Monitors Placement for All-Optical Networks with Linearly-Accumulated Impairments

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Abstract

The optimal placement and the number of monitoring modules that give the minimum number of monitoring hops for networks with linear accumulated impairment are investigated. Effects of overlapped paths on monitoring are studied.

I. INTRODUCTION

Optical performance monitoring (OPM) is essential to track the characteristics of lightpaths to provide various functions such as quality of service monitoring, lightpath setup, impairment compensation and network protection/restoration [1]. When optical signals traverse through all-optical network, impairments like noise and signal distortion accumulate as the signals propagate. Many promising OPM techniques have been proposed to monitor different kinds of impairments [2], such as OSNR [3], chromatic dispersion [4] and polarization mode dispersion [5]. With this performance information, quality of service of data channels can be estimated.

To minimize the operational expenditure (OPEX), monitoring should be performed on the available wavelengths of an optical link. Firstly, we assume that active probing signals can be generated by existing transmitters at optical network nodes, whereas only one or a few receivers or measurement equipment with high sensitivity can be installed as the monitor to enhance the monitoring performance. Therefore, all the nodes in the network are capable of sending out probing signals, whereas there are only a few nodes with a monitor installed. Secondly, we consider the linearly-accumulated impairments which can be derived from the information of impairments or their transforms, such as noise, chromatic dispersion and polarization mode dispersion [6]. With the above assumptions, we minimize the total number of hops that the probing channels need to traverse in order to reduce the usage of monitoring wavelengths and the probing time, thus minimizing the OPEX.

The paper is organized as follows. In Section II, the problem is formulated and optimized by minimum cost flow algorithms; in Section III, we discuss the overlapping of monitoring paths which may reduce the number of hops; and in Section IV, the optimal number of monitoring modules are evaluated based on simulation results.

II. NETWORK OPTIMIZATION

To monitor the impairment of a path p shown in Fig. 1, two probing signals from source node S to monitor M and from destination node D to monitor M are monitored, and the corresponding impairments are m_2 and m_1, respectively. Hence, the desired impairment of the path p is the subtraction of the two linearly-accumulated impairments, i.e. m_2-m_1.

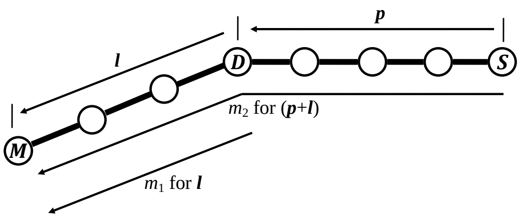

Fig. 1. Linearly-accumulated impairment

The numbers of hops in path l and path p are denoted by u_{p1} and u_{p2} respectively. It takes $(2u_{p1} + u_{p2})$ hops to monitor the path p. Hence, the total number of hops required for monitoring q paths can be shown below, where q is the number of paths to be monitored.

$$f = \sum_{p=1}^{q} 2u_{p1} + u_{p2}.$$

As u_{p2} is deterministic for a given path p, the minimization of the total number of hops is equivalent to

$$\min \sum_{p=1}^{q} u_{p1} \qquad (1)$$

Assuming that each path is probed independently, Eq. (1) is equivalent to finding the shortest distance between D and M for each path. To calculate this shortest distance, using Dijkstra's algorithm is one possible solution by setting the distance to be the number of hops. If multiple monitors are available, we can simply use the Dijkstra's algorithm to choose the closest monitor. We will discuss the case when each path is not probed independently in Section III.

The next step is to find the optimal positions for the installation of k monitors in an n-node network. Let U be the set of all the destination nodes of the q paths, and V be the set of all the nodes in the network. The problem of finding the optimal positions for the monitors can be formulated as a minimum cost flow problem:

$$\text{minimize} \sum_{i\in U, j\in V} a_{ij}x_{ij} \qquad (2)$$

$$\text{subject to} \sum_{j\in V} x_{ij} = 1,\ \forall i \in U,$$

$$\sum_{j\in W}\sum_{i\in U} x_{ij} = 0, W \subsetneq V, |W| \geq n-k,$$

$$x_{ij} \in \{0,1\}, \forall i \in U, \forall j \in V.$$

The shortest distance between node $i\in U$ and node $j\in V$ is denoted by a_{ij}, which can be evaluated by any all-pair shortest path algorithm such as Floyd-Warshall algorithm. W with at least n-k elements is a strict subset of V. $x_{ij} = 1$

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indicates that a path with destination i is monitored by a receiver installed at node j; $x_{ij} = 0$ indicates that either no monitor is installed at node j or the path with destination i is not monitored by a receiver installed at node j. The first constraint is that each path can only use one monitor and the second constraint is that the number of monitors is $\leq k$.

This problem can be solved by existing algorithms such as Ford-Fulkerson algorithm. A monitor should be installed at node j whenever the solution satisfies $\sum_{i \in U} x_{ij} > 0$. The minimum value of (2) is the optimal value of (1) when the paths are probed independently. The complexity of finding the optimal positions for k monitors is $O(q^2 n^3)$.

III. PATH OVERLAPPING

We now consider the case when several paths in q paths have overlapped as shown in Fig. 2, where sources and destinations are denoted by S and D respectively. There are t colored-paths, with b hops overlapped, to be monitored. The black paths are the shortest path from monitor M to other nodes. The number near the double arrows indicates number of hops in the path. Originally in the case of independent probing, the number of hops required to monitor these t paths is

$$f_1=(2u_{11}+a_1+b+c_1)+(2u_{21}+a_2+b+c_2)+\ldots+(2u_{t1}+a_t+b+c_t)$$

Whereas an alternative method by probing the overlapping part first, and then the branches individually gives

$$f_2=(b+2y_1)+y_2+(a_1+2u_{11}+c_1+y_2)+(a_2+2u_{21}+c_2+y_2)+\ldots+(a_t+2u_{t1}+c_t+y_2)$$

We define R to be the difference of these two methods as shown below.

$$R=f_2-f_1=2b+2y_1+(t+1)(y_2-b)$$

R is positive when t=2 or t=3 for $y_1+y_2>b$, which is true if the overlapping part is a shortest path. In this case, the original scheme is still optimal. However, when t>3, the result is not trivial and the alternative method outperforms the original scheme if R<0. Suppose that there are 10 paths overlapping in Fig. 2, the parameters are t=10; b=3; y_1=1 and y_2=2 , and the alternative method is found to be better as R=-3.

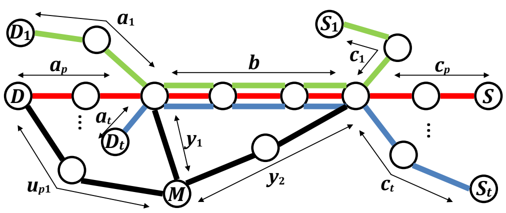

Fig. 2. Overlapping of monitoring paths

IV. SIMULATION RESULTES

Simulations have been carried out to evaluate the performance improvement by increasing the number of monitors when they are installed at the optimal positions. The NSFNET network is considered in the simulations.

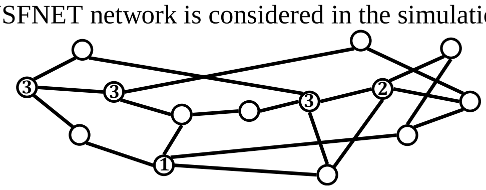

Fig. 3. The National Science Foundation (NSF) backbone network

There are 14 nodes and 20 edges in the NSFNET as shown in Fig. 3, in which q paths need to be monitored. In the simulations, q = 10, 20, 30, 40 paths are chosen randomly from the NSFNET. The number of monitors k varies from 1 to 5. For each value of k, 100 simulations are performed to obtain the average performance.

Simulation results show that the optimal position for single monitor is at the node with label "1"; the nodes with label "1" and "2" are the best positions for the installation of two monitors; and for three monitors, they should be at the nodes with label "3". When k>3, random placement of monitors achieves similar performance compared with the optimal approach.

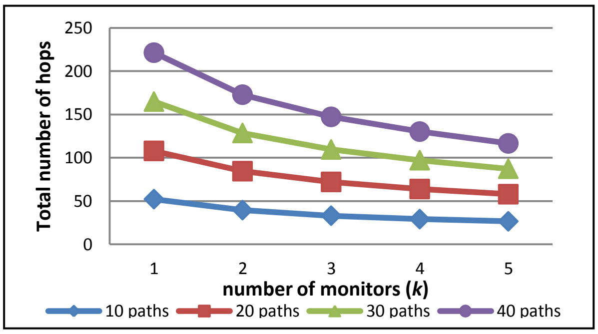

Fig. 4. The total number of hops vs. the number of monitors.

Fig. 4 shows that the total number of hops decreases when the number of monitors increases. Three monitors are desirable for NSFNET to balance the tradeoff between performance and the monitoring cost. The reduction of total number of hops by placing three monitors instead of one is around 34% to 36% for the four q values. From the simulations, with the alternative monitoring scheme in Section III, on average 14% reduction of the number of hops required for monitoring the overlapping paths can be achieved.

V. CONCLUSIONS

We have investigated and identified the optimal locations for monitoring modules that give the minimum number of hops for monitoring, thus reducing the OPEX. The desired number of monitors for NSFNET that balances cost and performance is three, which reduces the total number of hops by 34% compared to the single monitor case. We have also proposed an efficient method to reduce the number of monitoring hops for overlapping paths.

REFERENCES

[1] D. C. Kilper, et al, "Optical Performance Monitoring", J. of Lightw. Technol., Vol.22, No.1, Jan 2004.

[2] L. K. Chen, et al., "From optical performance monitoring to optical network management: research progress and challenges", ICOCN, Nov 2004.

[3] J. H. Lee, et al., "OSNR Monitoring Technique Using Polarization-Nulling Method", IEEE PTL, Vol.13, No.1, Jan 2001.

[4] Y. Ku, et al., "Chromatic dispersion monitoring technique using birefringent fiber loop", OFC/NFOEC, OFN2, Mar 2006.

[5] G. W. Lu, et al., "Simultaneous PMD and OSNR monitoring by enhanced RF spectral dip analysis assisted with a local large-DGD element", IEEE PTL, Vol.17, No.12, Dec 2005.

[6] Siu-Ting Ho, et al., "Monitoring of Linearly Accumulated Optical Impairments in All-Optical Networks", J. Opt. Commun. Netw., Vol.1, No.1, Jun 2009.