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Muhsen Aljada
Edith Cowan University

Kamal Alameh
Edith Cowan University

Adam Osseiran
Edith Cowan University

Khalid Al-Begain

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A Novel MicroPhotonic Structure for Optical Header Recognition

Muhsen Aljada[1], Kamal Alameh[1], and Adam Osseiran[2], and Khalid Al-Begain[3]
[1]Centre for MicroPhotonic Systems, [2]National Networked TeleTest Facility,
Electron Science Research Institute, Edith Cowan University, Joondalup, WA, 6027, Australia
[3]Mobile Computing, Communications and Networking Research Group, School of Computing,
University of Glamorgan, Pontypridd (Cardiff), CF37 1DL, Wales, UK.
Email: k.alameh@ecu.edu.au

Abstract

In this paper, we propose and demonstrate a new MicroPhotonic structure for optical packet header recognition based on the integration of an optical cavity, optical components and a photoreceiver array. The structure is inherently immune to optical interference thereby routing an optical header within optical cavities to different photo receiver elements to generate the autocorrelation function, and hence the recognition, of the header using simple microelectronic circuits. The proof-of-concept of the proposed MicroPhotonic optical header recognition structure is analysed and experimentally demonstrated, and results show excellent agreement between measurements and theory.

1. Introduction

The new generation high-speed optical networks require a potentially faster approach to decode the header bits optically so that a given routing decision can be made on-the-fly. Optical Header recognition is a promising concept to perform the header pattern optically by using time-domain correlator to match it to a look up table and get out with process command for the switch in order to make the packet switching.

Currently electronic technology is involved with the packet processing which cannot handle the high data rates of future generation packet switched optical networks, therefore, it is considered a bottle neck for high speed optical network [1]. Thus the development of fast structures for optical header recognition is crucial to route the incoming data packets to appropriate destinations. Several approaches have been proposed for optical header recognition includes a Fibre Bragg Grating (FBG) correlation [2]. Fibre match filters [3] which are not tunable. Optical Code Division Multiplex Access (OCDMA) coded headers [4]. Optical serial-to-parallel conversions in conjunction with an optical reflection switch [5]. Serial-to-parallel conversion using multi-wavelength pulse trains [6]. Optical label switching [7], time stretch pre-processing [8], Integrated optical chip [9] and loop mirror configuration with semiconductor optical amplifier [10]. FBG optical header correlators are inherently susceptible to optical interference due to the detection of delayed bits using a single photo detector. This optical interference generates beat noise that cannot be filtered out. Scaling the above structures to handle larger header bits is also difficult to achieve without a significant increase in complexity.

In this paper we propose and demonstrate a new structure for header recognition using a new MicroPhotonic structure that integrates an optical cavity, optical components and a photoreceiver array. The structure is scalable, and inherently immune to optical interference. This paper is organized as follow: in section 2 is a background on fibre Bragg grating based optical header recognition structure, the proposed microphotonic optical header recognition structure in section 3, results and discussion in section 4, and the paper is concluded with some remarks in section 5.

2. Fibre bragg grating based optical header recognition structure

A conceptual diagram of optical header recognition is illustrated in Fig. 1. The stream of information from source to destination usually consists of small packets. The packet is comprises of the header (which has all routing information processed only by the switch) and the payload (the body of the packet/information processed only by the source and destination). The header and the payload can be transmitted within the same packet or parallel on separate channels within the same fibre, for more details about packet coding techniques refer to [11]. An optical tap is used to by-pass a small power of the optical packets. This small power is then split into M outputs using the 1xM optical splitter. At the output ports of the optical splitter, an array of optical correlators is used. Each optical correlator recognizes a single destination address. Using the comparators, the electrical signals at the output ports of the M optical correlators are converted into control signals fed into the control ports of the N-port optical switch that routes the packet to its next hop

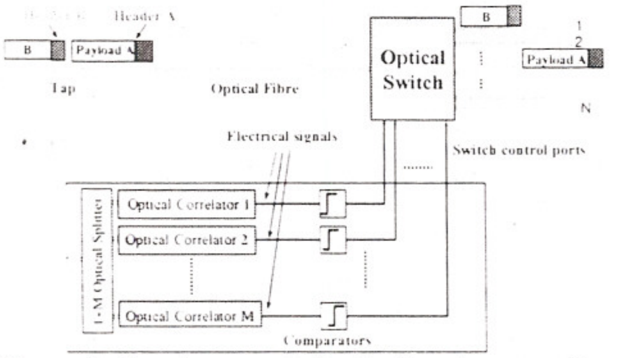

Figure 1. Generic concept of optical header recognition

Fibre Bragg Grating (FBG) is a wavelength-selective filter that picks out and reflects a specific wavelength (called Bragg wavelength) back along the fibre. Fig. 2 illustrate the principle of a conventional fibre Bragg grating (FBG) optical correlator. The optical correlator consists of a circulator, several cascaded FBGs, and a photodetector. The spacing between the FBGs is set to be a half bit time so that the round-trip time between adjacent gratings corresponds to a 1-bit time delay. To program a "1" bit in a correlation sequence, a grating is tuned to be partially or wholly reflective, and to program a "0" bit, a grating is tuned away so that it does not reflect. The reflectivities of the FBGs are also optimized so that the powers of all reflected bits arriving at the photodetector are equal. For example, in Figure 2, the optimum reflectivities that match the header pattern 1101 are 23%, 0%, 38%, and 100%. If the header pattern matches the grating reflectivity profile, the photodetected signal turns out to be the autocorrelation of the header signal, which has a peak at the time N·T, where N is the number of bits in the header word, and T is the bit time. By sampling the autocorrelation signal at time N·T and compare it to a threshold value a match signal is generated, indicating that the optical header has been recognized.

The conventional FBG correlator has a fundamental limitation: the peak of the autocorrelation signal is the detection of the sum of many optical bits generated by the same laser source (or transmitter), arriving at the same time. Since a single photodetector is used, optical interference, resulting from the long laser coherence length, takes place during the photodetection process. This optical interference generates phase-induced intensity noise, causing fluctuations of the peak value of the autocorrelation signal, and hence degrading the bit error rate performance of the FBG correlator.

3. Proposed microphotonic Optical Header Recognition Structure

Figure 3 schematically illustrates the proposed MicroPhotonic correlator architecture for optical header recognition of the present invention. The small power of

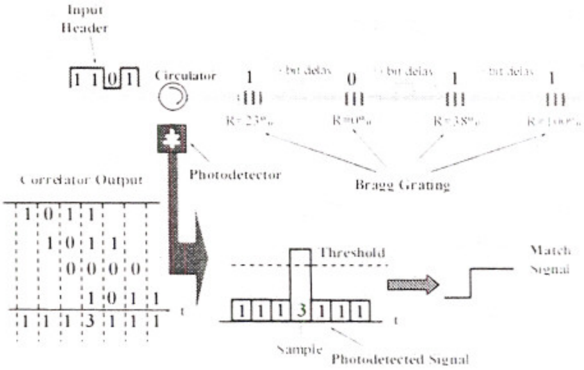

Figure 2. Principle of a FBG optical correlator

the optical packet, which consists of the optical payload and the optical header, is by-passed from the optical fiber using the optical tap (about 5% is tapped). The 1xN optical splitter equally splits the tapped optical packet into N packets. The microlenses are appropriately etched into the optical substrate in order to convert the in-fibre optical packets into collimated optical beams. Each collimated optical beam propagates within the optical substrate and undergoes several reflections in a cavity whose width defined by the mirror and the DOE. Every time a beam hits the DOE, a small fraction of the power of that beam is transmitted through the DOE for detection and amplification by an element of the wideband photoreceiver array that is integrated on the surface of the optical substrate, while the remaining large fraction is reflected and routed to for subsequent delayed photodetection. The gain of a photoreceiver can be set to a low value (0) or a high value (1). Each element of the combiner/comparator array adds the amplified photocurrents of a photoreceiver row, generates an output signal, and matches it to its destination address. The output control signals are fed into the control ports of the N-port optical switch (not shown in Figure 3) that routes the packet to its next hop.

For comparison with the FBG correlator, the correlator output of Figure 3 corresponds to the same optical header, 1101, of Figure 2. The first photoreceiver element, D1, which has a high gain (1), detects the bit stream 1101 and generates an electrical pattern 1101, whereas the second photoreceiver element, D2, which has also a high gain (1), generates an electrical pattern 1101, but delayed a bit time. The third photoreceiver element, D3, which has a low gain (0), detects the bit stream 1101 delayed two bit times, but, having a zero gain, it generates 0000 electrical pattern. The last photoreceiver element, D4 has a high gain (1), and receives the bit stream 1101 delayed three bit times. The autocorrelation of the header pattern, obtained by combining the electrical patterns of the various photoreceiver elements , has a peak that results form the summation of three equal electrical signals generated by different photoreceiver elements, thus, no optical interference is ever produced.

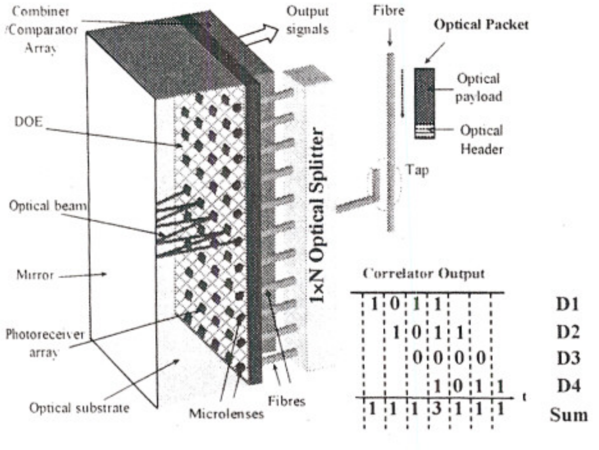

Figure 3. MicroPhotonic correlator architecture

Figure 4 schematically illustrates the interface between the photoreceiver array and the optical substrate and also illustrates the propagation of the optical beams inside the optical substrate. The input fiber represents an output port of the 1xM optical splitter discussed in Figure 3. The optical packet propagating in the input fibre is converted into a collimated optical beam via the microlens. The glass layer is used over the photoreceiver chip for protection. The DOE is inserted between the photoreceiver chip and the optical substrate. The DOE comprises two sections. The first section is the beam router, which is a hologram capable of steering collimated optical beam, while the second section (dashed) acts as a lens relay that prevents the cavity beam from diverging as it propagates along its optical path, and also maintains its diameter within an adequate range. The DOE can be appropriately coated to provide any desired reflectivity. As the cavity beam hits the DOE, a large portion of its power is reflected inside the optical cavity and its diameter is equalized for subsequent propagation, while a small fraction of its power is transmitted through the DOE and the glass layer and then detected by one of the photoreceivers. For a cavity length L and a photoreceiver spacing d, the steering angle, θ, of the beam router is arctan (d/2L).

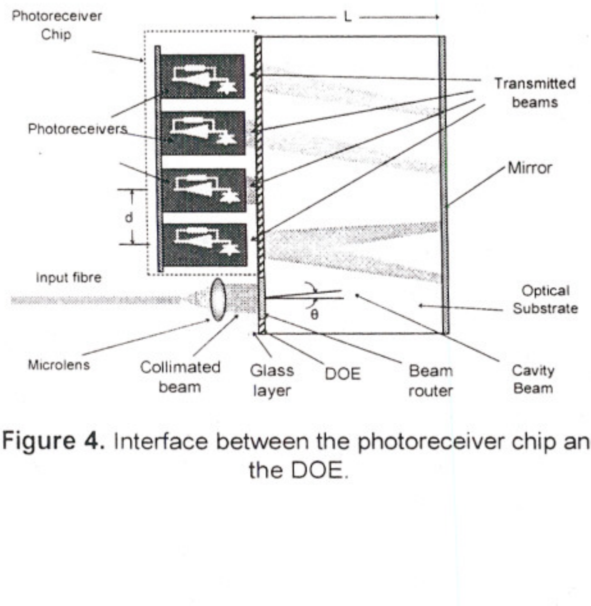

Figure 4. Interface between the photoreceiver chip and the DOE.

4. Experimental setup

The proof-of-concept experimental setup for optica header recognition is shown is figure 5. The pattern generator generates a 4-bit packet at 16.1Mbps, which modulates a 1550nm optical signal generated by an Agilent laser source. The modulated optical signal was split into 4 output fibre ports whose lengths chosen to delay the modulated optical signals by T_0, T_0+T, T_0+2T, and T_0+3T, where T_0 is an arbitrary delay and T = 50 ns, which is the bit time of the input pattern. A photoreceiver array, which integrates 4 discrete photodetectors, 4 variable-gain transimpedance amplifiers and an RF combiner, was designed and implemented in a discrete form to provide the gain pattern by simply switching the amplifiers gains between a "HIGH" and "LOW" levels, thus generating a gain profile that matches the input bit pattern. For example: for a Header 1101 we reduce the gain of the second transimpedance amplifier to below 10^{-2} corresponding to the "0" state, while increasing the gains of the other amplifiers to 100, which correspond to the "1" state. The output electrical signal from the RF combiner was monitored by a digital oscilloscope.

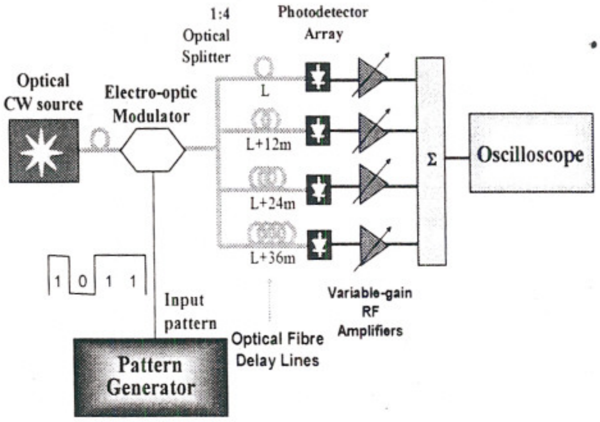

Figure 5. Header recognition experimental setup

5. Results and discussion

Figure 6 shows the measured and predicted output waveforms for a 1101 header. An excellent agreement between theory and experiment is seen, and a stable output autocorrelation is measured with no optical interference. High amplitude (spike) is clearly displayed when the input pattern matches the amplifier gains. To demonstrate the capability of the optical correlator to reject patterns that do no match its gain pattern, we launched a different input pattern namely 1101 while keeping the gain profile 1101. In this case the measured output waveform, which is shown in Fig. 6, did not show any spike. This demonstrates the proof of concept of the proposed optical header recognition approach.

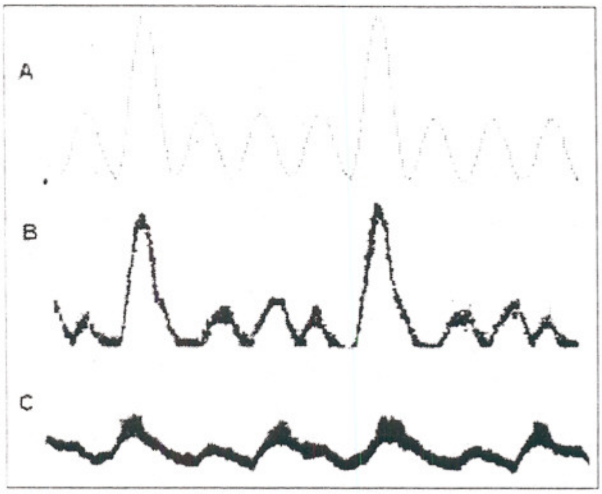

Figure 6. a) Theoretical results, b) Oscilloscope trace for recognition a 1101 header c) Oscilloscope trace for a 1011 header with a 1101 gain pattern

Conclusion

In this paper, we have proposed and demonstrated a MicroPhotonic structure integrating photoreceiver array and optical components on an optical substrate to perform optical header recognition. The use of a photoreceiver array eliminates the optical interference problem encountered in fibre Bragg grating based optical header recognition structures which used a single photodetector to detect delayed versions of the bit pattern. The proposed MicroPhotonic structure routes an optical header to different optical cavities of different gain patterns obtained by switching the individual gains of the photoreceiver array between "HIGH" and "LOW" levels. The proof-of-concept of the MicroPhotonic optical header recognition structure was experimentally demonstrated using a 4-element photoreceiver array integrated with discrete transimpedance amplifiers. Results have shown the synthesis of the autocorrelation of a bit pattern by simply matching it to the photoreceiver gain profile.

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