Cycle Attack-Free Logical Topology Design in Optical Code Path Networks

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Abstract *A tree-based logical topology design approach is proposed to resolves the unintended cycle attack problem in optical code path networks, demonstrating 50% of reduction in connection setup delay in large-scale networks.*

Introduction

The optical code (OC) path provides finer path granularity than the wavelength path in optical domain, leading to better wavelength utilization efficiency in wavelength-routed optical network [1]. In OC path networks, each data bit is encoded with a designated optical code, forming an OC path, and several optical code paths are multiplexed on a “single wavelength” based upon optical code division multiplexing (OCDM) technology. The optical code path is identified in the decoding process by performing optical correlation between the incoming encoded signal and the desires code. However, undesired optical code paths cause interference noise, so-called MAI noise in the decoding due to the cross-correlations, resulting in SNR degradation of the desired OC path. Therefore, the SNR of optical code path may deteriorate due to poorer optical correlation performance at following downstream nodes. Hence, if the MAI propagates among optical paths sharing the same wavelength which form a cycle, the MAI is accumulated after passing several nodes and eventually overwhelms the signals. This phenomenon has been termed as *cycle attack* [2].

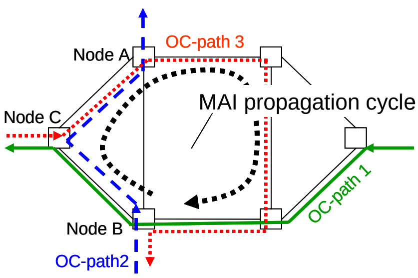

Fig. 1: Cycle attack by MAI propagation.

For example, suppose in Figure 1 that the input and output ports at every node are equipped with optical encoders and decoders, respectively, at Node A the MAI from OC path 2 is overlaid on OC path 3, and then the MAI is again overlaid onto OC paths 1 and 2 at Node B, and then the MAI is overlaid onto OC paths 2 and 3 at Node C. This MAI might go along the ring over again.

An effective heuristic wavelength assignment approach has been proposed to avoid this unintended cycle attack problem under dynamic traffic condition by centralized controlling [2]. However, this approach may experience long setup delay in distributed OC path establishment since which in turn leads to high blocking probability.

The main contribution of this paper is to propose a tree-based logical topology design approach to resolve the unintended cycle attack problem before the routing phase. Two main findings are obtained from the illustrative results: a) putting a high priority to the tree-based topologies with smaller average hops in the resource assignment phase is more effective to obtain better blocking performance; b) if the link delay is comparable to the connection request service duration, our proposed approach is more effectively to achieve better blocking and delay performance in the distributed OC path establishment.

Cycle attack-free logical topology design

The design principle to eliminate cycle attacks is to route OC paths in logical topologies without ring structures. Furthermore, since the MAI propagation phenomenon only occurs among the optical paths carried by the same wavelength, we propose a cycle attack free logical topology design approach using tree-based structures for each wavelength. Figure 2 illustrates that the logical topologies of each wavelength plane in our proposal are composed of a main tree and some sub trees. In the following explanations, how to create such trees along with the reasons and how to use them are given.

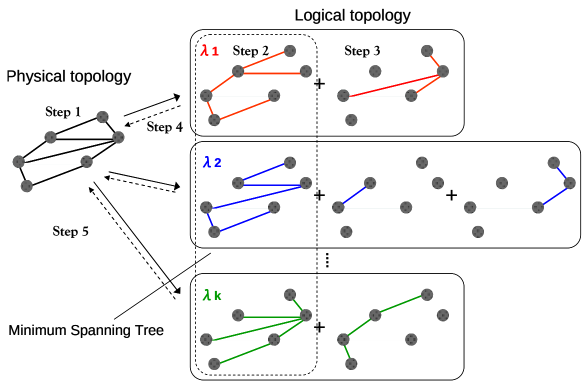

Fig. 2: Basic idea of our cycle attack-free approach.

Step1: Compute the weight of each link (the traffic matrix) based on the physical topology using shortest paths.

Step2: Create a minimum spanning tree by the Prim's algorithm [3] based upon the traffic weights in the above traffic matrix for each wavelength. A tree with minimum traffic weight is chosen.
Step3: Connect links which are not used in the minimum spanning tree to create sub trees.
Step4: Evaluate each tree's traffic capacity T_c and subtract it from the traffic matrix. T is given by:

$$T_c = \frac{E_l \cdot C}{\sum_{m=1}^{M} p_m \sum_{ij} \delta_{ij}}$$

Note that E_l and C are the number of links of a tree and the number of OCs per wavelength, respectively. p_m is the probability of m-th node pair and δ_{ij} indicates whether the OC path of m-th node pair passes through link i-j or not (1 if yes, otherwise 0).
Step5: Repeat Step2~4 for all left wavelengths.

Furthermore, we also propose three different tree selection schemes upon each connection request: *meanHop-FF (average hops of a tree)*, *tree-FF (tree sequence number)* and *Cost (total cost of the path)*. Since the tree-based topology degrades routing flexibility of original physical one, the selection of a tree is considered to have influence on network performance. In the simulation section, it can be it can be observed that the meanHop-FF performs the best.

Performance evaluation

We evaluate our proposal via computer simulations. A 6-node network and the NSFNET with bidirectional links are used. Each link has one fiber, eight wavelengths/fiber and five optical codes/wavelength, i.e. 40 OC paths per fiber. No wavelength conversion is allowed. Only link propagation delay is taken into account in distributed OC path establishment and the processing delay is excluded.

1) Evaluate tree selection schemes

Figure 3 shows the blocking probability using proposed algorithm with above three tree selection schemes. In this case, the link propagation delay is set to zero to make the tree selection effect evaluation more straightforward.
In our proposed approach, the meanHop-FF is observed to be best, because under this scheme, the trees with large average hops are avoided to be used which means a longer path is put lower priority in OC path establishment. The most interesting observation is that by using this scheme it can support connection request with larger hops more easily comparing to the tree-FF and the Cost schemes. Therefore, we can conclude that using small trees (smaller average hops) can be beneficial to achieving better blocking performance.

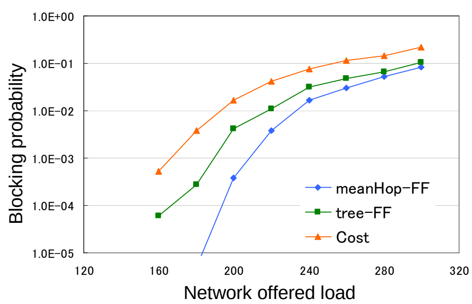

Fig. 3: Blocking probabilities with different wavelength assignment schemes.

2) Compare our proposal to the existing method

Figure 4 shows the connection setup delay and the blocking performance of NSFNET in which the link propagation delay is 7ms [4].
First, from the comparison of connection setup delay, it can be observed that nearly 50% of delay can be reduced even under high network offered load condition. This is because resource re-reservation is performed upon any detected cycle attack in the existing method and increases the delay overhead, but this does not happen in our proposal. Having said that the tree-based topology design degrades the routing flexibility, the reduction of connection setup delay overhead mitigates this disadvantage and contributes to provide better blocking performance by improving resource utilization efficiency.

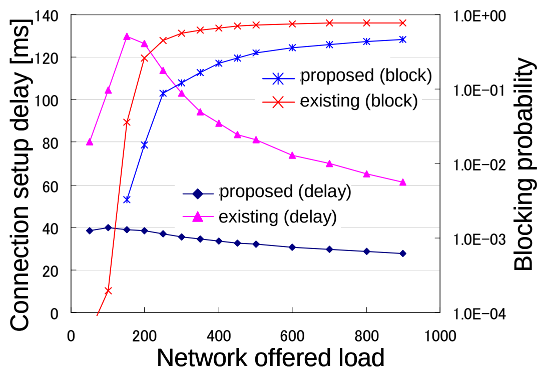

Fig. 4: Comparison between our proposal and the existing method.

Conclusions

An approach eliminating cycle attacks by tree-based logical topology design has been proposed. It has been shown to effectively reduce the connection setup delay in distributed OC path establishment.

Acknowledgement

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