

Fault Detection and Localization Scheme for Multiple Failures in Optical Network

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Abstract. This paper proposes fault detection and localization scheme to handle multiple failures in the optical network using wavelength-division multiplexing (WDM) technology. This proposed scheme is two-phased scheme containing (a) the detection of faults through monitoring devices raising alarms (fault detection) and (b) subsequently the localization of these faults (fault localization) by invoking an algorithm. The later phase will obtain a set of potential faulty nodes (links). We demonstrate the performance of the scheme on 14-node NSFNet and 28-node EuroNet. We compare our scheme with an existing algorithm [1] for locating faulty nodes (links). Our scheme outperforms the existing one.

Keywords: Fault Detection, Fault localization, WDM, Optical Network.

1 Introduction

High capacity optical networks are immensely used in industries due to its large transmission bandwidth and low cost. But these networks are also vulnerable to failures like malfunctions of optical devices, fiber cuts, soft failures i.e., the impairment due to subtle changes in signal power such as degrading signal to noise ratio (SNR), etc. One of the most important requirements to ensure high speed optical network survivable is to manage fault detection, localization and recovery. In this work we discuss only fault detection and localization and the block diagram of our proposed scheme is shown in Figure 1.

Fault diagnosis and localization is a challenging problem and hence it is an active field of research. Different approaches were used to solve the problem. Approximation algorithms were shown in [2]-[3] to reduce the number of monitoring elements. In [4] author showed that the optimal monitor placement (reduction) is an NP hard

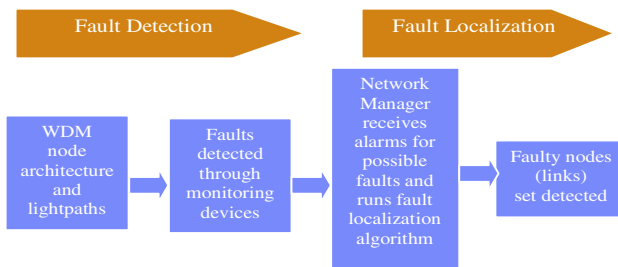
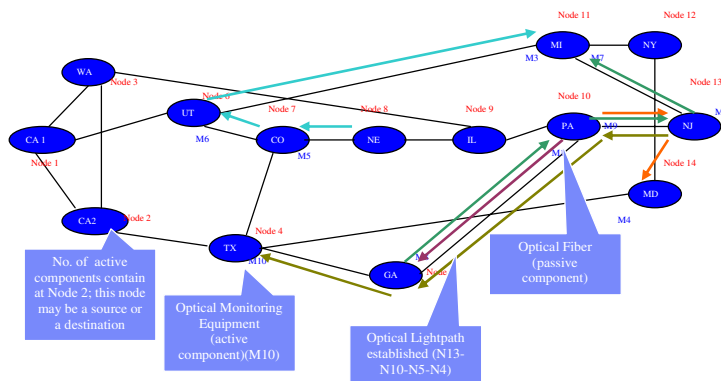


Fig. 1. Proposed fault detection and localization scheme

problem. Also in [1], [5] false and miss alarms are considered. In [5], authors showed that false alarms can be corrected in polynomial time but the correction of miss alarms is NP-hard.

We model the network by a directed graph $G = (V, E)$ where each node $v \in V$ of the graph represents an optical component, and the directed edge $(u, v) \in E$ represents a directed lightpath from u to v . We have taken 14-node NSFNet (shown in Fig 2) as our network model which is the backbone network for US. The Fig. 2 is self-explained.

**Fig. 2.** Reference NSFNet

2 Proposed Scheme

2.1 Fault Monitoring: Monitors Placement with Dynamic Lightpaths

Monitors initially are placed to all possible number of locations so that the failures can be detected and located for all components distinctly. In Fig. 2, M1 – M11 i.e., 11 monitoring devices are placed to achieve maximum coverage. We propose a greedy algorithm which determines the optimal number of monitors in such a way that failures can be located for all components (i.e., for node(s) or link(s)) distinctly and no component remains unattended i.e., if a fault occurs in a component it must not remain undetected. The algorithm is described detail in [3]. In Table 1 (generated from

Fig 2), ‘1’ denotes that if a node fails the monitor with ‘1’ triggers an alarm. The set of monitors which generate alarm on failure is called *Domain* of the faulty component(s). From Table 1 we can say that the set {M1, M2, M6, M8, M9} is the domain of ND5 (node 5). We have selected the optimal monitors using the algorithm [3] until domain patterns for all components are distinct. In the pre-computing stage, these domain patterns (see Table 2) are stored and used to locate the probable faulty components.

Table 1. Alarm matrix for reference network

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11
ND4	0	0	0	0	0	0	0	1	0	0	0
ND5	1	1	0	0	0	1	0	1	1	0	0
ND6	0	0	1	0	0	0	0	0	0	0	0
ND7	0	0	1	0	1	0	0	0	0	1	1
ND8	0	0	0	0	0	0	0	0	0	0	1
ND10	0	1	0	1	0	1	1	1	1	0	0
ND13	0	0	0	1	0	1	0	0	0	0	0

Table 2. Reduced Alarm matrix for reference network

	M8	M3	M6	M11	M1
ND4	1	0	0	0	0
ND5	1	0	1	0	1
ND6	0	1	0	0	0
ND7	0	1	0	1	0
ND8	0	0	0	1	0
ND10	1	0	1	0	0
ND13	0	0	1	0	0

2.2 Detecting Multiple Faults

When one or more monitors raise alarm, the network manager comes to know that probable faults occur in the network. This stage is called Fault Detection stage. So the function of this stage is to make the network manager alert about a possible failure in the network, so that he can run the fault localization algorithm (described later) to localize the faulty components.

2.3 Locating Multiple Faults

When there is any fault occurred in any component(s) some monitors which are in the domain of that component(s) will trigger alarms. But networks are frequently interrupted with corrupted alarms namely false and miss alarms. The fault localization algorithm (which also takes care for corrupted alarms) for multiple faults is described below. In this algorithm M is the set of all alarms, M_r is the set of all ringing alarms, M_s is the set of all silent alarms and C is the set of all components.

Algorithm for Locating Multiple faults

```

Set_of_multiple_fault(){
Initialize an empty set FC= $\emptyset$ 
Multiplefault( $M_r$ )
for ( i=1 to  $|M_r|$  ){
     $D_r = M_r \setminus M_r(i)$  where  $M_r(i) \in M_r$ 
    Multiplefault( $D_r$ ) }
for (i=1 to  $|M_s|$  ){
     $B_r = M_r \cup M_s(i)$  for  $M_s(i) \in M_s$ 
    Multiplefault( $B_r$ ) }
for (i=1 to  $|M_r|$  ){
     $G_r = M_r \setminus M_r(i)$  for  $M_r(i) \in M_r$ 
    for (k=1 to  $|M_s|$  ){
         $H_r = G_r \cup M_s(k)$  for  $M_s(k) \in M_s$ 
        Multiplefault ( $H_r$ ) }}
Output set FC;}
Multiplefault(set  $M_r$ ){
for (i=1 to  $|C|$  ){
    search for a component  $C_i \in C$  such that  $\text{Domain}(C_i) \subseteq M_r$ 
    incorporate  $C_i$  to S
     $FC = FC \cup \{C_i\}$  }}

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In our fault localization algorithm we have considered four cases i) No false alarm and no miss alarm ii) One false alarm and no miss alarm iii) No false alarm and one miss alarm iv) One false alarm and one miss alarm. We explain our algorithm using Table II. Let us consider at any time the *received alarm* (RAL) has been noticed {1 1 1 0 0} i.e., M3, M6, M8 have triggered alarms and M1, M11 remain silent. For case i) it is assumed that there are only correct alarms in the network. Now as $\text{Domain}(ND4) \subseteq M_r$, $\text{Domain}(ND6) \subseteq M_r$, $\text{Domain}(ND10) \subseteq M_r$, $\text{Domain}(ND13) \subseteq M_r$, {ND4, ND6, ND10, ND13} is included in faulty component (FC) (from Fault Localization algorithm). For case ii) we have made the all combination of received alarm pattern considering that there is one false alarm in the network. So, in the above mentioned received alarm pattern three more patterns are available. They are {(1 1 0 0 0), (1 0 1 0 0), (0 1 1 0 0)}. For case iii) where there is one miss alarm but no false alarm we have more combinations of received alarm pattern. They are {(1 1 1 1 0), (1 1 1 0 1)}. For case iv) where there are one false alarm and one miss alarm there are eight more possible combinations of received alarm pattern. They are {(0 1 1 1 0), (0 1 1 0 1), (1 0 1 1 0), (1 0 1 0 1), (1 1 0 1 0), (1 1 0 0 1)}.

3 Simulation Performance

We have implemented our scheme on 28 nodes EuroNet and the results are shown below. Fig. 3 shows that the cardinality of the set of possible faulty nodes in the case of single and double faults which is the output of fault localization algorithm. Fig. 4 and

Fig 5 show that the number of monitoring devices remains more or less same with the change of lighthpaths in three different situations namely a) during a single and double fault, b) after single and double fault and c) after addition of a new monitor (node) in the network.

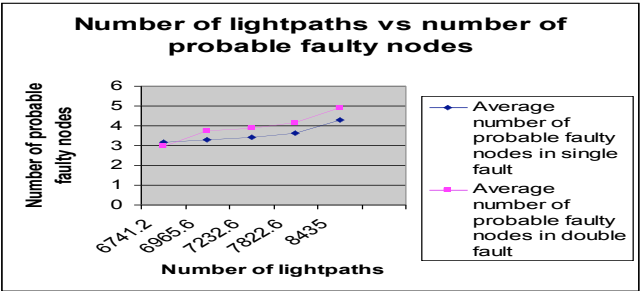


Fig. 3. Number of elements in faulty set vs. load

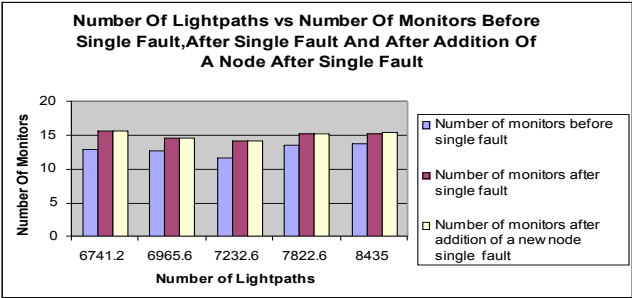


Fig. 4. Monitor number vs load before single fault, after single fault and after new node addition

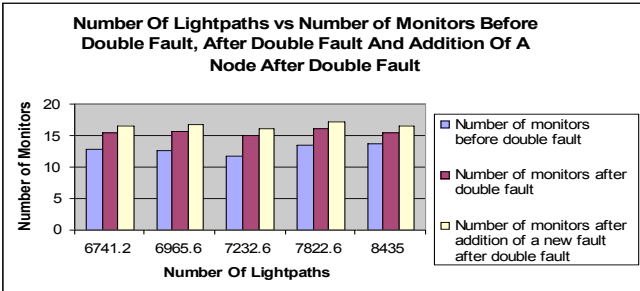


Fig. 5. Number of monitor vs load before double fault, after double fault and new node addition

4 Comparison Between Our Scheme and Algorithm Discussed in [1]

We have compared our scheme with the algorithm of [1] on the fault localization i.e., how the cardinality of the set of faulty nodes varies in both schemes (shown in Fig. 6 and Fig. 7). The cardinality set generated from [1] is higher in both cases. Therefore, our algorithm performs better in locating faults than existing one [1].

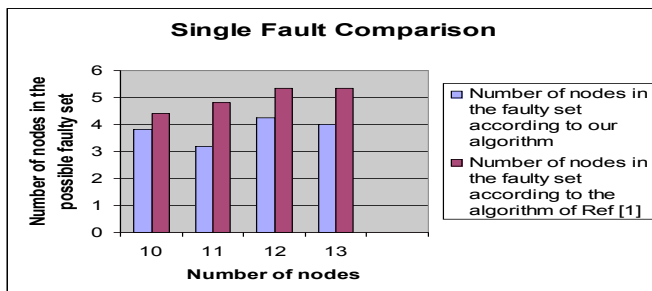


Fig. 6. Comparison of single fault

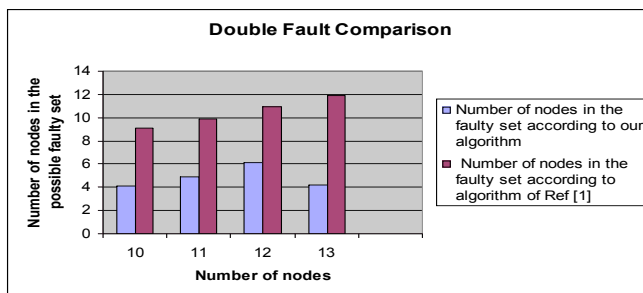


Fig. 7. Comparison of double faults

5 Conclusion

In this paper we have presented two-phased scheme containing (a) fault detection and (b) fault localization. We have shown the performance of our scheme on 28-node EuroNet and also compared fault localization scheme with an existing algorithm [1]. Clearly, it has been found that our algorithm outperforms the existing one.

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