and bit rate transparency.

We present an all optical packet switched network based on the Manhattan Street Network (MSN) [3,4] that is designed to simplify the optical processing that is required in the optical core. At the same time the benefits of increased flexibility and granularity that are inherent in a packet switched system are retained. We propose a slotted mesh type network architecture consisting of optically packet switched nodes. The nodes utilise all-optical label recognition and generation, and switch the optical packets using electro-optic switches. The network carries optical packets consisting of an optically coded destination label followed by a data payload. The optical label is generated and placed in front of the data payload at the source node in the network. The label is used to determine the routing of the packet throughout the network from the source node to the destination node.

All-optical label recognition is advantageous as it is transparent to the optical payload and significantly faster than electrical recognition using RAM based lookup tables. Optical label processing based on optical encoding and decoding of the label using matched filtering in complementary tapped delay line filters have been recently demonstrated. These were implemented in planar lightwave circuits and multi-wavelength coding using fibre grating [5, 6]. Here we propose an optical packet switch based on optically decoding an optically encoded label, that is used to label the packets, using phase coded superstructured fibre Bragg gratings (SSFBG) that have been developed for coherent OCDMA. Phase coded grating encoders/decoders offer several advantages. They are readily scaled to long code sequences (255 bit OCDMA codes previously demonstrated in the laboratory [7]), low cost, compact and integrate easily with other optical fibre based network components. The long code sequences that can be obtained with SSFBGs also allow for a large address space.

2. Self-Routed Mahattan Street Network

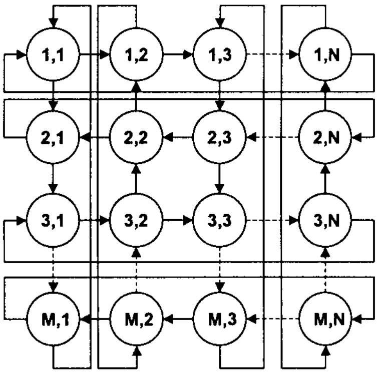

Figure 1 : An MxN node Manhattan Street Network

The MSN shown in Fig. 1 is a regular mesh-configured network consisting of M rows and N columns of interconnected nodes. Each node has a pair of input and output links as well as a local add/drop interface. Links in adjacent rows or columns travel in opposite directions. Each node in the MSN is addressed using its row and column number.

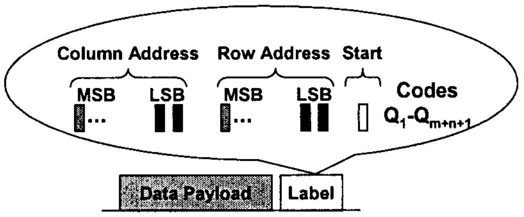

Fig. 2. Optical Packet Structure

The packet structure shown in Fig. 2 consists of a start bit followed by a destination row and column address. The number of bits required to represent the row and column addresses depends on number of nodes in the network. With this labelling scheme 2n address bits are able to support 2^{2n} nodes.

The regularity of this network allows for simple deterministic routing rules that are identical for all nodes. The routing approach is based on the shortest path algorithm [3]. At each node the packet destination address is decoded and the direction of the shortest path towards the destination node from the current node is calculated. This direction is translated into the optimum node output for the packet. This process is carried out for packets on both of the node inputs and the optical switch is configured to direct the packets towards their optimal outputs. Contention will arise when two packets want to exit from the same output port. This is resolved by arbitrarily deflecting one of the packets to the other output port. This will result in a higher latency for the deflected packet, although it has been shown that such deflection based contention protocols exhibit reasonable performance in well connected networks such as the MSN [8].

The packet is routed using an optically coded label that is encoded and decoded all-optically using superstructured fibre Bragg gratings. The encoding and decoding principle using SSFBGs is illustrated in Fig. 3.

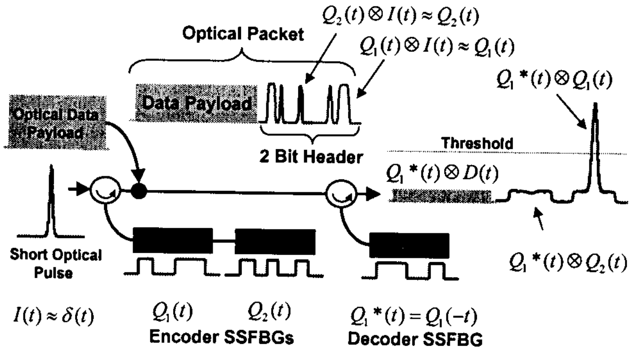

Fig. 3. SSFBG based Encoding and Decoding principle.

The optically coded address label is created by reflecting a short optical pulse off the encoder grating. The encoder grating contains the coding information within its spatial refractive index profile. The reflected signal is effectively the impulse response of the encoder grating and contains the code. In this illustration two address bits are generated using encoding gratings labelled Q_1 and Q_2. The data payload is then appended to the label.

Code recognition at the decoder is obtained by matched filtering of the coded signal, using a decoder grating with the time reversed (conjugate) impulse response to that of the encoder grating. Such an impulse response is readily obtained using a grating with exactly the same refractive index profile as the encoder grating and by illuminating it from the opposite end. In this illustration the coded optical pulse is reflected off a decoding grating containing the code Q_1^* that is matched to the first address bit. The reflected signal from the decoder grating shows a strong correlation peak when the incoming label code is matched to a decoding grating. When the decoding grating is not matched to the incoming signal the cross-correlation results in a low level background as is observed for the second address bit. The cross-correlation with the data payload also results in a low level background. An electrical or optical thresholder is then used to reject these low-level background terms.

The coding scheme used here is based on direct sequence phase encoding using codes developed for mobile radio systems. To date we have demonstrated code lengths ranging from 15 to 255 chips at 20 to 320 Gchip/s, using both bipolar and quaternary phase encoding [7]. These codes have distinct well defined autocorrelation properties, and mutually low cross-correlation properties. The number of distinct codes is proportional to the code length thus it is relatively easy to provide a large address space.

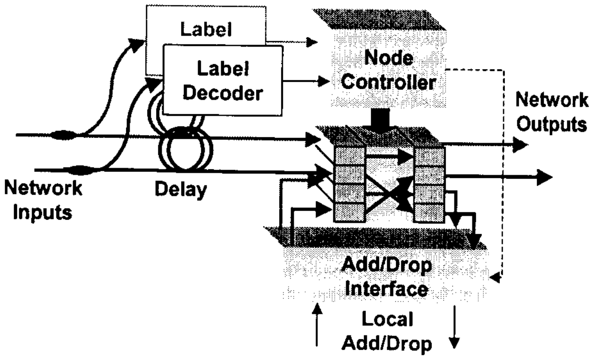

Fig. 4. Node Structure

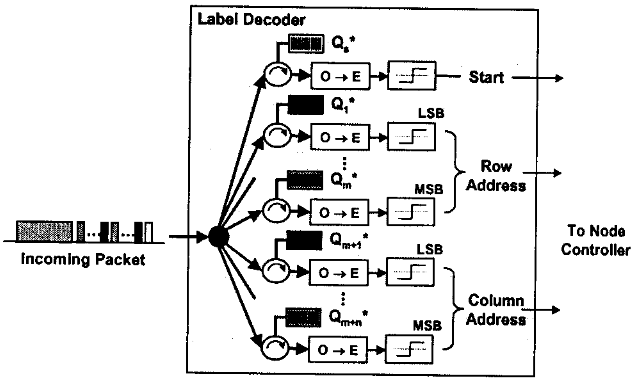

Fig. 5. Label Decoder - the address bits are decoded in parallel

The node structure is shown in Fig. 4. The switch carries out three sequential operations; optical label decoding, contention resolution and routing. At each input of the switch, part of the optical signal is picked off in a fibre coupler and sent to an optical address decoder. The remaining signal is sent to the optical switch via a variable optical delay; firstly to compensate for the fixed label processing time and secondly to ensure that the packet slots from the different inputs are aligned. The label decoders, shown in Fig. 5, consist of a parallel array of optical decoders whose codes correspond to the start bit and the individual address bits.

The decoded start bit is used for node synchronisation whilst the decoded address bits are sent to the node controller. The node controller electronically implements the deterministic routing protocol to determine the optimum routing for the packets, and resolves packet contention. The node controller also controls the adding and dropping of packets at the node. Packets are dropped if their destination address corresponds to that of the current node. Packets are only added to the network, from the local buffer, if a packet has been dropped or one of the two input packet slots are empty. The node controller then sets up the optical switch to correctly route the optical packets. The optical switching is carried out using 2x2 Lithium Niobate electro-optic switches to allow for fast packet switching. The 4x4 switch required for the link input and output and the local add/drop is constructed from three 2x2 crossbar switches as shown in Fig. 6.

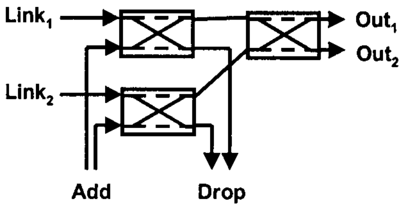

Fig. 6. MSN node optical switch configuration

3. Experimental Demonstration

A packet with a four bit address label suitable for use in a 16 node MSN was generated. The coded address label is shown in the top trace of Fig. 7 (left). The address label was optically encoded by reflecting 20 ps duration optical pulses off a series of four SSFBGs each containing a unique code. The SSFBGs used within this experiment contain the coding information within their spatial refractive index profile that allows the generation of 16-Chip, 20 GChip/s quaternary phase coded pulse sequences. The packet switching is transparent to the bit-rate and format of the data payload employed. In this experiment it was convenient to use 10 Gbit/s (PRBS 231-1) NRZ data as the payload. The resulting packets were 25 ns in duration.

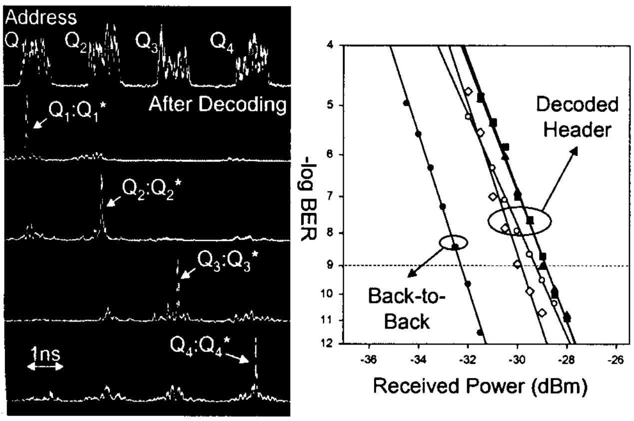

Fig. 7. (Left) A four-bit optically coded address label before and after the parallel decoding operation on each of the four bit codes. (Right) BER for each of the four codes in the address label after the decoding operation.

The label decoder was implemented to experimentally demonstrate the parallel all-optical address decoding technique. The decoded signals for the four bits are shown in Fig. 7 (left). The extinction between the autocorrelation peaks arising from the correctly decoded address bit and the crosscorrelation signals from the remaining bits is approximately 8 dB. BER measurements on the decoded outputs were used to characterise the quality of the decoding operation. Fig. 7 (right) shows BER measurements on the label decoding process indicating that error free operation is obtained for all four codes with a 3 dB penalty observed over back-to-back measurements of the un-coded pulses.

5. Conclusion

We proposed a self-routed optical packet switched MSN that considerably simplifies the optical processing required in the core. This system utilises coded SSFBGs to both encode the destination address label at the source node and to decode the label at each node the packet encounters within the optical core to determine the optimal packet routing. The system uses a simple deterministic routing protocol based on the shortest path and deflection based contention resolution that does not require packet relabelling. The optical code based addressing scheme scales well with network size as only 2n unique codes are required to address a 2^{2n} node MSN. Experimental results showed error free operation for the all-optical address encoding and decoding system on a four-bit address label.

6. References

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7. Glossary

BER	Bit Error Rate
MSN	Manhattan Street Network
OCDMA	Optical Code Division Multiple Access
PRBS	Pseudo Random Bit Stream
SSFBG	Superstructured Fibre Bragg Grating