NOVEL OPTICAL TECHNIQUES FOR LIGHTPATH TRACING AND MONITORING IN ALL-OPTICAL RECONFIGURABLE WAVELENGTH ROUTING NETWORKS

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Abstract

A lightpath tracing scheme based on prime-number-encoded tags is proposed for all-optical reconfigurable wavelength routing networks. All traversed network nodes along the lightpath of a received optical packet can be identified at the destination node.

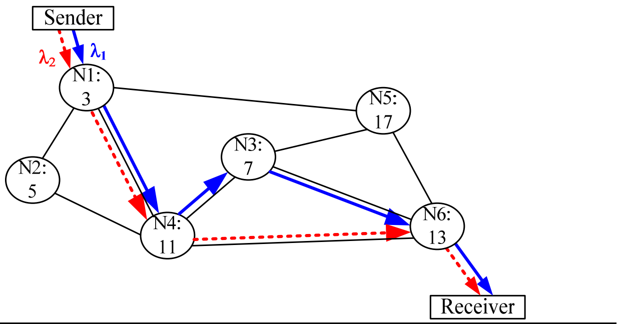
1 Introduction

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, lightpath 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 [3-5] have been proposed to monitor the connections within an OXC. However, they suffered from slow monitoring and poor scalability, respectively. Another electronic-CDMA-based scheme [6] was also proposed to encode the path trace labels. However, it could only be applied to the optical network in which the routing path of each optical data packet has already been determined at ingress node. 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.

2 Network Node Tracing Scheme

Fig. 1 shows an example of a wavelength routing network with six network nodes. Each network node comprises an OXC and is assigned with a distinct prime number (starting from the value of 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 individual network nodes that it has traversed along its whole lightpath, via an optical encoder residing at each output port of the OXC. Note that the optical encoders on all output ports of the same OXC are identical, as they are performing the prime number multiplication with the same tag value. At the receiving node, the label of the received optical data packet is extracted and detected and its contained value is decoded for further prime-number factorization. The retrieved prime-number factors imply the exact network nodes that the optical data packet has traversed. Fig. 1 illustrates two optical data packets on wavelengths λ_1 and λ_2, as examples, and they travel from node N1 to node N6, via different lightpaths. For the optical data packet carried on λ_1, its label, with an initial value of 1, is multiplied by 3, 11, 7 and 13, as it traverses N1, N4, N3 and N6, respectively. The final label value at the output of N6 is 3003. The receiver then computes the prime-number factors (i.e. 3, 7, 11, 13) from the received label value of 3003, thus identifies the traversed network nodes as N1, N3, N4 and N6. Furthermore, the scheme is capable of detecting any network looping problem, whenever the same prime-number factor appears more than



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>*.

once in the result of prime-number factorization of the received label value at the receiving node.

3 Optical Implementation

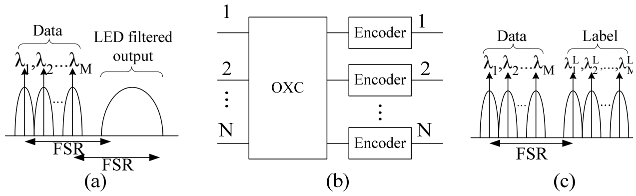


Fig. 2: (a) Input signal spectra at ingress node input. (b) Structure of a network node with an encoder on each OXC output port. (c) Output signal spectra at output port of OXC.

One feasible optical implementation 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.

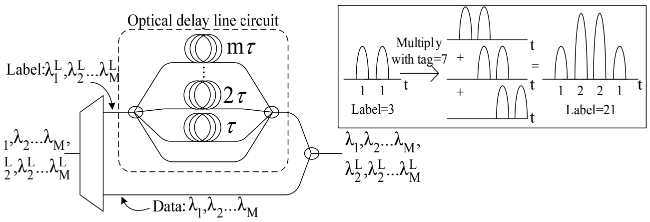


Fig. 2: Structure of the optical encoder for prime number multiplication. Inset shows an example of multiplying tag “7” to the input label “3”.

The 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, as examples.

Table 1: Examples of label multiplication at optical encoder

Input label value	Tag value (Impulse response)	Output label value
1,1=**3** (2-bit)	1,0,1=**5** (3-bit)	1,1,1,1=**15** (4-bit)
1,1=**3** (2-bit)	1,1,1=**7** (3-bit)	1,2,2,1=**21** (4-bit)
1,0,1=**5** (3-bit)	1,1,1=**7** (3-bit)	1,1,2,1,1=**35** (5-bit)
1,1,1,1=**15** (4-bit)	1,1,1=**7** (3-bit)	1,2,3,3,2,1=**105** (6-bit)

4 Summary

We have proposed the use of prime-number tag as a distinct identifier to label each network node so as to realize lightpath tracing in a reconfigurable wavelength routing network. The proposed optical label encoder for prime-number multiplication is an all-optical and passive device, which supports simultaneous multi-wavelength and bi-directional operations, and has good network scalability The proposed scheme can offer useful information to detect any possible network routing error, and diagnose the possible causes of signal quality degradation in the received optical data packets, hence, greatly facilitates the network management of an all-optical reconfigurable network.

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