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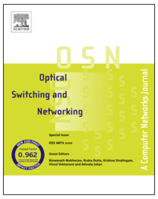

Practical issues for the implementation of survivability and recovery techniques in optical networks

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ABSTRACT

Failures in optical networks are inevitable. They may occur during work being done for the maintenance of other infrastructures, or on a larger scale as the result of an attack or large-scale disaster. As a result, service availability, an important aspect of Quality of Service (QoS), is often degraded. Appropriate fault recovery techniques are thus crucial to meet the requirements set by the Service Level Agreements (SLAs) between carriers and their customers.

In this paper, we focus on practical issues related to the deployment of fault recovery mechanisms in commercial optical networks. In particular, we outline the most important functionalities that, to the best of our knowledge, need to be implemented, as well as discuss the related problems making deployment of fault recovery mechanisms difficult. Investigated topics include fault recovery challenges (fault detection, location, and recovery), multiple failures recovery, as well as application of reliability mechanisms in Elastic Optical Networks, and in multiprovider multilevel networks.

1. Introduction

Network survivability, defined in [1] as the ability to provide continuous service in the presence of failures, is a critical issue for high-bandwidth backbone optical networks with arbitrary mesh topologies. Failures in fiber-optic networks occur often due to the fact that they are a cable-based technology and the infrastructure is co-located with networks for other utilities. Thus, damages usually happen during work being done for the maintenance of other infrastructures.

Furthermore, due to the use of wavelength division multiplexing (WDM) technology in these networks, each fiber can carry an extremely high volume of traffic, thus more traffic is concentrated on fewer routes, increasing the

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number of customers that can be potentially affected by a failure.

In this paper, we focus on deployment issues of fault recovery mechanisms in commercial optical networks. In particular, we discuss the current needs concerning implementation of failure recovery techniques as well as the related problems following, e.g. from hardware constraints.

Over the past two decades, various approaches have been proposed for the recovery of the traffic when a failure event occurs. They are mainly based on utilization of alternate paths, called *backup paths* (*BPs*), used to redirect the traffic after a failure of a network element affecting the primary routes, called *working paths* (*WPs*) [2]. Specific schemes of backup routes include link-, path-, segment-, and cycle-based techniques.

The general requirement when providing protection against failures of nodes/links is that the respective backup paths should be node- (link-) disjoint from the working paths being protected [3]. In addition, link capacities reserved for backup paths can be shared along certain links, if the considered backup paths protect mutually disjoint working paths [2]. Failures of single links/nodes are the most frequent types of failures. However, due to the often observed inter-failure correlation, a large set of solutions is dedicated to the case of multiple failures, i.e. a simultaneous failure of several network elements [4].

Survivability can be provided either in a proactive way – using a *protection* strategy, implying establishment of a backup path before the occurrence of a failure (i.e., at the time of working path establishment), or by means of a reactive *restoration* strategy. In the latter case, the network tries to establish a new connection using available resources only after a failure has occurred. Protection typically has faster recovery speed but lower resource-efficiency than restoration [5].

There are many types of service disruptions in optical networks, which can be classified in two major types: soft and hard failures [6]. *Hard failures*, such as fiber cuts and failure of a network linecard occur suddenly and have a severe impact on services, causing major loss of traffic. *Soft failures*, such as aging of an amplifier, cause subtle changes in performance, resulting in a wide spectrum of service degradations which are far more difficult to detect and localize.

Some failures, called *self-reported*, are very easily detected because they interfere with the correct functioning of the upstream device and are flagged by internal control mechanisms. Most hard and a large number of soft failures are self-reported [7]. Soft failures that are not self-reported can be very hard to detect and accurately localizing them is time-consuming and very costly.

Even though failures cannot be avoided, quick detection, identification, and recovery of faults are crucial aspects in the successful deployment of telecommunication networks. A network fault that goes unattended for a long period of time can cause both tangible and intangible losses for the company that provides the service, as well as for its clients. Therefore, the current trend is for more and more networks that are virtually uninterruptible.

Currently, carriers are bound to *service-level agreements* (SLAs) with their customers guaranteeing that the customer will be provided with services with a prescribed service availability (e.g., 99.999% availability – equivalent to less than 5 min of down time per year), with financial penalties if the SLA availability is not met. It is therefore clear that in optical backbone networks it is essential to have effective fault recovery mechanisms to prevent the loss of information due to fiber cuts or equipment failures, which may occur often enough to cause major service disruptions.

Furthermore, the constant growth of traffic in computer networks mainly due to popular services such as cloud computing and content-oriented networks has triggered the need to develop an efficient and scalable optical transport platform for capacities beyond 100 Gb/s. One of the technologies, which enables improved use of flexible optical network is a scalable and efficient architecture called *Elastic Optical Networks* (EONs). The key innovation of EONs compared to currently used WDM (Wavelength Division Multiplexing) networks is the possibility of using sub-wavelength granularity with 6.25 GHz slices for low-rate transmission and super-channel connectivity for accommodating ultra-high capacity client signals within a common network [8]. Accordingly, the optical spectrum can be used much more flexibly compared to the fixed grid of 50 GHz channels in WDM.

One of the consequences of the flexible grid provided in EONs is the possibility to provision asymmetric traffic where demands of the same bidirectional connection between a particular pair of nodes have different bandwidth requirements in each direction. Especially, in the context of network survivability based on path protection, this option seems very attractive, since significant savings of network resources in terms of optical spectrum should be obtained.

Although much research has been performed in the area of optical networks' reliability and survivability over the last two decades, there are still many practical issues that need to be addressed for the successful commercial implementation of fault recovery techniques in optical networks. In this paper, we identify the most important of them, with invited sections from panelists based on their presentations at IEEE/IFIP RNDM (Reliable Networks Design and Modeling) 2013 [9]. In particular, in Section 2, we outline the fault recovery challenges related to fault detection, localization, and recovery related to physical layer impairment issues, shared protection, as well as switch design considerations, especially for the case of transparent or translucent optical networks, where the signal remains in the optical domain for the entire end-to-end path or for large parts of the path. In Section 3, we extend our investigation to the case of multiple failures. Next, in Section 4, we investigate applicability of reliability mechanisms in the context of Elastic Optical Networks. In Section 5, we address the resilience and recovery issues concerning multiprovider multilevel networks, while Section 6 concludes the paper.

2. Fault recovery challenges

A number of challenges can be identified for the practical implementation of recovery techniques in mesh