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A new asymmetric spectrum assignment method to improve spectrum efficiency for spectrum-sliced optical network

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ABSTRACT

Bandwidth flexible optical network, referred to as spectrum-sliced elastic optical path network (SLICE), is a promising solution to achieve both high data rate transport and high spectrum-efficient. However, current methods to solve Routing and Spectrum Assignment (RSA) problems for SLICE network, conservatively accept the constraint that spectrum resources should be assigned symmetrically in both directions of one optical path. Since most data traffics are asymmetric by nature, the conventional way to simply aggregate them to form symmetric flows for transport layer is not as flexible as offering a direct asymmetric transport layer mechanism. In this paper, we present a novel Asymmetric Spectrum Assignment (ASA) method to future improve spectrum efficiency by saving redundant spectrum resources for the lighter load direction of one optical path to accommodate more incoming connection requests. We describe the concept of ASA and the enabling technologies to implement it. To compare the performance of proposed ASA with conventional Symmetric Spectrum Assignment (SSA), we classify the evaluations into four scenarios. We also observe the effect of various grid width values. Simulation result shows that: (i) ASA method always significantly outperforms the SSA method in any situation. (ii) Routing asymmetry is not necessary needed and spectrum assignment optimization takes obvious effect only under the situation of "random slot" grid width value.

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1. Introduction

Given a set of connection requests, the process of routing and assigning wavelength to each request through intermediate nodes in Wavelength-Division Multiplexing (WDM) optical network is called Routing and Wavelength Assignment (RWA) problem. While for spectrum-sliced optical network (SLICE) [1–4], the counterpart is defined as Routing and Spectrum Assignment (RSA) problem. Many approaches have been proposed to solve the RWA and RSA problems, such as integer linear program (ILP) [5,6] for small scale network topology and static connection request, heuristic method for complex topology and dynamic connection request. The combination of routing and wavelength/spectrum assignment can be divided into two separate sub-problems: the routing process (RA) and wavelength/spectrum assignment process (WA/SA). (i) The classical method to solve RA is to present the network topology by a graph, and use a cost function to present the weight of each link in the graph, and then use shortest-path algorithm to compute the minimum cost path between two given nodes. Typically Dijkstra's algorithm is adopted for single shortest-path computation [7] while k-shortest path algorithm is adopted for backup path computation [8]. The key of the routing process is to find the appropriate cost function of each link for shortest-path computation. The function can be based on some predefined metric such as minimum number of hops, link distance, load balance, or even physical impairment and energy consumption (evaluation of these two factors should be formulate beforehand). (ii) For the SA process, graph-coloring approach [9] is used for static lightpath establishment, and heuristics algorithm is used for dynamic case where first fit (FF) is wildly adopted for its simple calculation, low overhead and good network performance.

Those RWA and RSA approaches mentioned above struggle to utilize spectrum resources as efficient as possible, but all on the premise of symmetric spectrum assignment. It means during the wavelength/spectrum assignment process, the wavelength/spectrums assigned along the lightpath for both directions are always identical to each other, assuming that traffic load on both directions are symmetric. However, this assumption does not necessary hold. The actual traffic load could be asymmetric, i.e., the load of one direction could be much heavier than the other direction, such as BT traffic, application migration or backup, and other cloudbursting type services between data centers (DCs) [10]. If both directions occupy the same amount of bandwidth, redundant spectrum resource on the lighter load direction will be wasted, and reluctant to accommodate more connection request. Therefore to

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improve the spectrum efficiency, it is appropriate to assign spectrum resource asymmetrically according to the asymmetrical traffic load for each direction. In fact most data traffics are asymmetric in nature, and the traditional way is to groom and aggregate the upper layer traffic to form symmetric flows for transport layer, which is less flexible than directly offering an asymmetric transport layer mechanism.

Network asymmetry is a common research topic for wireless network where load balancing and resource allocation are considered [11–13], and for general network design such as urban traffic network [14]. As for wired network, the term "asymmetry" is often referred to routing asymmetry, which is an important routing phenomenon and can influence the way we analyze Internet. Ref. [15] described how routing asymmetry can affect feedback-based transport protocol such as TCP; Routing asymmetries of Internet are systematically quantified [16]; The general reasons for this asymmetry is analyzed [17] and in some case the inherently asymmetrical traffic (TCP background radiation) should be filtered [18]. In general, for a pair of host A and B, if path from A to B (forward direction) is different from path from B to A (reverse direction), we say these two hosts exhibit routing asymmetry. Current network infrastructure is based on optical network and resource allocation problem evolves from electrical domain to optical spectrum domain. In order to offer more flexibility from transport network, asymmetry should also be taken into account for spectrum assignment. However, asymmetry analysis for optical network is restricted to component design issues such as asymmetry traffic between output ports of one single switch node [19] or optical power equilibrium of different lightpaths. The asymmetry for spectrum resource allocation in optical network is ignored.

In this paper we propose Asymmetric Spectrum Assignment (ASA) method to achieve further spectrum efficiency. We divide core network into asymmetric domain and symmetric domain, and ASA is restricted in asymmetric domain. To the best of our knowledge, it is the first method to adopt asymmetry into spectrum assignment, similarly with adopting asymmetry into routing which has been done before. Since RSA/RWA is divided into two sub-problems of RA (i.e., routing problem, which can be asymmetric) and SA/WA (actually WA is a special case of SA), this paper tries to find whether SA is also appropriate to be asymmetric and how it can affect RSA computation. Comparing to the definition of routing asymmetry, for a pair of host A and B, if the spectrum resource allocated from A to B is different from B to A, we say that they are SA asymmetric and ASA is adopted. In WDM network, transmitting port and receiving port embedded in one transponder are started up simultaneously. If necessary, they can be further designed asymmetrically by separating the power supplies of transmitting and receiving ports. In SLICE network, transmitting and receiving parts are currently two independent systems and have not been integrated into one single module yet, thus asymmetry is naturally satisfied. Therefore, instead of treating fibers of two directions as one single tunnel, which results in topology information loss and spectrum inefficiency, the ASA assigns spectrum resource on each lightpath individually. ASA eliminates the constraint that symmetric spectrum should be assigned for both directions, and is independent of all the RSA/RWA algorithms mentioned above. For the sake of simplicity, in this paper we evaluate the performance of ASA just for RSA problems and dynamic connection requests with heuristic algorithms adopted. The evaluation consists of four scenarios:

(i) *The basic:* Dijkstra's algorithm or Breadth-first search algorithm for routing computation and First-Fit for spectrum assignment. The cost of each link is 1 for Breadth-first search and a customized function for D's algorithm respectively. Theoretically in spite of which type of SA method is adopted, the latter should always outperform the former, if not, we say RA process is disturbed by SA method. This case intends to verify the basic optimization effect of ASA and see whether ASA can disturb the RA process.

(ii) *Routing asymmetry:* We verify whether adopting routing asymmetry is also appropriate along with ASA. Asymmetric routing is calculated by computing shortest path for each direction respectively in a diagraph. We focus on whether routing asymmetry, with more computation complexity, can perform better than symmetric routing.

(iii) *SA optimization:* based on scenario (i), we adopt two optimization methods for SA process. We focus on whether this SA optimization has significant impact too.

(iv) *Various grid width values:* the above three scenarios all adopt single unified grid width, and we observe what will happen by setting the grid width to various values.

The idea of ASA is inspired by routing asymmetry and also by asymmetric digital subscriber line (ADSL) and PON system where uplink and downlink speed are asymmetric, e.g., GPON is about 1.25 Gbps of uplink and 2.5 Gbps of downlink and 10G EPON is 1 Gbps of uplink and 10 Gbps of downlink. We expect this paper could inspire more study of asymmetric resource allocation for SLICE or even traditional WDM network, to further improve the spectrum efficiency for backbone network and data center network, and further enlighten the service-oriented feature of optical internet [20].

The rest of this paper is organized as follows: Section 2 discusses the key idea of ASA and the potential enabling technologies in the future. Section 3 describes the related work for waveband grooming and multi-granularity grooming. Section 4 adopts ASA for heuristic algorithm in four scenarios to evaluate the ASA's impact on RSA algorithms. Finally we present simulation results in Section 5 and conclusion in Section 6.

2. Concept and enabling technologies of Asymmetric Spectrum Assignment (ASA)

2.1. Concept of Asymmetric Spectrum Assignment (ASA)

First of all we assume that the optical transport network can be divided into symmetric and asymmetric domains as shown in Fig. 1. The symmetric domain follows the conventional symmetric principle, while the asymmetric domain adopts the novel ASA method where asymmetry is taken into account for optical spectrum allocation, following the actual traffic demand such as BT, cloud or D2D application migration or any other asymmetric traffic demand. The division rule for these two domains can be

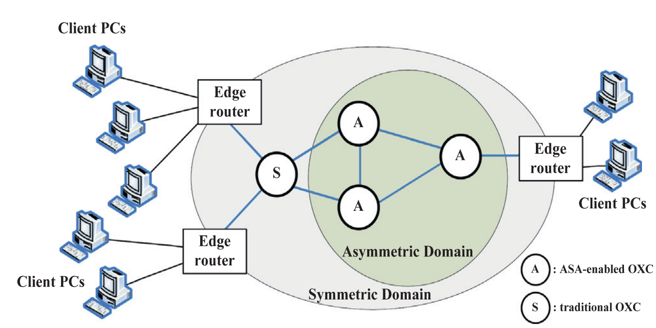

Fig. 1. Network comprising asymmetric domain and symmetric domain.

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