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# Ant colony optimization based multi-faults localization mechanism in elastic optical networks

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ABSTRACT

In order to withstand and recovery from multi-faults in elastic optical networks, we propose a novel multi-fault localization mechanism based on ant colony optimization and mixed line-rates. Multi-faults localization has been proved to be a NP-complete problem in wavelength switched optical networks, and all existing multi-faults localization algorithms require time that is super polynomial in the input size. Furthermore, multi-faults localization in elastic optical networks gets new features that the affected high-bit-rate services will play a greater role than the affected low-bit-rate services. In order to handle the mixed line-rates, we introduce the dependency metric which is used to describe dependency between alarms and likely causes. We establish the linear programming model for multi-faults localization and propose an objective function while considering the mixed line-rates. We implement the ant colony optimization based multi-faults localization mechanism on the stateful PCE-based multi-domain elastic optical networks test bed. The numerical results show that ant colony optimization based multi-faults localization mechanism has low flooding time and alarm packets, high success rate compared with the existing localization algorithms. We choose the best configuration of ant colony optimization based multi-faults localization by adjusting the parameters.

## 1. Introduction

With the rapid growth of broadband services such as video-sharing, high definition video-on-demand and network computing, optical transport networks need to provide the ultra-high capacity to support the tremendous internet traffics [1]. The spectrum-sliced elastic optical path network (SLICE) which was based on orthogonal frequency division multiplexing (OFDM) technology was proposed to enables sub-wavelength, super wavelength, and multiple-ratedata traffics accommodation in a highly spectrum-efficient manner [2,3]. The center frequency and allocated bandwidth of an optical channel can be assigned arbitrarily in elastic optical networks. It provides the flexibility and ultra-high capacity to support the emerging broad band services, but it also brings many new challenges for network planners while maintaining a high level of survivability. Network survivability has been a concern of utmost importance in large-capacity and high-speed elastic optical networks [4].

Fault localization is a prerequisite for the protection and restoration mechanisms. Usually, centralized fault localization mechanisms provide a list of components whose faults explain the observed alarms. Such as [5], use pre-computation or sequential diagnosis to keep up with scalability. Distributed mechanisms rely on keep-alive or notification messages to locate the root of a fault. One of the most representative distributed-localization mechanisms is the link management protocol (LMP) [6], which is part of the GMPLS protocol suite. The LMP requires an always on supervisory channel ($\lambda_0$) to locate faults, which should not be in-fiber to avoid loss of the supervisory channel in the event of a link fault. Sichani and Mouftah presents a distributed fault localization protocol, called limited perimeter vector matching (LVM) protocol for localizing single link fault in all optical networks [7]. This protocol assumes that no power monitoring is available at each intermediate node and only destination node and gateway node are able to detect the power loss or quality degradation of an optical signal. Also parallel limited perimeter vector matching (P-LVM) protocol is proposed for localizing multi-link faults in all optical networks [7]. To handle multi-link faults, it tries to separate each fault in a small perimeter area after identifying each perimeter area with its

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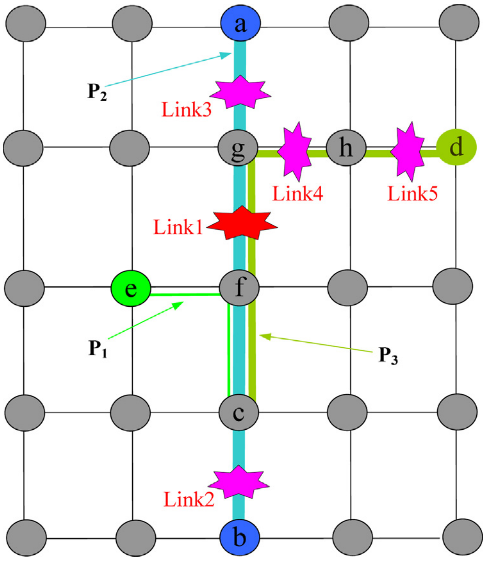

**Fig. 1.** Multi-faults and mixed line-rates in elastic optical networks.

corresponding fault and then localize the faults in parallel, respectively, in a distributed manner. In the paper [8], the author implement fuzzy fault set based multi-link faults localization mechanism in multi-domain large capacity optical networks. It has high scalability, speed and success rate compared with extended LVM protocol.

Ant colony optimization (ACO) has been applied to many combinatorial optimization problems. It can run continuously and adapt better to changes in real time [9]. We apply Ant colony optimization into multi-faults localization aiming at search the optimal fault set. The rest of the paper is organized as follows. Section 2 introduces the existing fault localization algorithms and analyses the used optimization strategies. Section 3 gives the detailed analysis of multi-faults localization in elastic optical networks. Section 4 applies ACO into multi-faults localization and gives the detailed description of the ant colony optimization based multi-faults localization algorithm (ACOMFL). Section 5 evaluates the performance of ACOMFL algorithm through numerical results. Finally, we conclude this paper in Section 4.

## 2. Multi-faults localization in elastic optical networks

In this paper, we focus on the fault model where multiple links fail in a random and concurrent order. We only consider the multi-domain elastic optical networks without signal monitoring at each intra-domain nodes and only gateway nodes, destination nodes are equipped with monitoring devices. Once such a link fails, a set of destination nodes connected to light-paths with mixed line-rates detect signal loss or high signal-to-noise ratio.

As presented in Fig. 1, the established light-paths with mixed line-rates in the network are $P_1$: $c \to f \to e$ (two subcarriers), $P_2$: $b \to c \to f \to g \to a$ (eight subcarriers), $P_3$: $b \to c \to f \to g \to h \to d$ (four subcarriers). Then the destination nodes *a*, *d* detect the signal loss but the destination node *e* does not detect any abnormal. So the occurred faults affect the light-paths: $P_2$, $P_3$. In the case of single link fault, we could diagnose $Link_1$ is the failed link without a doubt. But under multi-link faults, we cannot determine which link has a fault because there are several link combinations which can cause observed alarms, such as: $Link_3 \cup Link_4$, $Link_2 \cup Link_3$, $Link_3 \cup Link_4 \cup Link_5$, etc. Moreover, links located in light-path $P_2$ will be the most preferred option because $P_2$ is the light-path with largest line-rate. The affected light-path $P_2$ with high line-rate will be more likely to indicate the location of likely causes than other affected light-paths with low line-rate. In other words, we must consider the line-rate of each established light-path when we search the optimal fault set from all likely causes.

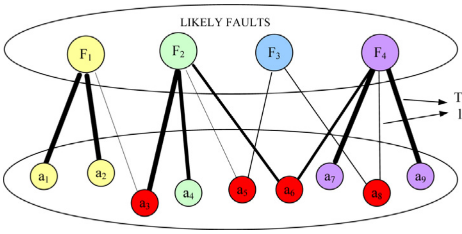

**Fig. 2.** The dependency between alarms and likely faults.

## 3. Key principle of multi-faults localization and Lp model

We use a bipartite graph to represent the dependency between possible observable symptoms (e.g., alarms) and corresponding likely causes (e.g., link fault) [10]. The bottom partition consists of all the received alarms and the top partition consists of the likely causes. An edge exists between an alarm and a likely cause if that alarm can be observed given the likely cause. The edge exists between an alarm and a likely cause in elastic optical networks has a dependency metric which reflects the line-rate of affected light-path. We use the notation *Bip_G* to represent the bipartite graph. Notation *F* represents the likely fault set and notation *A* represents the received alarm set. Notation *a* represents one received alarm, *Fault*(*a*) represents all the likely causes whose failures can cause the alarm *a*. Notation $F_a^i$ represents the *i*th fault in *Fault*(*a*) and the *line-rate*($a$, $F_a^i$) represents the line-rate of the affected light-path which passes through the fault $F_a^i$ and also causes the alarm *a*. Notation *NLP* represents the set of the normal light-paths and *n* represents one normal light-path in the *NLP*. *Normal* (*n*) represents the total normal elements in normal light-path *n*. The steps of proposed algorithm are given as follows.

```
Algorithm 1 Bip_G
Require: Bip_G to be set up
$F \leftarrow \Phi$
for $a \in A$do
        Find all likely fault: Fault(a) and record the dependency
        F = F∪Fault(a)
endfor
for $n \in NLP$do
        Find all normal element Normal (n)
                F = F/Normal (n)
endfor
for $a \in A$do
    Calculate the weight for each dependency based the line-rate
        weight(a,$F_a^i$) = line-rate(a,$F_a^i$)/max(line-rate)
endfor
Return A, F and the dependency metric
```

As presented in Fig. 2, the bipartite graph is composed by alarms, corresponding likely faults and the dependency metrics. The weight for dependency metric is calculated based on the line-rate of all affected light-paths. Considering the dependency metric on the edge between an alarm and a likely fault in elastic optical networks, the linear programming model of multi-faults localization in elastic optical network is as follows. The likely cause set is described by the faults set *F*, indexed by *i*. The observable alarm set is described by the alarms set *A*, indexed by *j*. The edge exists between an alarm and a likely cause is described by $e_{ij}$, and $w_{ij}$ represents the weight on this edge. The largest weight on edges incident to likely fault $F_i$ is described by $w_{i.}$ $A(t)$ represents total received alarms at the network management center in the *t* period of time. $A(F_i)$ represents