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Multi-domain integrated grooming algorithm for green IP over WDM network

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ABSTRACT

With the continuous expansion in the network scale and growing popular Internet applications, the sharply increasing electrical consumption and even carbon dioxide emissions have became bottlenecks of the future network development. Consequently, *greening network* comes to a very important issue. Foremost, ensuring the scalability and robustness, we divide the network into multiple domains for the distributed routing and management. As these tendencies undergo widespread attentions, providing solutions for multi-domain green networks are of the utmost importance. This paper enables the power conservation in multi-domain IP over WDM networks by means of presenting a power- and port-cost- efficient approach. This approach delves into power-efficient channel provisions of connection demands and an effective integration of the hybrid grooming and the waveband merging. For each intra-domain connection demand, our method executes the intra-domain hybrid grooming within the physical topology and updates the power efficiency of this domain in real-time. For each inter-domain connection demand, through link-cost adjustments, our method first computes the loose route which is the most power-efficient path from the source border node to the destination border node within the logical topology. The link-cost adjustment aims to make the loose route traverse over higher power-efficient domains and logical links. Next, it orderly performs the intra-domain hybrid grooming between two selected border nodes in each traversed domain of this loose route, from the source node to the selected border node in the source domain and from the selected border node to the destination node in the destination domain. In final, within each single domain, our method merges several full-loaded lightpath segments into a single waveband tunnel along with more than two physical hops by the intra-domain waveband merging. The Optical Cross-Connect (OXC) ports are able to be further saved. In comparison to the traditional multi-domain grooming approach, our method exhibits the higher power efficiency and port savings.

1. Introduction

Switching demands electrically on IP layer requires marginal router power at all of immediate nodes, while promisingly, one practical method embedded by an IP over Wavelength-Division-Multiplexing (WDM) network can overcome this drawback. It is called the hybrid grooming and it has two key components [1]: (a) the traffic grooming migrates multiple IP-level demands into a high-capacity lightpath to reduce electrical Transmission Ports (TPs), and (b) the optical bypass ensures a lightpath can be switched as an All-optical (OOO) single unit without having any intermediate Optical-Electrical-Optical (OEO) conversions. As a consequence, the power consumed by router ports and OEO operations are thereby greatly decreased. As shown in Fig. 1, on the upper IP layer, the electrical switching consumes twelve TPs (i.e., ports 1–12). Nevertheless, based on the hybrid grooming, these demands from IP layer are multiplexed into the lightpath and switched as an entity (i.e., the solid line on WDM optical layer of Fig. 1). Accordingly, the traversed devices have been replaced from power thirsty routers to Optical Cross-Connects (OXCs) whose power consumptions are negligible. On the basis of assumption above, the hybrid grooming provides the saved power from twelve TPs in comparison to the electrical switching. On the other hand, comparing with the traffic grooming without any optical bypass (i.e., the dashed line of Fig. 1), two Grooming Matrix Ports (GMPs) (i.e., ports 22 and 23) and two transceivers (i.e., transceivers 18 and 19) are saved. However, in the process of executing the hybrid grooming, the power consumed by establishing lightpaths is the performance penalty. In Fig. 1, for instance, the power of six aggregating ports (i.e., ports 33–38), two GMPs (i.e., ports 21 and 24), and two transceivers (i.e., transceivers 17 and 20) are consumed. This observation motivates us to place significant attentions on a novel aspect of the hybrid grooming, and it is the power efficiency [2]. Without losing a generality, a power-efficient IP over WDM network should be the network that can save more

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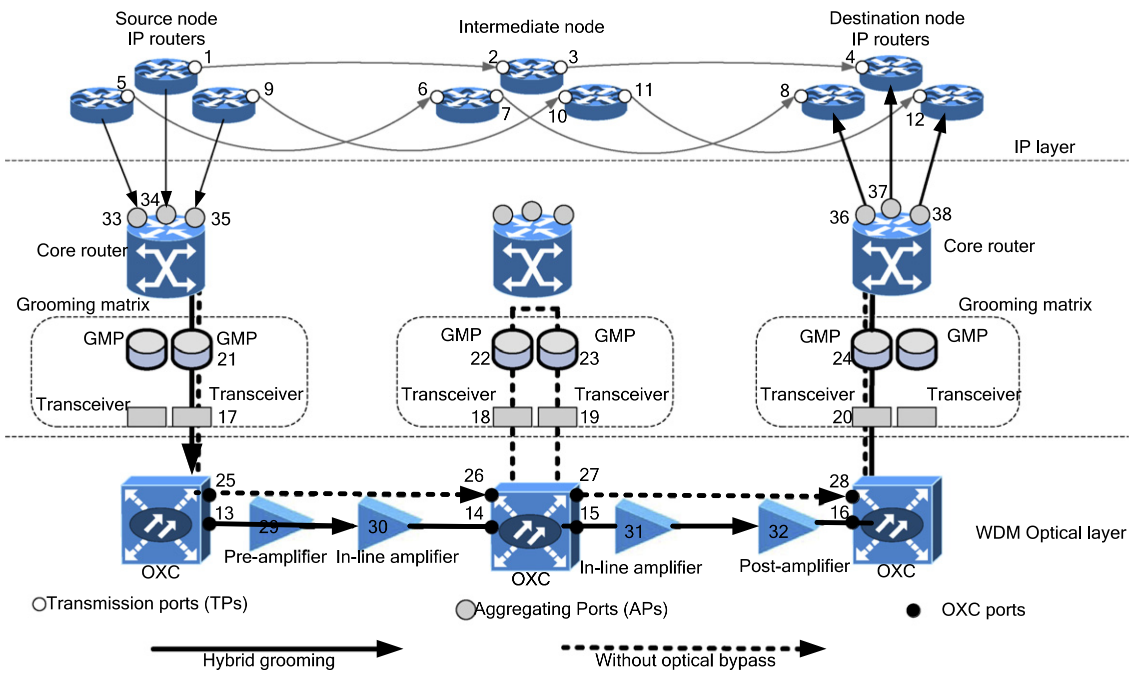

Fig. 1. Hybrid grooming in IP over WDM networks.

power with the hybrid grooming at the slightly additional cost of the power consumed by establishing lightpaths. Currently, there are two main approaches of implementing the hybrid grooming [3]: (a) only the single-hop lightpath segment can be found to carry demands, which we call the single-hop hybrid grooming and (b) several lightpath segments (at least one) are cascaded hop-by-hop for carrying demands, and each lightpath segment is not confined to the newly-found one, it can also be the established one. Approach (b) is called the multi-hop hybrid grooming. Our previous work [2] has exhibited the better power efficiency of the latter, and in the following parts of this study, we directly call the approach (b) as "*hybrid grooming*" for simplicity.

On the other hand, for the purpose of security and scalability in a multi-domain optical network, the single domain operator shares scarce information resource with the others from the different domains. Furthermore, the accurate information of physical topologies and link states is not within the scope of the inter-domain information exchange. In other words, the partial information oriented and inter-domain hybrid grooming is not easily implemented in the whole network through the single stepping. This unique characteristic makes the multi-domain hybrid grooming for the power efficiency become a more complex issue. Fig. 2 exhibits the physical topology of a typical multi-domain optical network, wherein two types of physical links are involved: the intra-domain link denoted as a thin line and the inter-domain link of a coarse line. Two nodes within the same domain are connected by an intra-domain link while the inter-domain link is built between two border nodes (i.e., dark circles) of its two adjacent domains. Each border node has the knowledge of both its located domains' physical topology and the global information of physical link states, while the other interior nodes exclusively know the local information.

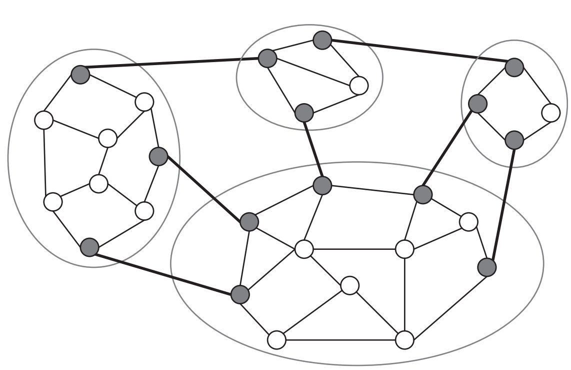

Fig. 2. The physical topology of a multi-domain optical network.

As performed in the previous work [4], we require making the abstraction of the global topology to form a two-layered topology structure. This structure includes an abstracted logical topology on high layer and independent and single-domain physical topologies on low layer, shown in Fig. 3. The full-mesh scheme is adopted to enable the topology abstraction. In detail, we find at most K ($K \geqslant 1$) different shortest paths as a group for each border node pair within every domain in Fig. 2, and each path group is abstracted into a logical link (denoted as a dashed line on the high layer of Fig. 3). One member of the path group also belongs to the respective logical link and is known as the logical sub-link. Owing to the tight relationship between the saved power of the hybrid grooming and the number of physical routing hops [5], each link of Fig. 2 has one unit of cost in the case of exploiting the full-mesh scheme described above. Hereafter, on the high layer of Fig. 3, each domain has been changed into a meshed area that includes its own logical links and border nodes, and the global multi-domain physical topology has became into a logical one that includes all of logical links, border nodes and inter-domain links; on the low layer of Fig. 3, the global multi-domain physical topology has been divided into several independent and single-domain physical topologies.

1.1. Related works

Zhu [6] first estimated the Bit-Error-Rate (BER) evolution of mixed regenerator operations by their analytical model, and then addressed the cost- and power-efficient design in translucent optical networks based on the estimation above. This approach