Optical Switching and Networking 18 (2015) 59–70

Contents lists available at ScienceDirect

Optical Switching and Networking

journal homepage: www.elsevier.com/locate/osn

Fast fault localization mechanism based on minimum dominating set clustering in WDM networks

Yu Xiong [a,b], Hong Zhang [a,*,1], Xue Fan [a], Ruyan Wang [a]

[a] Key Laboratory of Optical Fiber Communication, Chongqing University of Posts and Telecommunications, China
[b] School of Computer Science, Chongqing University, China

ARTICLE INFO

Article history:
Received 24 June 2014
Received in revised form
23 October 2014
Accepted 1 April 2015
Available online 9 April 2015

Keywords:
Cluster
Fault localization
Minimum dominating set
Optical network.

ABSTRACT

Several out-of-band mechanisms have been proposed as effective approaches for link fault localization in WDM networks, such as monitoring cycle, monitoring tree and monitoring trail. However, such technologies need extra resources, including dedicated supervisor lightpaths and monitors. On the contrary, an in-band mechanism called limited-perimeter vector matching fault localization protocol (LVM) is proposed to localize single link failure with low overhead using traffic lightpaths. Nevertheless, LVM leads to the high dependence of traffic lightpaths and the long fault localization time. In order to solve these issues, a fast fault localization mechanism based on Minimum Dominating Set Clustering (MDSC) is proposed in this paper. MDSC consists of two phases: the cluster allocation algorithm using minimum dominating set (CAM) and the fault localization algorithm based on clustering (FLC). According to CAM, the network is reasonably made up of a lot of clusters, and a sink node will then be selected. According to FLC, a failure can be effectively localized by a cluster headers or the sink node by collecting the status of traffic lightpaths. Theoretical analysis and simulation results demonstrate that the proposed mechanism can efficiently reduce the dependence on traffic lightpaths and optimize the speed of fault localization.

1. Introduction

With the development of Wavelength Division Multiplexing (WDM) technology in all-optical networks, optical fibers have gained tremendous importance due to their abilities to transmit a high-speed data stream. However, it makes the fiber links more prone to break down. Any link failure may result in large number of data losses, even in a short period of time [1–3]. Accordingly, it is essential to design an efficient and cost-effective fault localization mechanism in WDM networks.

Since a failure event at the optical layer may also cause alarms at the upper layers. Either upper layer protocols or optical layer schemes can work alone for fault monitoring, and they can also work together in a cross-layer manner. However, compared with an optical layer mechanism, an upper layer protocol needs a longer detection time [4,5]. Therefore, a localization mechanism in optical layer is required to achieve rapid and efficient failure localization.

In optical layer, the localization mechanisms can be divided into two categories: out-of-band mechanisms and in-band mechanisms [6,7]. The former localizes the link failure using the dedicated supervisory lightpaths, while the later only employs the existing lightpaths.

* Corresponding author. Tel.: +86 136 48347040; fax: +86 023 62461473.
E-mail addresses: xiongyuphd@gmail.com (Y. Xiong), zhanghong1987824@gmail.com (H. Zhang), fanxuebella@gmail.com (X. Fan), wangry@cqupt.edu.cn (R. Wang).
[1] Postal address: Chongqing University of Posts and Telecommunications, Nan'an District, Chongqing, P.R. China, Zip code: 400065.

http://dx.doi.org/10.1016/j.osn.2015.04.001
1573-4277/© 2015 Published by Elsevier B.V.

The out-of-band mechanisms have been extensively studied in the past years [8]. They employ different structures of supervisory lightpath for failure localization. Each supervisory lightpath is equipped with a dedicated monitor. The monitor, which can detect loss of light and issue alarms, is applied to monitoring the ON – OFF status of supervisory lightpaths. The reading of the monitor status serves as a single bit of an alarm code. And the “OFF” status indicates the failure of one link along the supervisory lightpath. The alarms are flooded in the control plane, and then an alarm code can be generated by collecting the alarm bits in the control plane to identify the failed link. The concept of monitoring cycle (m-cycle) is proposed in [9–11]. M-cycle computes a series of circular supervisory lightpaths. And each lightpath is equipped with a dedicated monitor. If one link fails, the supervisory lightpaths passing through it would be interrupted, and the monitors would generate an alarm code. Then, the failure can be localized by a pre-defined alarm code table. Although the m-cycle can localize the failure efficiently, it generally produces huge monitoring cost for a given network. The paper investigates monitoring-tree (m-tree) which further reduces the overhead of fault localization by decreasing the supervisory lightpaths consumption and the cost of transmitters in [12], but the optical network nodes require the capability of broadcasting in m-tree. Furthermore, the m-tree increases the number of monitors. To attain precise fault localization and cut down the overhead of localization, the monitoring-trail (m-trail) has been introduced [13], and many mechanisms have been introduced to accomplish the m-trail allocation by the Integer Linear Programming (ILP) and heuristics algorithms [14–16]. Different from the m-cycle, the m-trail consists of arbitrary paths. That means an m-trail possibly traverses nodes multi-times but a link at most once, so any failure along the m-trail can be sensed by on-trail nodes. The m-trail tries to find a tradeoff between supervisory lightpaths and optical monitors compared with the m-trees. Furthermore, among all the monitoring structures, m-trail is the most general and flexible one, and it is shown that m-trail achieves the best performance.

It is worth noting that a new Network-Wide Local Unambiguous Failure Localization (NWL-UFL) scenario is proposed for the m-trail application [17]. NWL-UFL scenario is aimed at completely removing the dependency on control plane signaling. All the nodes traversed by the m-trail can share the status of the m-trail by means of optical signal tapping. Then each node can localize the failure according to the locally available ON – OFF status of the m-trails traversing the node.

Although the out-of-band mechanisms can effectively track down the fault, the out-of-band mechanisms introduce large overhead in terms of the dedicated monitors and transponders, a large number of supervisory lightpaths, added channel interference and necessary maintenance. Opposite to the out-of-band mechanisms, the in-band mechanisms rely on traffic lightpaths to localize the failure. A novel approach has been proposed to minimize the number of traffic lightpaths to be monitored while still achieving efficient failure localization [18]. In [19], an optimal upgrade in the monitors is investigated if there is any change in the set of lightpaths. In [20], an efficient scheme for hierarchically distributed monitoring and fault localization is presented. The central and local fault managers can independently activate monitors in their monitoring domains when the set of new lightpaths is provisioned. In [21], it is proved that the monitor activation problem is NP-hard. Namely, computing the optimal set of monitors to be activated for a given set of provisioned lightpaths cannot be solved fast enough to be useful in dynamically provisioned networks.

In such technologies, the objective optimally deploys optical monitors in order to unambiguously localize each network failure. The mechanisms incur no bandwidth costs, the monitoring cost only accounts the number of required optical monitors. However, it is constrained by traffic lightpath changes and network routing policies. Furthermore, a complex fault management is required to decide the activated or deactivated status for monitors when the traffic lightpaths change.

Therefore, a novel in-band mechanism called limited-perimeter vector matching fault localization protocol (LVM) has been described in [22]. By exchanging the detected ON-OFF status of traffic lightpaths between the nodes, LVM protocol tactfully takes the advantage of the relevance between the traffic information to achieve unambiguous fault localization. The advantage of the protocol is that it skips any power monitoring and spectrum analysis at intermediate nodes on a lightpath without requirement of any supervisory lightpaths, so it can save a large number of monitoring resources.

Obviously, the performance of LVM is greatly influenced by traffic distribution. In [23,24], two integer linear programming (ILP) models have been formulated for minimizing fault localization time and maximizing fault localization rate. Meanwhile, a heuristic approach is proposed to reduce the ILP running time. However, LVM has the following two shortages:

- High traffic dependence: LVM can localize a link failure if there are at least two distinct lightpaths with different source-destination pairs passing through the failed link. Otherwise, LVM is unable to localize the failure [24].
- Long failure localization time: Exchanging the detected traffic information multi-times results in extremely slow fault localization speed.

In order to solve these issues, a novel fault localization mechanism based on Minimum Dominating Set Clustering (MDSC) is proposed in this paper for localizing single link failure. The MDSC mechanism contains two phrases—Cluster Allocation algorithm using Minimum dominating set (CAM) and Fault Localization algorithm based on Clustering (FLC). Firstly, the network can be conducted to a two-layer structure via CAM. The first layer consists of Cluster Header (CH) and Cluster Member (CM), and the other includes the CHs and a Sink Node (SN). In CAM algorithm, the nodes in minimum dominating set are set as CHs of the clusters. Let a node join a CH's cluster to be a CM If the node is adjacent to the CH. Then an appropriate