A Novel Optical Encoding Scheme for Network Node Tracing in All-Optical Reconfigurable Wavelength Routing Networks

Kam-Hon Tse and Chun-Kit Chan
Department of Information Engineering, The Chinese University of Hong Kong,
Shatin, N.T., Hong Kong SAR, China, tkh008@ie.cuhk.edu.hk

Abstract *An optical prime-number-encoded tag is employed as distinct network node identifier so as to realize network node tracing in reconfigurable wavelength routing networks, via prime number multiplication. Possible network looping problem can also be identified.*

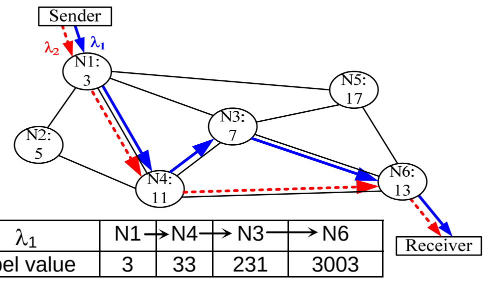
Introduction

In an all-optical reconfigurable wavelength routing network, the lightpath of the optical data packets can be reconfigured, via the optical cross connects (OXC) residing at each network node. To facilitate the network management, network node tracing is desirable to identify the exact network nodes that the optical data packets have traversed and thus the complete lightpath can be estimated at the receiving node. Such information is indispensable to detect any possible network routing error and diagnose the possible causes of signal quality degradation in the received optical data packets.

Recently, schemes based on pilot-tones[1,2] and time-delay recognition[3-4] have been proposed to monitor the connections within an OXC. However, they suffer from slow monitoring and poor scalability, respectively. Another electronic-CDMA-based scheme[5] was also proposed to encode the path trace labels. In this paper, we propose to assign a distinct prime number as the identification tag for each network node and employ optical encoders based on prime number multiplication at the OXCs to achieve network node tracing. The traversed network nodes of each received optical data packet can be easily identified by simple computation at the receiving node. The scheme shows substantial reduction in the requirement of fiber delay lines, as compared to the time-delay recognition technique. Besides, possible network loop problem can also be detected.

Network Node Tracing using Prime-number Tags

Figure 1 shows an example of wavelength routing network with six network nodes. Each network node comprises an OXC and is assigned with a distinct prime number (starting from 3), as the node identification tag. Each optical data packet comprises a data payload and a label. Its label starts with a value of 1 and will be multiplied by the tag values of all the network nodes that it has traversed along its whole lightpath. At the receiving node, the label of the received optical data packet will be extracted and detected for computation of all factors in prime numbers. The retrieved factors imply the exact network nodes that the optical data packet has traversed. In particular, if the same prime-number factor appears more than once, it means that that respective network node has been traversed more than once and thus network looping may have occurred. Figure 1 illustrates two optical data packets on wavelengths λ_1 and λ_2, as examples, and they travel from node N1 to N6, via different lightpaths. For the optical data packet carried on λ_1, its label starts at a value of 1 and is multiplied by 3, 11, 7 and 13, as it



λ_1	N1 →	N4 →	N3 →	N6
Label value	3	33	231	3003

λ_2	N1 →	N4 →	N6
Label value	3	33	429

Fig. 1: An example wavelength routing network to illustrate the network node tracing scheme using the proposed prime-number tags. Node notation: *N<node number>:<tag>*.

traverses N1, N4, N3 and N6, respectively. The final label value at the output of N6 is 3003. As a result, the receiver can identify the traversed network nodes by computing all prime-number factors in the received label value. Similarly, the optical data packet carried on λ_2 traverses N1, N4 and N6, respectively, and the final label value at the output of N6 is 429.

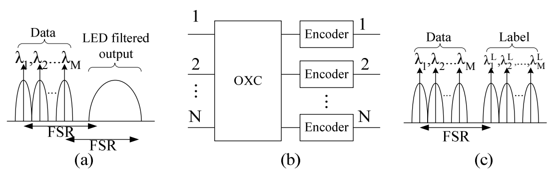


Fig. 2: (a) Input signal spectra at ingress node input. (b) Structure of a network node with an encoder on each OXC output port. (c) Output signal spectra at output port of OXC.

For optical implementation, one feasible approach is to employ a broadband light source, such as light-emitting-diode (LED), whose filtered spectral range is about one free-spectral range (FSR) of the OXC away from the data wavelengths ($\lambda_1,\ldots,\lambda_M$), as shown in Fig. 2(a), at the ingress node. The optical carriers for the labels ($\lambda_i^L=\lambda_i$+FSR; for $i=1,\ldots,M$) of their respective data wavelengths are generated via spectral slicing at the OXC, as in Fig. 2(c). With the cyclic spectral property of the OXC, the label wavelengths can pass through the same transmission passband of the OXC with the respective data wavelengths. At the input of the ingress node, the LED is modulated with a single optical pulse when the data wavelengths start carrying the optical data packets. Thus, each label wavelength starts with a single optical pulse (i.e. label=1). At each output port of the OXC, the switched data wavelengths and their corresponding encoded labels from different inputs are fed into an optical encoder to perform multiplication of its assigned prime-number tag to the incoming label, and its structure and principle are illustrated in Fig. 3. The

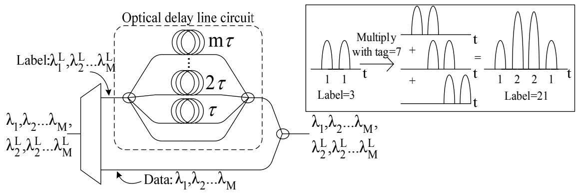


Fig. 3: Structure of the optical encoder for prime-number multiplication. Inset shows an example of multiplying tag "7" to the input label "3".

data wavelengths and the label wavelengths of the incoming composite signal are first separated such that the label wavelengths are fed into an optical delay line circuit for multiplication of the label values and the prime-number tag of the OXC. The optical delay line circuit comprises an optical power splitter, an array of fiber delay lines, followed by an optical power combiner. By setting appropriate number of fiber delay lines, it can generate an impulse response which represents a particular binary number. Thus the output pulses obtained correspond to the product of the input label value and the tag value. For instance, as shown in the inset of Fig. 3, when an incoming label with a value of 3 (i.e. two optical pulses) is fed into the optical delay circuit with fiber delays of 0, τ, 2τ, which represents a tag value of 7, the output will have four pulses with relative amplitudes 1, 2, 2, 1, respectively. By substituting these relative amplitudes as the coefficients of the polynomial expression, $1\times y^3+2\times y^2+2\times y^1+1\times y^0$ with y=2, a decimal number of 21 is obtained and this correspond to the product of the input label value (3) and the tag value (7). Table 1 shows outputs of the optical encoder for different input label values. Fig. 4 shows the simulated signal intensity at encoder output when the label passes through three consecutive OXCs with respective tag values of (a) 3; (b) 5; and (c) 7.

Table 1: Examples of label multiplication at optical encoder

Input label	Tag	Output label
3 (2-bit)	5 (3-bit)	1,1,1,1=15 (4-bit)
3 (2-bit)	7 (3-bit)	1,2,2,1=21 (4-bit)
5 (3-bit)	7 (3-bit)	1,1,2,1,1=35 (5-bit)
15 (4-bit)	7 (3-bit)	1,2,3,3,2,1=105 (6-bit)
15 (4-bit)	11 (4-bit)	1,1,2,3,2,2,1=165 (7-bit)

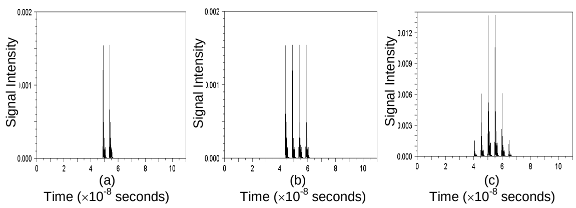


Fig. 4: Simulated signal intensity at encoder output when the label passes through three consecutive OXCs with respective tag values of (a) 3; (b) 5; and (c) 7.

At the receiving node, the label wavelength of the received optical data packet is extracted and detected. By examining the detected label pulses, the label value is determined. Through prime-number factorization of the label value, the traversed network nodes by the received optical data packet can be identified. Hence, network node tracing is achieved. The total number of network nodes the optical data packet has traversed is equal to the number of distinct prime number factors obtained. Possible network looping problem can also be detected when a particular prime-number factor occurred more than once. Based on the obtained network node trace at the receiving network node, the actual lightpath can be estimated, although it is possible that more than one lightpaths may involve the same set of network nodes.

Scalability of the Proposed Encoding Scheme

Recently, different time-delay recognition schemes[3-4] have been proposed to identify the state of input-output connections in OXCs. They can also be applied to realize network node tracing. It can be achieved by setting the sequence of 2^{k-1} fiber delays at the k^{th} OXC. Therefore, given a maximum fiber delay of D at each OXC, it supports up to $[\log_2(D)+1]$ OXCs in an optical network. However, in our proposed scheme, by considering the occurrence of the prime numbers and their binary representation at the optical encoder, it is found that it supports up to $2^D/\ln(2^D)$ OXCs in an optical network. Fig. 5 shows the scalability comparison. It is shown that our proposed encoding scheme requires far less maximum fiber delay than the previously proposed different time-delay recognition method[3-4].

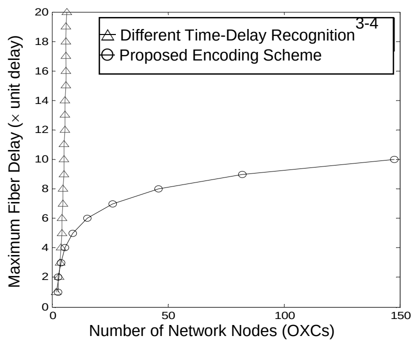


Fig. 5: Maximum fiber delay required at each node for different time-delay recognition schemes[3-4] and our proposed encoding scheme under different number of OXCs in the optical network

Summary

We have proposed a novel optical label encoding scheme for network node tracing in a reconfigurable wavelength routing network. Prime-number tags are assigned to the OXCs and network node tracing is achieved via the optical encoders at each OXC for multiplication of the input label values and the OXC tags. The proposed scheme has also showed significant scalability improvement in terms of maximum fiber delay as compared with the previously proposed different time-delay recognition schemes.

References

1. E. Kong et al., IEE Electron. Lett., Vol. 35, pp.1481-1483 (1999).
2. S. Zhong et al., IEEE PTL, Vol. 12, No. 9, pp.1249-1251 (2000).
3. C. C. Lee et al., IEEE PTL, Vol. 17, No. 12, pp. 2745-2747 (2005).
4. J. Yu et al., COIN-NGNCON, Paper PS-13 (2006).
5. V. Vaishampayan et al., IEEE Trans. Comm., Vol. 53, No. 10, pp.1729-1737 (2005).

978-3-8007-3173-2 © VDE VERLAG GMBH