Optical Switching and Networking 19 (2016) 78–96

Contents lists available at ScienceDirect

Optical Switching and Networking

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

Differentiated quality of protection: An energy- and spectral-efficient resilience scheme for survivable static and dynamic optical transport networks with fixed- and flexible-grid

Jorge López Vizcaíno [a,b,*], Paola Soto [a], Yabin Ye [a], Peter M. Krummrich [b]

[a] Huawei Technologies Duesseldorf GmbH, Riesstr. 25, 80992 Munich, Germany
[b] Technische Universitaet Dortmund, Chair for High Frequency Technology, Friedrich-Woehler-Weg 4, 44227 Dortmund, Germany

ARTICLE INFO

Article history:
Received 10 September 2014
Received in revised form
6 February 2015
Accepted 29 March 2015
Available online 13 April 2015

Keywords:
Dynamic network
Elastic optical networks
Energy-efficiency
Network planning
Optical VPN
Protection
Spectral-efficiency

ABSTRACT

Optical transport networks are being continuously upgraded to cope with the ever increasing capacity requirements. Improving the energy- and spectral-efficiency while maintaining high service availability is emerging as a strategic priority for the operators. This article proposes a differentiated quality of protection (Diff QoP) scheme to achieve this goal by matching the actual client/service requirements for network protection. This strategy can be especially valuable in future networks where heterogeneous services and users with different requirements will coexist in the network. The applicability of such scheme is evaluated in different network and traffic scenarios, ranging from the conventional current static wavelength-division-multiplexing (WDM) networks to the innovative flexible-grid elastic optical networks (EON).

Simulations carried out on realistic deployment scenarios operated with static and dynamic traffic network operations allowed us to quantitatively analyze the potential energy- and spectral-efficiency improvements that a Diff QoP scheme can provide to telecommunication operators with respect to the common dedicated protection 1+1 (DP 1+1).

1. Introduction

The Internet traffic has grown dramatically in the past years due to the ever increasing number of users and the emergence of bandwidth-hungry services like Internet video. Global IP traffic will show a compound annual growth rate (CAGR) of 23% from 2012 to 2017 [1]. The core or backbone network, which is based on wavelength division multiplexing (WDM) technologies, will be considerably affected by this exponential traffic growth. This situation is driving operators to continuously upgrade their networks to cope with the new capacity requirements. A network capacity upgrade entails not only increased capital expenditures (CapEx) due to the necessary investment in additional equipment, but also higher energy consumption which affects both operational expenditures (OpEx) and the greenhouse gas emissions. In fact, telecom operators are becoming one of the major energy consumers in the society. For instance, Telecom Italia was reported to be the Italy's second biggest electricity consumer in 2012 [2].

Furthermore, considering the ever increasing amount of data transported over a fiber as well as the growing number of critical services that rely on the telecommunications infrastructure, guaranteeing high service availability and survivability to network failures will become even more critical in the future. Resilience in optical networks can be provided by protection (pre-planned recovery in case of failure) or restoration (on-the-fly recovery) schemes. Nowadays, the most commonly used method to ensure high resilience and

* Corresponding author at: Huawei Technologies Duesseldorf GmbH, Riesstr. 25, 80992 Munich, Germany. Tel.: +49891588344227.
E-mail address: Jorge.vizcaino@huawei.com (J. López Vizcaíno).

http://dx.doi.org/10.1016/j.osn.2015.03.006

availability is the so-called dedicated protection 1+1 (DP 1+1), based on provisioning redundant resources (duplicated spectral resources and equipment) to be used in case of failure. Despite being the most secure and fastest known mechanism, it is obviously the least energy- and spectral-efficient protection scheme due to its high redundancy [3].

All in all, operators will need to face several challenges when designing and upgrading future networks such as:

- *Need for an efficient and flexible utilization of the spectral resources*: The future generations of optical systems will need not only to provide higher spectral efficiency (more transmitted bits per spectral unit), but also to make a more flexible usage of the scarce spectral resources. The rigid wavelength grids of traditional WDM networks (International Telecommunications Union – Telecommunication Standardization Sector (ITU-T)) could be replaced by flexible bandwidth slices in the future. The adoption of flexible-grids will enable the migration to elastic optical networks (EON), which will allow for adapting the bandwidth and/or modulation format to the actual service demand.
- *Need for improved energy-efficiency*: Reducing energy consumption is emerging as a strategic priority for the operators of the optical transport infrastructure. Improving the energy-efficiency of the equipment and networks is one of the primary ways to achieve this goal. Recently, a great number of energy-efficient strategies were presented in the literature. Nevertheless, some of those approaches may affect the reliability of the network and it is rather unlikely they will be applied to the network (e.g. sleep mode might not be hitless for the operation of the network).
- *Need to guarantee a reliable and highly available service*: Providing high service availability when designing the network is indispensable to fulfill the service level agreements (SLA) terms.
- *Need to cope with heterogeneous traffic demands*: New services (e.g. optical virtual private networks (O-VPN), cloud computing, etc) with different requirements are emerging and will coexist in the network with the conventional users/services. Therefore, the traffic demands of the optical network are becoming more heterogeneous not only in terms of capacity, but also in terms of service requirements (e.g. availability).
- *Need for a dynamic network operation to meet the traffic variations*: The optical transport network is envisioned to move from the static to a dynamic operation in the future to achieve a higher utilization of the network resources. In fact, offering bandwidth-on-demand services by allocating the resources according to the variable traffic requirements of the clients is one of the most promising functionalities expected for a software defined networks (SDN).

Operators are therefore interested in solutions and mechanisms which can address all the previously mentioned challenges. In this paper, we proposed a resilience mechanism to improve the energy- and spectral-efficiency of optical transport networks by matching the particular reliability requirements of each service or user which could be applicable for current and future networks. This strategy is in contrast with the currently adopted one, where DP 1+1 is applied to all traffic without distinction, even if it actually exceeds the protection requirements of some specific services/users. The proposed differentiated quality of protection (Diff QoP) scheme allows an operator to provide its customers with different resilience levels that can match the requirements and expenditure restrictions of the clients.

The concept of Diff QoP was first introduced in [4,5] to reduce the blocking probability with respect to DP 1+1. The present paper aims at presenting how Diff QoP can help with the above mentioned challenges, extending our previous work on these topics [6–9]. In summary, the main contributions of this paper are:

(i) A detailed explanation of Diff QoP (and parameters affecting its performance) and a potential application in a real deployment scenario;
(ii) A thorough explanation of the heuristic algorithms proposed for the routing and resource allocation with Diff QoP in static (offline) and dynamic (online) scenarios considering traditional WDM networks and EONs;
(iii) A comprehensive study to validate the benefits in terms of energy- and spectral-efficiency in different scenarios (i.e. ranging from static fixed-grid WDM with a single line rate to future dynamic EONs). More specifically the following scenarios were considered: (a) Different network architectures: WDM with single line rate (SLR) or mixed line rate (MLR), and the innovative EON; (b) Traditional static or dynamic (bandwidth-on-demand) network operations; (c) Two long-haul realistic networks (with different number of nodes and mesh levels) under different traffic conditions.

The rest of the paper is organized as follows: Section 2 summarizes the related work and recent achievements on related topics. Section 3 describes the main concept of Diff QoP and possible application scenarios for real deployment. Section 4 includes a thorough description of the methodology. Section 5 describes the network and traffic scenarios used in our analyses. Section 6 presents a comprehensive analysis of the results, and Section 7 concludes the paper.

2. Related work on energy-efficient resilience in optical transport networks

Despite the numerous publications on energy efficiency in telecommunications networks, the topic of energy-efficiency related to resilience in optical transport networks has not been extensively studied so far. As protection schemes provide the most common resilience mechanisms for optical transport networks, in [3], the energy efficiency per GHz of schemes such as DP 1+1, DP 1:1 and shared protection (SP) for three network architectures (single- and multi-rate WDM networks, and EONs) was evaluated. The results show the superior