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Survivable power efficiency oriented integrated grooming in green networks

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ABSTRACT

The wide interests in the power savings of IP over wavelength-division-multiplexing (WDM) optical networks have recently risen in both academic and industrial communities. In an effort to tackle this problem, the hybrid grooming (traffic grooming along with an optical bypass) approach has been presented to reduce the power consumed by the entire network infrastructure, including the transmission ports of routers and optical-electrical-optical (OEO) conversions. However, the related works pay little or no attention to the power consumed to ensure the resiliency of the overall network. Meanwhile, the power consumed by components used for establishing lightpaths is not simultaneously taken into account. One survivable network with the higher power efficiency thereby save more power with hybrid grooming, require the lower power consumption of establishing lightpaths and exhibit the shorter recovery time. For the first time, this paper proposes the evaluating models of both survivable power ratio and protection switching time. We subsequently compare two green and survivable grooming heuristics, known as Single-hop Survivable Grooming with considering Power Efficiency (SSGPE) and Multi-hop Survivable Grooming with considering Power Efficiency (MSGPE). Simulation results demonstrate that, MSGPE obtains the higher power efficiency and resiliency although it has the slightly higher time complexity in comparison to SSGPE. Furthermore, it is effective to exploiting waveband merging in our MSGPE to form integrated grooming for further port savings.

1. Introduction

Using IP-based routing technology to transport demands router-by-router consumes an enormous number of power in Transmission Ports (TPs) of IP routers at all of immediate nodes, especially for the network survivability with respect to the dedicate path protection, where additional backup and power thirsty resource is redundantly configured to ensure demand protection. Inversely, switching these small-granularity connection demands in the optical domain requires less power than electronic processing in the IP layer and we can make use of lightpath pair (Baliga et al., 2009). This observation re-motivates us to pay attention on the definition of Generalized Multi-Protocol Label Switching (GMPLS) (Mannie, 2004; Qu et al., 2003) and derived survivable IP over wavelength-division-multiplexing (WDM) network. A typical structure of this network is shown in Fig. 1. The main power-consuming components include grooming matrixes, amplifiers and router ports. Among which, the amplifier is further divided into post-, pre- and in-line one; the router ports contain Aggregating Ports (APs) in core routers and TPs in IP routers; a grooming matrix is equipped with Grooming Matrix Ports (GMPs) and transceivers. The utility of such many components still may cause power thirsty. One practical solution that can be adopted to greening IP over WDM network is hybrid grooming (i.e., traffic grooming along with an optical bypass), which has been studied in the recent literatures (Li and Ramamurthy, 2005; Idzikowski et al., 2010; Idzikowski et al., 2011; Hasan et al., 2009; Wu et al., 2009; Hamad and Kamal, 2005; Shen and Tucker, 2009; Xia et al., 2011; Hasan et al., 2010; Monti et al., 2011; Cavdar et al., 2010). This technique multiplexes several small-granularity connection demands into a high-capacity lightpath and then switches these small-granularity connection demands all-optically as a single entity to ensure both the number of TPs and the times of optical-electrical-optical (OEO) conversions reduction. Beside these factors, an interesting point here is the further improvements of power savings from survivable hybrid grooming, where a group of the working lightpath and the backup lightpath is established for each accepted small-granularity connection demand. The wavelength-routes of these two lightpaths are link-disjoint.

In the following, we provide an example to illustrate how to save power with survivable hybrid grooming. As shown in Fig. 1, the orderly arriving small-granularity connection demands are from the source node to the destination node. Followed by survivable hybrid grooming, the lightpath pair is established in the WDM optical layer and only eight Optical Cross-Connect

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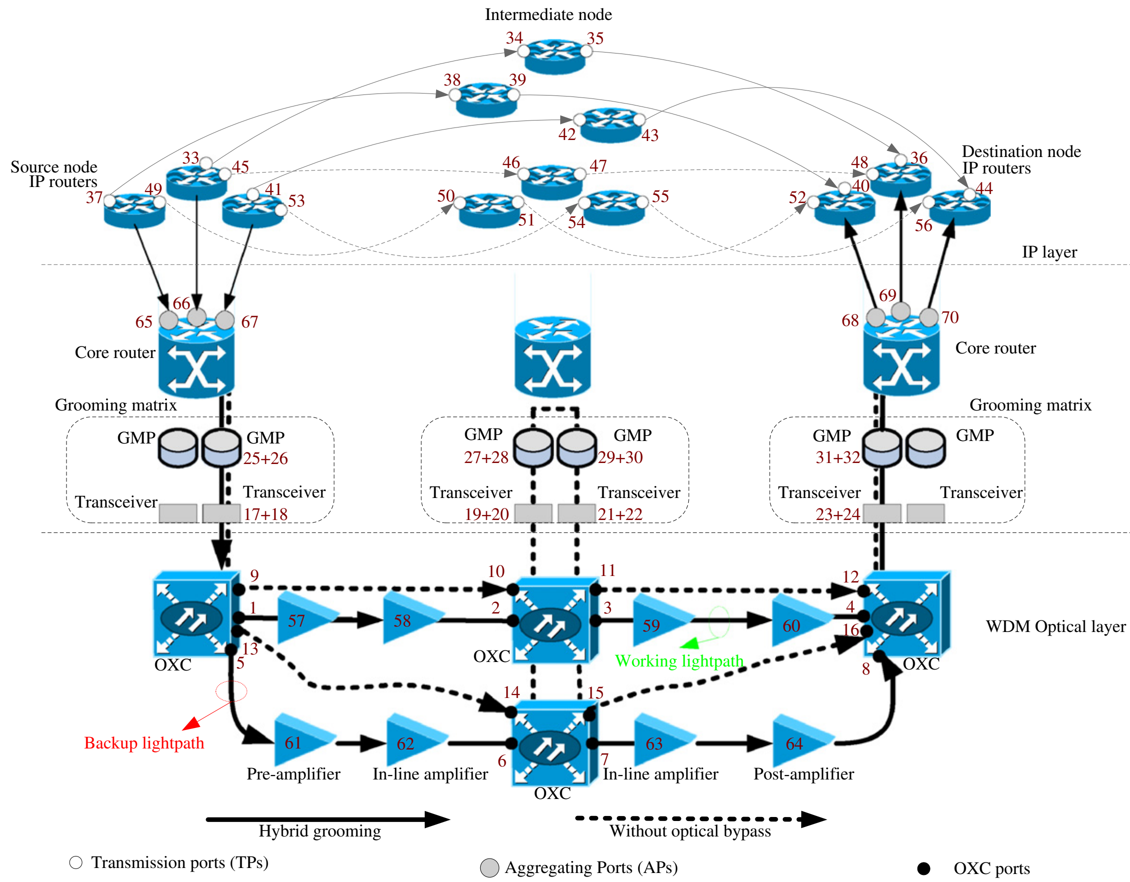

Fig. 1. Power efficiency in survivable IP over WDM network.

(OXC) ports (i.e., ports 1–8) are consumed. This part of scare power consumption is negligible in this paper since the OXC is one of all-optical components (Qu et al., 2003). If without any optical bypass, although the lightpath pair also consumes eight OXC ports (i.e., ports 9–16), the total number of consumed GMPs and transceivers brings up to 16 (i.e., transceivers 17–24 and GMPs 25–32). While in survivable hybrid grooming, four transceivers (i.e., transceivers 19–22) and four GMPs (i.e., GMPs 27–30) are saved in this instance because it no longer enables OEO conversion at the intermediate nodes. On the other hand, by using IP-based routing, the working paths for three demands are the solid lines in the upper part of Fig. 1 and the number of consumed TPs is 12 (i.e., ports 33–44). Accordingly, the backup paths for three demands are the dashed lines in the upper part of Fig. 1 and the number of consumed TPs is also 12 (i.e., ports 45–56). Therefore, compared with the IP-based routing, using the survivable hybrid grooming saves 24 TPs' power in this instance. We can see that, the hybrid grooming provides the further power savings for survivable IP over WDM optical network because the dedicate lightpath protection finds a group of lightpaths (working and backup) simultaneously for each accepted small-granularity connection demand, which fundamentally doubles the power saving effect of hybrid grooming regardless of survivability.

However, the consumed power of establishing lightpath pairs becomes an important issue. Also as an example in Fig. 1, this part of power consumption mainly comes from the optical amplifiers (i.e., amplifiers 57–64), aggregating ports (i.e., ports 65–70), transceivers (i.e., transceivers 17–18 and 23–24) and GMPs (i.e., GMPs 25–26 and 31–32). Therefore, the IP over WDM network with the higher survivable power efficiency should save more power of TPs and OEO conversions at the cost of slightly consumed power for establishing lightpath pairs. Beside of this, the established and full-loading lightpaths in higher power-efficient and survivable IP over WDM network, that combines the advantages of survivable hybrid grooming and waveband merging, can be further merged into the waveband tunnel along with more than two physical routing hops (Li and Ramamurthy, 2005). This reflects into a demand for proposing survivable power efficiency-oriented integrated grooming.

1.1. Related work

- Green hybrid grooming

  The traffic switching between the different lightpaths were proposed in Idzikowski et al. (2010, 2011). In this method, a partial of traffic on one lightpath was tuned to the idle spectrum of another lightpath. As such, the traffic on the previous lightpath was vacated and the associated interfaces were turned off to save power at the WDM optical layer. However, the traffic re-organization schemes make the network topology dynamically change, which worsens the delay and error rate. The authors in Hasan et al. (2009) pioneered to concentrate on how to save power consumption by enabling routers and switches to sleep when there is low traffic load. The authors in Wu et al. (2009) investigated power-aware traffic grooming for dynamic WDM optical networks and assumed that switches could manage and operate power autonomously. Based on an auxiliary graph model, the simple heuristics were proposed in Wu et al. (2009) for daily traffic variations. The authors in Hamad and Kamal (2005) considered developing a power consumption model for a WDM optical network in the terms of power consumed by