Linear Random Code-based Label Encoding Scheme for Label Swapping Free OLS Networks

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Abstract: This paper presents a Linear Random Code (LRC)-based label encoding scheme for label swapping free Optical Label Switching (OLS) networks. Simulation results show that a 8-byte label is long enough for networks within 300 nodes.
OCIS codes: (060.4510) Optical communications; (060.4250) Networks

1. Introduction

Using label switching paradigm makes MPLS a successful design to enable networks with high-speed packet forwarding and flexible traffic engineering capability. OLS follows the same idea to apply label switching in the optical domain. However, due to the lack of optical random access memory, using fiber delay lines to provide constant delay time for OLS switches is the most practical approach. Thus, adopting short and fixed sized labels is especially important to simplify the implementation of OLS networks.

Several OLS testbeds using various header/payload multiplexing schemes have been implemented. In our OPSINET testbed [1], we use a superimposed ASK-based modulation to multiplex the 10Gbps payload and the 125Mbps label. Two AM modulators are needed in the OPSINET OLS switch, one is used to erase old labels and the other is used to add new labels. Other techniques include multiplexing ASK payloads with different modulation formats including subcarrier labels [2], DPSK labels [3], and FSK labels [4]. Alternately, the label modulation format can be ASK superimposed [5] and PolSK [6] on a DPSK modulated payload. Although those techniques show header and payload multiplexing and label swapping can be achieved in OLS systems, they are still quite expensive. Label swapping also imposes some power penalty and raises synchronization issues.

The Key Identification Scheme (KIS) [7] is proposed to use fixed labels in OLS networks without label swapping. Each KIS switch is assigned a unique key value. Those keys have to be pair-wise relatively prime for any two switches. Given a routing path, a source node applies Chinese Remainder Theorem to decide a label for a packet. As a packet is received by a switch, its label is divided by the key and the remainder is the output port ID of the packet.

Besides label swapping free and simple operation on decoding, KIS reduces the synchronization pressure for the OLS networks. However, the label size obtained from KIS strongly depends on the routing path. By analyzing the Chinese Remainder Theorem, one could realize that the length of a label is proportional to the multiplication of the key values of those nodes along the path. Since the keys have to be maintained mutually prime between any two switches, it makes the length of the label grow exponentially as the network size becomes large.

Applying Optical Code Division Multiplexing (OCDM) for encoding packet headers is another scheme to implement label swapping free networks. In [8], a switch can decode the OCDM label using optical correlator. The benefit of this scheme is its possibility of implementing in the optical domain. However, the length of an encoded label is very long. As shown in [8], for a network with 30 nodes, the label encoded by Quadratic Congruence Code and Extended Quadratic Congruence Code requires 961 and 1891 bits, respectively. Such a large packet header results in poor network utilization.

To decrease the label length, we propose a Linear Random Code-based (LRC) label encoding scheme. In the system, each node is assigned a k-bit vector that is called key hereafter. A k-bit label is attached to a packet. As a node receives a packet, its label and key are XORed to determine the output port. The benefit of our scheme is presented in three parts. First, the label size is small. As the network size increases, the label size of using LRC encoding grows linearly unlike the label size of using KIS and OCDM grows exponentially. Second, label decoding is easy. Only XOR operations are used in our system. The XOR operation can be implemented by a very small number of XOR gates. It is even easier to be implemented than the long integer division required in the KIS scheme. Third, the label size is fixed. Just like MPLS networks, each packet in our system owns a fixed sized label. It enables OLS to handle headers in a more cost effective way.

2. Label Encoding Using Linear Random Code

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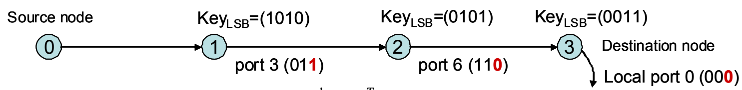
The proposed LRC scheme is inspired by the theory of Fountain Code [9]. In linear fountain coding, the n-bit codeword y is obtained by multiplying the k-bit message x with a randomly generated matrix G, e.g., $y=Gx$. After transmission through an erasure channel, the received information y' is only part of y. This process can be considered as $y'=G'x$, where G' is obtained from G by eliminating the rows corresponding to the missing bits of y. The original x can be recovered if G' contains an invertible k by k matrix. For a randomly generated G, the probability of G' containing invertible k by k matrix increases dramatically as n increasing.

The concept is used in designing our labels. However, the given vector is y in stead of x in the erasure coding. To simplify the notations, only the label to compute the LSB of the port ID is explained in the following expressions. By applying the same technique, the other bits for the output port ID can be determined.

Consider a network having n switches, we randomly assign node i a row vector g_i, which is the key of node i. The stacking of all row vector g_i ($i=0,\ldots,n-1$) forms the G matrix. We use vector y_p to denote routing path p. Each entry in y_p represents the LSB of port ID for the nodes in path p.. Without loss of generality, we assume path p starts from node 0, and goes through node 1, node 2, …, until it reaches destination node d. Since the packet will be terminated at node d, nodes outside the path won't receive it. Thus, we don't need to care the value for the entry larger than d in y_p. In other words, we can eliminate rows indexing larger than d in the G matrix and entries larger than d of vector y to obtain G' and y' just like the fountain coding. If there exists a solution x_p such that $G'x_p=y_p'$, x_p is the label for path p.

To assign a key to each node, the network operator has to determine all the paths used in the network first. Please note that each source-destination pair needs to be assigned more than one path for the purposes of traffic engineering and enhancing network survivability. After assigning a random key to each node, we examine if every desired path can find a label for it. If it is not, new random keys are generated for the nodes of the path and the new label is checked again. The process repeats until each path has its label. As we cannot find a label after trying many G matrix, the label and the key size is increased by 1 to raise the probability of finding a feasible solution.

Figure 1 depicts an example. In this example the routing path include 3 hops. Since the ingress node, Node 0, knows its output port as well, we don't need to include node 0 in the key matrix G'. In this example, key for node 1, 2, 3 is {1010}, {0101}, and {0011}, respectively. By applying the label x={0111}, the LSB for output port of the routing path for node 1, 2, 3 are 1,0,0, respectively.



$$G'_{LSB} \cdot x_{LSB}^T = y_{LSB}$$

$$\begin{bmatrix} 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 1 \end{bmatrix} \begin{bmatrix} 0 \\ 1 \\ 1 \\ 1 \end{bmatrix} = \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$$

Fig. 1. An example for the LRC-based scheme

3. Simulation Results

We have carried out simulations to study the performance of the LRC and the KIS schemes for worst case label size. In the simulations, we apply the K-shortest path algorithm on randomly generated network topologies to obtain the set of required routing paths. Each edge consists of two opposite directional links and the link weight is set to 1 for the K-shortest path algorithm. Thus for K=1 case, a path with the minimum hop count is used for each communication pair. All node pairs are considered in the simulations. Therefore, for a network with N nodes, the total number of paths is KN^2. Since nodes in a transport network typically have no more than five immediate neighbors, we use three bits to represent the output port ID. ID 0 is specially used to indicate the local drop port which means that the switch is the destination node.

Fig. 2 shows the simulations results. We first observe the impact of the network size on the label size. The proposed LRC scheme outperforms KIS in all networks. As the network size increases, both schemes require longer labels. However, the KIS is very sensitive to the network size. For example, for networks with mean degree=3 and K=1, the bits required for 50-node and 300-node networks are 58 and 139, respectively and the gap between those two networks is 81 bits. On the contrary, the bits for 50-node and 300-node networks in LRC are 27 and 51, respectively. The gap of using LRC is 24 bits and this value is much smaller than the gap of using KIS.

In the second set of experiments, we study the label length under different number of paths for each communication pair. Observing Fig. 2 we could find that the label length is not very sensitive to different K values for both LRC and KIS. It indicates both schemes are scalable on the number of paths. In some topologies, the KIS label size of K=1 is shorter than that of K=3. It is because the worst case label length strongly depends on the node keys along the path. It would happen that some paths going through nodes with larger keys. In that case, the worst case label is quite large. For some communication pairs, there are more than one set of optimal K-shortest paths. Their label lengths might be quite different. For example, there exists another set of optimal paths for K=2 in 200-node topology. The label length is 128 bits. It is much larger than 99 bits shown in Fig. 2(b).

In the final set of experiments, we observe label lengths under network with different degrees. Since the number of nodes is fixed, the larger network degree, the denser the network is. The KIS scheme is very sensitive to the network degree. For example, for the network with 300 nodes and K=2 paths, the label length increases from 73 bits for degree 5 network to 134 bits for degree 3 network; however, the label is increased from 45 bits to 57 bits as encoded by LRC.

4. Conclusion

This paper presents an LRC-based label encoding scheme for label swapping free OLS networks. It enables cost reduction and maintains maximum SNR by eliminating expensive header/payload multiplexing and label erasing functions in OLS switch. Using the LRC scheme, switches use only simple XOR operations to decide packet routing. Compared to the KIS scheme, the LRC scheme is insensitive to network sizes and network degrees. It makes the network has better scalability. Simulation results reveal that the LRC scheme outperforms the KIS and OCDM scheme on the label sizes. In LRC, an 8-byte label is large enough for networks within 300 nodes.

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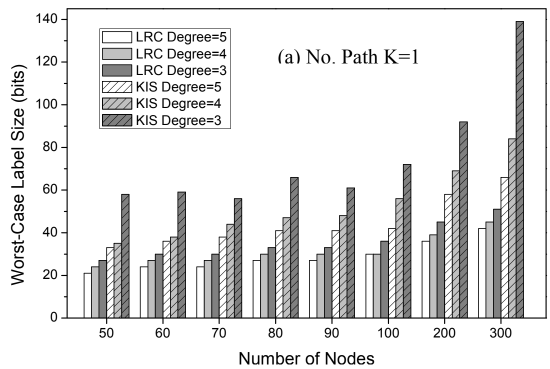

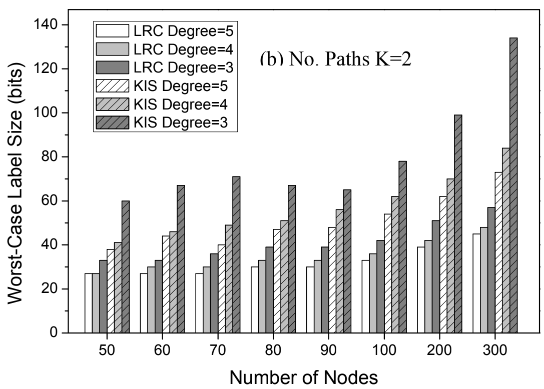

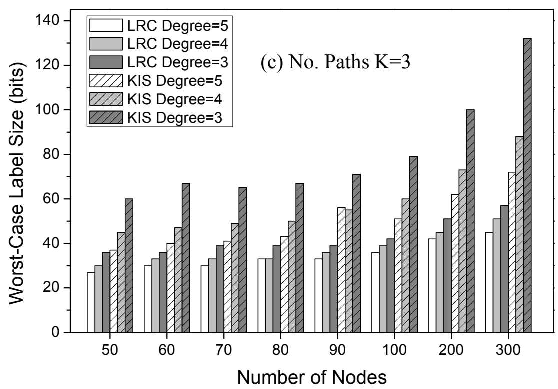

Fig. 2. Performance comparison on label length under different network topologies and paths