13. B.E. Olsson, P. Ohlen, L. Rau, G. Rossi, O. Jerphagnon, R. Doshi, D.S. Hunphries, D.J. Blumenthal, V. Kaman and J.E. Bowers, "Wavelength Routing of 40 Gbit/s Packets with 2.5 Gbit/s Header Erasure/Rewriting using an All-Fiber Wavelength Converter," Postdeadline Paper, ECOC, Vol. 2, p. 52–53, Nice, France, September 1999.

WO4 **2:30 pm**

An All-Optical Packet Header Recognition Scheme for Self-Routing Packet Networks

Kit Chan, Frank Tong, Chun K. Chan, Lian K. Chen, Wai Hung, *Dept of Information Engineering, The Chinese University of Hong Kong, Hong Kong, SAR, China, Email: kchan0@ie.cuhk.edu.hk*

Introduction

In future ultrahigh-speed self-routing optical packet networks, the packet header has to be examined at each packet node to retrieve the destination information, which is essential for making routing decision. As the data rate (several tens of Gbit/s) of the packet stream is far beyond the processing capability of the common electronics, several all-optical signal processing techniques have been proposed to perform ultrafast packet header recognition.[1,2] However, these approaches have limitations in terms of complexity and scalability.

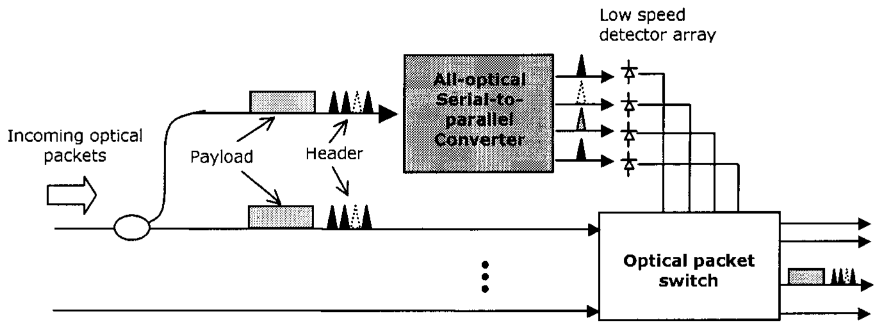
With optical serial-to-parallel conversion of the packet header, header recognition and control signal generation for self-routing will be much simpler as a result of relaxed speed requirement.[3] Therefore, an array of common electronics can be adapted to process individual packet header bits. For a self-routing network node, the recovered parallel header bit sequence can be used to control the routing switch at different stage in a switching matrix, as shown in block diagram Fig. 1.

In this paper, we propose an all-optical ultrafast packet header recognition scheme for self-routing switch based on all-optical serial-to-parallel conversion. Each bit in the packet header is converted to a distinct wavelength, which is then separated by a 1 × N wavelength demultiplexer. Thus, a parallel header bit sequence, each at a lower bit rate, can be obtained and it will be used to perform packet routing.

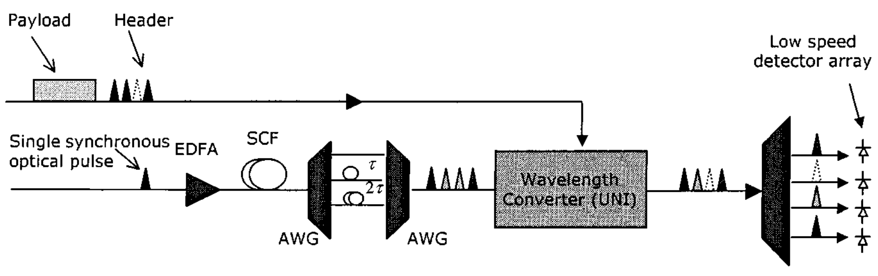
Proposed Scheme

Fig. 2 shows the schematic of the proposed scheme. As an incoming packet enters the network routing node, a single pulse (sync pulse) is generated to mark the start of the optical packet, which can be performed either by cross-correlation technique[4] or by power differentiation. The generated sync pulse is amplified and injected into a segment of super-continuum fiber (SCF). The output pulse with broadened spectrum is then spectrum-sliced with a pair of array waveguide gratings (AWG) in which fiber delays are inserted between different wavelength channel with time delay of 0, τ, 2τ . . . $n\tau$, where τ is the bit duration of the packet header and n corresponds to the total number of bits in the packet header. As a result, wavelength interleaved pulse stream is produced at output of the pair of AWG.

The multi-wavelength pulse stream is then launched into a wavelength converter with ultrafast nonlinear interferometer (UNI) configuration, which consists of a semiconductor optical amplifier (SOA) and some polarization-controlling components. A portion of the incoming packet is tapped off and injected into the UNI as the control signal. The relative time delay between the multi-wavelength pulse stream and the control signal is properly adjusted in such a way that each bit in the packet header is converted to a distinct wavelength at the output of UNI. The wavelength converted signal is then demultiplexed with an AWG. With fine adjustment of the fiber delay, different bits in the packet header can be detected by the low-speed photodetector array simultaneously. The retrieved packet header parallel bit sequence is fed into the switch control unit to trigger the $N \times N$ optical packet switch so as to route the high-speed optical packet to the destined output port.



WO4 Fig. 1. All-optical serial-to-parallel converter enabled self-routing node.



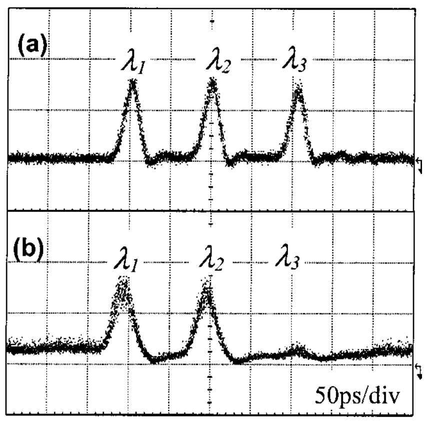
WO4 Fig. 2. Our proposed all-optical serial-to-parallel converter.

Experiment

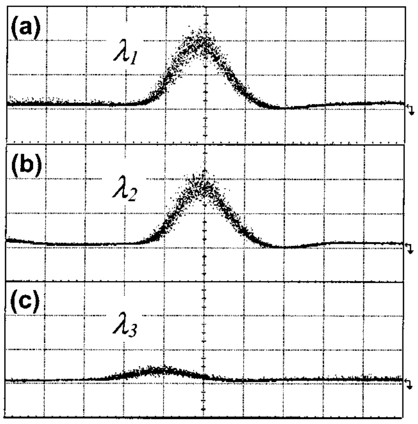
In our experiment, a three-bit packet header with bit pattern "110" was generated. It was then followed by a payload of 40 ns. Both packet header and payload were at a bit rate of 10-Gbit/s in return-to-zero (RZ) format. The generated sync pulse was injected into the SC-fiber with a launch power of 19 dBm. The generated SC spectrum with spectral width more than 10 nm was then spectrum-sliced with an AWG with 100 GHz spacing. Three wavelengths, 1554.1 nm (λ_1), 1554.9 nm (λ_2), and 1555.7 nm (λ_3), were selected respectively. At the second AWG, those three spectrum-sliced optical pulses with different wavelengths were combined with a temporal delay of 100-ps introduced between adjacent wavelengths. Fig 3(a) shows the resultant wavelength interleaved pulse stream. It was then input to the wavelength converter as probe signal.

With proper adjustment of time delay between the probe signal and the incoming optical packet, only the packet header was wavelength converted by feeding both signals into the UNI device and the output signal was shown in Fig 3(b). The slightly reduced magnitude of second bit (λ_2) was due to the pattern effect of the SOA in the wavelength converter (UNI); this could be improved by using holding light injection.[5] As each bit in the packet header was mapped to different wavelengths, serial-to-parallel operation could be easily achieved by using a wavelength demultiplexer. Fig 4 shows the output waveform at different output ports of the serial-to-parallel converter.

With this serial-to-parallel conversion for packet header processing, low speed photodetector array can be used for parallel optical signal detection. For header recognition, CMOS based electronic logic gate can be used. For self-routing network, the parallel-generated signal can be di-



WO4 Fig. 3. (a) Wavelength interleaved pulse from spectrum-slicing of SC generation. The three wavelengths are 1554.1 nm, 1554.9 nm, and 1555.7 nm respectively. (b) Wavelength converted packet header "110". (50 ps/div).



WO4 Fig. 4. Output of the serial-to-parallel conversion. Optical signal appear at converter output, which corresponding (a) 1st bit in header "1", λ_1 = 1554.1 nm; (b) 2nd bit, "1", λ_2 = 1554.9 nm, and (c) 3rd bit, "0", λ_3 = 1555.7 nm.

rectly used to control the switching state of the optical packet switch as shown in Fig. 1.

Conclusion

We proposed a serial-to-parallel conversion scheme for optical packet header processing. All-optical recognition of a three-bit packet header was demonstrated. The obtained parallel optical signal from the converter can be detected by low speed photodetector array, and can be used as switching control signal for the optical packet switch in a self-routing network node.

References

1. Ki-Hwan Park and Tetsuya Mizumoto, *JLT, 2001,* 19, *pp* 1076–1084.
2. D. Cotter, J.K. Lucek, al. Electron. Lett. (1995), *pp* 1475–1476.
3. Ryo Takahashi and Hiroyuki Suzuki, *Proc of ECOC* 2001.
4. Shabeer, M.; Lucek, J.K. al, Electron. Lett. (1995), *pp* 1476–1478.
5. Jianjun Yu; Jeppesen, P. *JLT, 2001,* 19, *pp* 614–623.

WO5 2:45 pm

Forward-Error Correction for time-slotted optical packets

D. Penninckx, E. Caro, O. Audouin, and M. Khan, *Alcatel Research & Innovation, route de Nozay, F91460 Marcoussis, France Tel.: +33 (0) 169631046, fax.: +33 (0) 169631865, Denis.Penninckx@alcatel.fr*

O. Aït-Sab, *Alcatel Submarine Networks Division, Centre de Villarceaux, F91625 Nozay, France*

1. Introduction

Optical packets should allow to increase the efficiency of optical networks because their smaller granularity compared to optical circuits improves the use of the optical resources. However, optical circuit can already take advantage of forward error correcting codes (FEC) like the one defined in the ITU-T G.975 standard.[1] FECs allow to design systems at a lower optical signal-to-noise ratio (OSNR) and hence either to increase the performance (e.g.: propagation distance or number of wavelengths) or to use cheaper components. Hence, to be competitive, optical packets will also require FEC. However, because of their short duration optical packets may require a dedicated FEC. We will only consider fixed-duration (or time-slotted) optical packets which are best suited to avoid high logical packet loss rate due to packet contention in optical switching matrices.[2] In the following, we will first present the constraints for the choice of an FEC for optical packet. We then consider the main classes of FEC and we will show that Reed-Solomon FEC are among the best suited for optical packets. We finally show how to choose the correct parameters of the Reed-Solomon FEC. Among the conclusions, we show that the standard RS(255, 239) according to G.975 is not convenient for short optical packets.

2. Constraints of FEC for optical packets

In order to avoid resource under-utilization, optical packets have to be short. Otherwise most of the packets would have to be conveyed partially empty after the time-out has been reached. We will consider in the following around N_b = 12000 bits long optical packet, i.e., around 1.2 µs at 10 Gbit/s. This yields a first constraint: the FEC frame length should be around N_b excluding redundancy bits.

A second important constraint comes from the processing speed of a FEC, which is limited to below 1 GHz. We have therefore considered that n_{DMUX} = 16 FEC encoders/decoders work in parallel as in current FEC coders/decoders. Hence, the packet length should be equal to a multiple of the minimum packet length, i.e., a multiple of 16 times the individual FEC frame. Moreover, the complexity of the encoding and decoding algorithms should be sufficiently low to be implemented at high bit-rates and with low processing latency.

Physical (optical and electrical) impairments give a third constraint on the overhead (redundancy added by the FEC). We will assume the overhead to be less than OH_{max} = 15%.

The fourth constraint comes from the coding gain which should be as high as possible. The coding gain is the ratio of the OSNR required without FEC to get a given bit error rate (BER) to the OSNR required to get the same BER with FEC. However, the relevant parameter for optical packets is not the BER but the packet loss rate (PLR). Hence, the coding gain G will be expressed for given PLRs (10^{-6} and 10^{-12}). If one assumes that a packet is lost as soon as one bit of the information it carries is erroneous, then PLR = $1-(1-\mathrm{BER})^{N_b}$. For low BER, PLR ≈ N_b.BER. Note that for a proper design of an optical packet system, the PLR due to BER degradation should of the same order of magnitude as the PLR due to packet contention if one wants to avoid over-dimensioning of some resources.

A fifth constraint is often added. The FEC should be able to correct burst of errors. This features is interesting when a part of a FEC frame is degraded while the remaining part is transmitted error-free. Hence, the error-free part of the FEC frame is used to correct the degraded part. However, with FECs used for optical circuit transmissions, the maximum number of consecutive errors is around a few hundreds or even a few thousands, which corresponds to around 0.1 µs at 10 Gbit/s. Since there is no optical phenomenon at this time scale (polarization-mode dispersion time scales range from a few ms to a few days[3]), the ability for burst error correction is not critical. In the case of optical packets, we will consider that either the whole packet is degraded or not (depending for instance on the path).

3. The different classes of FEC

3.1 Bloc codes

Bloc codes seem interesting for optical packets since they already look like fixed-length packets. Only linear block codes are considered if one wants to reduce the complexity of the coding/decoding algorithms. Two kinds of block codes can be distinguished: binary and m-ary FEC.

Among the binary block codes, Hadamard codes have a very long overhead and are not suited for optics. Hamming codes are able to correct one error in a frame with a small overhead but the coding gain is rather low as we will see in the following (Figure 1).

The most famous m-ary codes are Reed-Solomon (RS) codes. They are characterized by m, the number of bits per symbol and by t, their error correcting capability, i.e. the number of symbols that can be corrected among the frame which length is $2^m - 1$ symbols, i.e., m.($2^m - 1$) bits. RS codes are noted RS(n = $2^m - 1$, k = $2^m - 1 - 2t$) where n and k stand for the frame length and the information data length expressed in number of symbols. They are interesting for optical transmission because they have a high coding gain, relatively low decoding complexity and an optimum overhead for a given error correcting capability. Indeed, one of them has been standardized for optical transmissions.[1] In section 4, we will analyze the optimum choice of the parameters for optical packets.

3.2 Convolutional codes

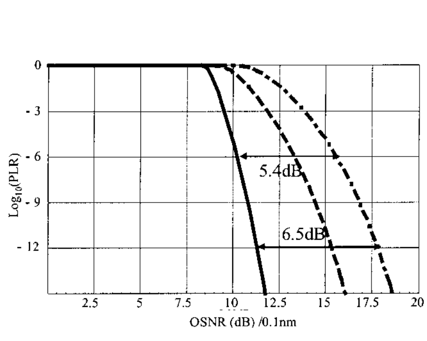
The overhead of convolutional such codes is too high for high bit-rates transmissions. A technique, called puncturing, allows to reduce the redundancy but the coding gain decreases significantly.

3.3 Turbo codes

Although Turbo codes have a high coding gain, they require soft decision samples (a quantification of the bits instead of a hard decision "0" or "1") which is not available now in optics. Turbo decoding algorithms are very complex and their implementation is a hard task for high bit rates.

3.4 Conclusion

Hence, Reed-Solomon codes are the best candidate for optical packet FEC. The aim of the next



WO5 Fig. 1. PLR versus OSNR within 0.1 m for an NRZ signal at 10 Gbit/s with RS(127, 111) (solid line), Hamming (511, 501) (dashed) and without FEC (dotted-dashed).