Differentiated Quality of Protection to Improve Energy Efficiency of Survivable Optical Transport Networks

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Abstract: A differentiated quality of protection scheme is evaluated in terms of energy efficiency for fixed-grid WDM and flexible-grid OFDM-based networks. Significant energy savings can be achieved by exploiting the heterogeneous protection requirements.

OCIS codes: (060.4261) Networks, protection and restoration; (060.4251) Networks, assignment and routing algorithms.

1. Introduction

Telecommunication networks are becoming more and more indispensable for the availability of many services in our society. In this situation, telecommunications carriers need not only to cope with the new capacity requirements, but also have to ensure high service availability and resilience. Upgrading the network capacity is commonly accompanied by additional capital expenditures (CapEx) and operational Expenditures (OpEx) that may result, among others, from higher energy consumption. Therefore, the operators have to face the challenges of providing more capacity and resilience while maintaining acceptable profit margin. In the last years, the research on optical transport networks has been focused on enlarging the network capacity by increasing the individual wavelength capacity in wavelength division multiplexing (WDM) networks operating with the rigid International Telecommunications Union (ITU-T) grid. Recently, flexible-grid or elastic networks have been proposed as a promising alternative to improve both the spectral and energy efficiency by exploiting the heterogeneity of traffic demands that will co-exist in the network. Resilience in these networks is usually provided by a dedicated protection 1+1 (*DP 1+1*) scheme, where the data are duplicated and then transmitted on two different link-disjoint paths. This implies a reservation of twice the spectral resources (i.e. in working and protection paths), and requires the deployment of duplicate transponders (high CapEx) with significant additional power consumption since both have to be active for the working and protection paths. Even though this scheme is the most reliable and offers the shortest recovery time, it is costly and in many cases the clients may not require such a high level of reliability for their service. Accordingly, exploiting the heterogeneity of the traffic demands and protection requirements requested by the clients would allow a significant improvement on cost and power consumption. Following the last approach, Telecom operators would be able to offer a differentiated quality of protection (Diff QoP) to their customers depending on their service quality requirements and the cost they are willing to pay for it. It has been previously shown that a significant reduction of blocking probability can be achieved by employing different protection schemes based on traffic classes [1, 2]. To the best of the authors' knowledge, this is the first study that evaluates the energy efficiency of a Diff QoP scheme. This paper presents the energy savings that can be achieved with Diff QoP compared to the conventional *DP 1+1* scheme for both the current ITU-T grid WDM and flexible-grid or elastic networks based on Orthogonal Frequency Division Multiplexing (OFDM) technologies. The analysis has been carried out in a realistic network scenario under different traffic load conditions and diversity of clients.

2. Problem description

The study will be focused on corporate service deployments exclusively involving optical transport infrastructure. This means that Optical VPN (virtual private network) services will be offered to enterprise customers, connecting their sites and headquarters locations. In this context, a Diff QoP scheme is proposed to provide different protection levels for each VPN connection, according to the client protection requirements. The energy efficiency of this scheme has been evaluated for both the ITU-T grid WDM networks and the flexible-grid OFDM-based networks.

In our elastic OFDM-based network model, a frequency slot of 12.5 GHz has been considered, so the transmission rate of a single subcarrier in a single polarization can be 12.5, 25, 37.5, 50, 62.5 and 75 Gb/s for binary phase shift keying (BPSK), quadrature phase shift keying (QPSK), 8 quadrature amplitude modulation (QAM), 16QAM, 32QAM, and 64QAM respectively (with a transmission reach of 4000, 2000, 1000, 500, 250 and 125 km [3], respectively). Moreover, a bilateral guard band of one subcarrier per side (25 GHz in total) has been considered to separate adjacent channels. In the WDM case, up to 80 wavelengths within the 50 GHz channel spacing in the C-band, and line rates of 10 Gb/s, 40 Gb/s, and 100 Gb/s, with reaches of 3200, 2200, and 1880 km have been assumed [4], respectively. Single line rate (SLR) of 40 and 100 Gb/s, and mixed line rate (MLR) approaches,

Table 1. Power Consumption of CO-OFDM Transponder for different modulation formats.

Modulation Format	*Subcarrier Capacity (Gb/s)*	*Power Consum. (W)*
BPSK	12.5	112.374
QPSK	25	133.416
8QAM	37.5	154.457
16QAM	50	175.498
32QAM	62.5	196.539
64QAM	75	217.581

Table 2. Description of the different QoP Classes.

QoP Class	*Description*
C1-Maximum Protection	*DP 1+1*, duplicate transponder(s), fastest recovery.
C2-High protection	*DP 1:1*, single transponder(s) for working path.
C3-Medium protection	Shared Protection (*SP*), single transponder(s) for working path.
C4-Unprotected	Best Effort.

combining the transmission of three line rates in a single fiber (10/40/100 Gb/s), have been considered. In the MLR approach, the C-band is divided into two bands separated by a guard band of 200 GHz to minimize the nonlinear cross-talk between adjacent channels of different transmission technologies: 1) for 10 Gb/s (NRZ-OOK) transmission, and 2) for both 40 and 100 Gb/s which are based on DQPSK modulation format.

Three energy-consuming devices are considered: transponders, optical amplifiers and optical cross connects (OXCs). The elastic OFDM-based network employs a bandwidth-variable transponder (coherent optical-OFDM) whose power consumption depends on the number of subcarriers and modulation format. Table 1 presents the values for the transmission and reception of a single subcarrier with different modulation formats [3]. The power consumption values for WDM transponders are 34, 98 and 351 W for 10, 40 and 100 Gb/s transponders, respectively [5]. The erbium doped fiber amplifiers (EDFAs) are assumed to consume 30 W per direction with an overhead of 140 W per node location [5], and the power consumption of an OXC is assumed to depend on the node degree (*N*) and the Add/Drop degree (α) as follows:$(N * 85 + \alpha * 100 + 150)\ [W]$, where 150W is the overhead [5].

Traffic grooming of the client signals at the transport nodes has been assumed to be performed with ODUFlex (optical channel data unit flexible) containers with 1.25 Gb/s capacity, which permits to fit any client rate into any higher level ODUk of OTN (optical transport network). The optical add/drop nodes are supposed to have no "packet level" intelligence (e.g. virtual local area networks (VLAN) or multiprotocol label switching-traffic profile (MPLS-TP) switching), so that the complete client port capacity or part of it (if the optical node is able to perform a rate-limit) is mapped into an integer number of ODUFlex slots. Four different QoP classes, ranging from maximum protection (C1) to unprotected or best-effort (C4), have been defined (Table 2). Client signals with the same destination can be groomed together, provided that the QoP requirements of each client can be fulfilled so that a better utilization of the network resources can be achieved. For instance, if a lightpath has already been established for a C1 traffic demand, but its capacity is not fully used (e.g. a 15Gb/s demand in a 40Gb/s channel), it would be preferable to "upgrade" lower QoP connections to C1 and temporarily provide for these clients a better protection for free (since spectral resources are already reserved and WDM transponders consume constant power independent of the actual load). As soon as C1 resources are needed in a future network upgrade, lower classes could be preempted and moved to a different transponder dedicated for lower QoP requirements.

A network protected by a *DP 1+1* scheme (total aggregated demand is protected without traffic differentiation), has been compared with a Diff QoP scheme for both the WDM and the elastic OFDM-based network scenarios. It is worth mentioning that in the WDM case, the traffic differentiation is performed at wavelength granularity, meaning that a particular transponder has to be dedicated to a specific QoP, whereas the elastic approach allows for a differentiation at subcarrier granularity, so that a transponder can be used for different QoP classes (i.e. a CO-OFDM transponder can transmit/receive different subcarriers, which can be treated independently). The methodology used in this study is based on heuristics algorithms for the routing and resource allocation for the elastic OFDM- based network, WDM SLR and WDM MLR in [3]. In the *DP 1+1*, the demands from the traffic matrix are, in a first step, sorted in descending order of aggregate traffic demand value. Then, it is evaluated whether working and protection paths (link-disjoint paths) can be provided for each particular demand from a set of candidate paths (*k*-shortest paths). In the Diff QoP, the demands are classified into four independent traffic matrices (one for each QoP Class). Then, the allocation is evaluated consecutively for each of the groups of demands according to their protection scheme, and in descending order of protection requirements (i.e. starting from the ones requiring maximum protection, C1, and finishing with those not requiring any protection, C4). As mentioned before, a demand can be upgraded to a higher QoP class. Thus, for traffic demands different than C1, it is firstly evaluated whether they can be groomed into the remaining spectral resources of the already established lightpaths of higher QoP with the same destination. In this regard, the elastic network offers an additional advantage as it is possible to increase the capacity of the lightpath by increasing the modulation order. If a traffic demand cannot be served with the requested QoP requirements, then it is blocked.

Table 3. Description of traffic scenarios.

Traffic Scenario	*C1(%)*	*C2(%)*	*C3 (%)*	C4(%)
S1	41	27	19	13
S2	19	13	41	27
S3	25	25	25	25

Fig. 1. Telefónica Spanish core network topology.

Table 4. Power consumption Savings (%) with respect to DP 1+1.

		Total Traffic Load (Tb/s)			
		1.56	***7.81***	***15.62***	***23.43***
Network Technology	***Scenario***	***Power Consumption Reduction (%) with respect to DP 1+1***			
Elastic	***S1***	5.68	7.06	8.76	11.93
	S2	15.02	16.71	18.22	20.99
	S3	7.74	9.99	11.93	13.35
SLR 40G	***S1***	5.01	9.93	13.66	18.55
	S2	10.4	12.99	16.00	21.52
	S3	9.90	13.16	17.98	21.27
SLR 100G	***S1***	6.97	6.97	10.73	14.01
	S2	14.46	14.46	17.10	18.95
	S3	12.52	12.52	15.31	17.28
MLR	***S1***	3.30	10.89	11.75	17.18
	S2	7.79	16.25	12.27	16.94
	S3	4.34	13.42	10.02	20.75

3. Simulation results

The simulations have been carried out using the Spanish core network model provided by Telefónica for the studies within the ICT STRONGEST project [6]. The network model comprises 5 regional domains interconnected by a national domain. It is composed of 150 nodes and 319 bi-directional links as depicted in Fig.1. Table 3 presents three traffic scenarios with different percentages of each QoP class (i.e. S1: big corporations with high QoP requirements are predominant, S2: small and medium size companies are predominant, and S3: intermediate between S1 and S2). These scenarios are evaluated for four overall traffic load values, starting from an initial take-up rate of 1.56 Tb/s. The second value assumes an average 50% traffic growth over a 4 year period, while the rest of the traffic loads are multiples of the second value. A set of traffic demands (552 of each type) have been uniformly distributed among 47 nodes located in the most populated cities, where an Optical VPN service is available.

Table 4 shows the power savings with respect to a network protected with *DP 1+1* for the different technologies and traffic scenarios. A differentiated QoP scheme brings energy savings in all the evaluated scenarios compared to the classical *DP 1+1* scheme. The saving values depend on the network technology, the distribution of traffic classes, and the total traffic load. At low traffic load, the savings are lower since a significant part of low QoP traffic demands (C2, C3 and C4) are groomed into lightpaths of QoP C1 (i.e. if traffic is low and just one client demands QoP C1, those clients demanding other QoP are upgraded to fill the wavelength capacity). However, as traffic increases, it is possible to apply more traffic differentiation and higher energy savings can be achieved by using more energy-efficient protection schemes (*SP* and *DP 1:1*) for some fraction of the total traffic. More significant savings can be achieved in S2 and S3, as a lower percentage of clients demands maximum protection.

4. Conclusion

Providing differentiated QoP by exploiting the heterogeneous protection requirements of the clients has been evaluated as a technique to improve the energy efficiency of fixed-grid WDM networks and flexible-grid elastic OFDM-based networks. The results show that this approach can bring significant energy savings, up to 21%, compared to the conventional *DP 1+1* scheme.

This work was supported by the EU FP7 funded projects TREND and CHRON.

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