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Reliability threshold based service bandwidth recovery scheme for post-disaster telecom networks

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ABSTRACT

As natural disasters (e.g., earthquake, tsunami, hurricane, etc.) frequently threaten and damage the widely-deployed telecom infrastructure, maintaining the connectivity, transmission bandwidth, and reliability of various service connections becomes a crucial concern in post-disaster telecom networks (such as optical backbone networks). Based on a probabilistic failure model, in this paper we proposed a reliability threshold based service bandwidth recovery (RBR) scheme for recovering the bandwidth and reliability of the impacted service connections after a disaster. Here, the impacted service connections include the ones completely disrupted and/or the ones undisrupted but their reliability decreased beyond the corresponding reference thresholds. Since there is severe lack of bandwidth resource in the post-disaster network, some connections are difficult to obtain enough bandwidth. Under the resource crunch case, RBR employs relaxation policies based on reliability thresholds to explore reliable routes for the impacted connections and to optimize their bandwidth resource utilization. Simulation results show that RBR scheme can make a good trade-off between the bandwidth resource utilization and service connection reliability. It can also achieve satisfactory performance in terms of connection loss ratio, traffic loss ratio, and average connection reliability.

1. Introduction

Natural disasters (i.e., earthquake, tsunami, hurricane, etc.) critically threaten the widely-deployed telecom infrastructure and usually make severe damages on telecom networks (such as optical backbone networks) [1,2]. Different from random network failures such as single/double link failures [3–5], a large-scale disaster can cause multiple, geographically correlated and cascading network failures leading to enormous amount of connection disruptions and data loss especially in the big data era [6,7], as well as high risks of power outage and/or aftershock which may further deteriorate the reliability and resource utilization of the residual network [8]. Here, reliability refers to the probability that network component(s) can survive against potential failures. It can also be expressed as a function of the probability of network component failure(s). Since most of the existing survivability solutions aiming at random network failures are difficult to combat large-scale disaster failures, disaster survivability would become a significant issue of the network survivability research area in the future [9–11].

1.1. Previous work

In recent years, disaster survivability has attracted much attention of researchers from network and communication area. The authors in [12] studied the issue of assessing the network vulnerability to disasters. By modelling a geographical disaster event as a line segment cut or a circular cut, polynomial-time algorithms were proposed to identify the most vulnerable parts of the network that would suffer the maximum disruptive effects in terms of capacity and connectivity in a disaster. In [13], the authors studied the network reliability under random geographic disasters. By utilizing geometric probability techniques, the authors developed tools to analyze network connectivity and evaluate average two-terminal reliability under geographically correlated failure models.

In [14], the authors studied survivable routing schemes against disaster failures. Considering the probabilistic link failures, the traditional shared risk link group (SRLG) framework was generalized to a probabilistic SRLG (PSRLG) for modeling correlated failures due to disasters. Based on which, the authors formulated the path protection problems for the case of multiple probabilistic failures and developed routing algorithms to find paths with minimum joint failure probability. In [15], the authors proposed a dynamic network failure probability

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model to evaluate the impact of large-scale disasters. In light of the disaster intensity and the geographical characteristics of the related area, it was assumed that the range of a disaster expanded in circular pattern with time, and the failure probability of involved part of the network varied with time as well. With this time-varying model, a preventive protection scheme was developed to enhance network service survivability by rerouting the endangered traffic to more reliable paths.

In order to minimize the risk of disasters, the authors in [16] studied the traffic engineering problem for both pre-disaster and post-disaster optical backbone networks. They exploited a probabilistic disaster model to assess the risk of disruption and loss from a possible disaster and its aftershocks, then developed disaster-risk-aware provisioning and re-provisioning schemes to let service connections survive and reduce the loss in case of a disaster. In [17], the authors studied the joint traffic engineering and risk mitigation problem under multiple probabilistic failure scenarios, and proposed a path protection solution – joint path pair load balancing (JPP-LB) algorithm. Using a PSRLG network model, JPP-LB provisions service connections on path pairs with minimum joint path failure probability for service connections to improve the network performance in terms of connection failure ratio, bandwidth blocking ratio, and post-fault connection reliability.

In survivable optical networks, bandwidth degradation and multipath routing were usually considered as desirable strategies to solve resource shortage issue [18,19]. In [20], the authors proposed a fairness-aware degradation based multipath re-provisioning (FDM) scheme to recover disrupted connections in the post-disaster network. Based on fairness-aware bandwidth degradation and multipath deployment, FDM globally re-provisions connections to maintain service connectivity and maximize traffic flows, however it did not take into account the potential risks of power outage and/or aftershock in the post-disaster network. In [21], the authors studied a reliability based restoration scheme for post-disaster networks which focused on combating threats of post-disaster failures. In order to increase the reliability of a service connection, the restoration scheme first computes a path pair for this connection, then provisions at most a half of the required bandwidth on each of the two paths. Although double-path deployment can significantly upgrade the reliability of this connection, it might sacrifice resource utilization to some degree.

In this paper, we study a restoration scheme to recover the bandwidth and reliability of the disaster-impacted services and to achieve good trade-off between service connection reliability and bandwidth resource utilization in the post-disaster network.

1.2. Our contribution

Network survivability was defined as the capability that the network can maintain the necessary quality of service upon various network failures [22], while the connectivity, bandwidth, and reliability of the network would be significant concerns for disaster survivability.

In this paper, we employ a probabilistic failure model to simulate the adverse effect of disasters on a network, in which the network components located within a disaster zone would be destroyed completely, viz., failed with a probability of 100%, while the failure probability of other components near this disaster zone would increase to some degree. Based on this model, we study a restoration solution for post-disaster networks to recover the service bandwidth and maintain the connection reliability after a disaster.

The contribution of this work is to propose a post-disaster survivable scheme for recovering the impacted service connections in post-disaster telecom networks and a corresponding heuristic algorithm named as reliability threshold based service bandwidth recovery (RBR) algorithm. In which, we define the impacted service connections as the ones completely disrupted and/or the ones undisrupted but their reliability decreased beyond the corresponding reference thresholds. The RBR algorithm firstly searches for the most reliable routes to recover the impacted connections in terms of connectivity, bandwidth and reliability. When some impacted connection cannot obtain enough bandwidth, then, the RBR further reroutes them and increases their bandwidth by limitedly relaxing the reliability constraint without breaking through the given reference thresholds. Numerical results illustrate that our algorithm gains a desirable trade-off between connection reliability and bandwidth resource utilization, also achieves a good network survivability in various disaster scenarios.

The rest of this paper is organized as follows. In Section 2, we state the problem and present the network model. In Section 3, we present the routing method and relaxation policies employed in our scheme, develop a corresponding heuristic algorithm, and illustrate our scheme by a simple example. In Section 4, we present the simulation model and analyze the numerical results. Section 5 concludes this paper.

2. Problem statement and network model

In this section, we first state the problem of post-disaster recovery, then present the network model used in our work.

2.1. Problem statement

In this work, we study a service recovery scheme for post-disaster networks. We assume that a disaster occurs with the probability of one, the network components within a disaster zone are destroyed completely and the others near this disaster zone might suffer high risks of power outage and/or aftershock in the near future. Thus, the service connections traversing through the disaster zone are assumed broken down immediately after the main shock and some others traversing through the nearby areas might break down with a certain probability.

For indicating the risk levels of service connections in the post-disaster network, different reliability thresholds can be defined for different kinds of services according to relevant service level objectives (SLOs). On this basis, the connections disrupted in the disaster and the ones with less reliability than the corresponding reliability thresholds are defined as the impacted connections in this paper.

The goal of our work is to recover the impacted connections over single-paths to meet the reliability threshold requirements and the bandwidth demands, particularly, to make a good trade-off between the resource utilization and connection reliability (to be defined in Section 3.1).

2.2. Network model

The network model used in our work is presented as follows. Given an optical WDM mesh network $G(N, L)$, where N is the set of nodes and L is the set of links. In this network, we assume that each node has full wavelength conversion capability, each link is bidirectional and has a fixed bandwidth capacity. Before a disaster occurs, there are $|C|$ service connections with different reliability level requirements existing in the network. Each connection is provisioned over a single path with a certain amount of bandwidth units (e.g., wavelengths). Since our scheme is designed for the post-disaster network, we assume that there is only one disaster occurring at a time and the probability of occurrence is one. After a disaster occurs, the node and/or links within the disaster zone are destroyed completely, while the reliabilities of links near the disaster zone decrease to some degree. In general, the probability of a link failure depends on many factors (such as the distance from the disaster's epicenter, the type, intensity, and diffusion pattern of the disaster), which need interdisciplinary knowledge from geography, geology and climatology, etc. For simplicity, in this paper, the irregular annulus is used to mark a disaster zone and the reliability of a nearby link is changed according to the distance from the disaster zone.