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Extending light-trail into elastic optical networks for dynamic traffic grooming

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ABSTRACT

A light-trail in a traditional *ITU − T* fixed wavelength grid optical network is a generalization of a lightpath. Multiple nodes in a light-trail are allowed to communicate each other along the light-trail, leading to sub-wavelength granularity utilized traffic grooming. Architecturally, a light-trail is analogous to a shared wavelength optical bus. Moreover, a new light-trail is always equipped by a guard band for non-interference of optical signals. Therefore, multiple light-trails must be accompanied by multiple guard bands, which indeed is an absolute wastage of optical spectrum resources. In the recent years, besides *RWA* (Routing and Wavelength Assignment) in *WDM* (Wavelength Division Multiplexing) optical networks, the Routing and Spectrum Assignment (*RSA*) algorithm is widely being adopted in many new and emerging elastic optical mesh networks to perform traffic grooming. In such networks, Orthogonal Frequency Division Multiplexing (*OFDM*) technology is a promising candidate to execute a *RSA* algorithm and implement an elastic lightpath as a result. The algorithm is capable of transmitting high-speed data stream using multiple low-speed spectrum overlapped sub-carriers (mini-grids). Hereafter, in this paper we have introduced a novel concept (based on our knowledge and belief) elastic light-trail (a variant of an elastic lightpath) in elastic optical networks and proposed an algorithm "Multi-hop Elastic Light-Trail – *MELT*" that performs an elastic light-trail expansion and/or contraction (in frequency domain), instead of creating a new elastic light-trail where applicable. Otherwise, the algorithm creates a new elastic light-trail that facilitates required data transportation. In this work, we investigate optical spectrum utilization efficiency for proposed elastic light-trail, existing elastic lightpath (Multi-hop Elastic Lightpath algorithm – *MEL*) and *ITU − T* wavelength grid fixed lightpath (Multi-hop Lightpath algorithm – *ML*) and perform comparison measurements.

1. Introduction

Over the last decade, it is been observed that, growth rate of traffic demands in the core network has been increased drastically to cope up with current trend in the telecommunication system. As the technology has been evolving over the time, hopefully, in future it will continue to exhibit exponential growth rate in traffic demand due to the emerging applications such as high-definition and real-time video communication in a distributed environment [1,2]. In this regard, a light-trail [3] (an advanced variant of a lightpath shown in Fig. 1) in the *ITU − T* fixed wavelength grid network is capable of enhancing data transportation up to a certain extend. Details of a light-trail will be discussed later in the next section. However, in near future, the *WDM* optical

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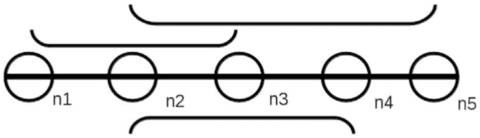

Fig. 1. A fragment of a *WDM* optical network contains (n_1, n_5) light-trail with intermediate communicated nodes pairs (n_1, n_3), (n_2, n_5), and (n_2, n_4).

mesh network will most probably become obsolete and be replaced by an elastic optical mesh network [4–8]. In this novel network architecture, a lightpath (a source to destination logical path passes through possibly multiple fiber links by allocated same range of spectrum) is not constrained by fixed $ITU-T$ wavelength grid, and it is setup by *OFDM* [6] that provides flexibility, reconfigurability, and network agility. Such advancements facilitate expansion and contraction (in frequency domain) of a lightpath (which is therefore referred to as elastic lightpath) according to the traffic volume. Flexibility in the elastic optical network must be fully utilized to facilitate enhanced dynamic traffic grooming for future technological boost up in real-time data transportation.

However, in *WDM*, entire bandwidth in an optical fiber is divided into fixed wavelength grid according to $ITU-T$ specifications. A source to destination lightpath is setup by utilizing an available wavelength λ_i from $ITU-T$ wavelength grid and optical signals are transmitted over a channel which does not necessarily fit the entire bandwidth capacity of the channel. Moreover, two or more parallel lightpaths must be separated by guard bands. Hence, the fixed wavelength grid leads to inefficient spectrum utilization. Since, a large frequency gap between two adjacent wavelength channels (i.e. lightpaths) is reserved as a guard band to facilitate undistorted propagation of optical signals, thus, a large portion of the spectrum in an optical fiber is wasted.

To overcome inefficiencies in the *WDM* optical network, recent research works have introduced the elastic optical network which does not implement $ITU-T$ fixed wavelength grid allocation. The prime factor of an elastic optical network is to make the entire bandwidth of an optical fiber grid-less and assign required bandwidth elastically for a given traffic demand. Moreover, several *OFDM* channels can be typically aggregated into a superchannel, which occupy less spectrum resources than *WDM* because of eliminated guard bands within these channels. However, due to limitations of optical equipments, the fully grid-less optical network cannot be achieved. A more practical variant of grid-less network is implemented by introducing a mini-grid network [4]. Here, mini-grid (interchangeably used as slot) granularity (shown in Fig. 2) is much finer than $ITU-T$ grid specifications. A lightpath's spectrum may span over multiple mini-grid. Each orthogonal carrier span over a single mini-grid does not interfere with each other, though they overlap in a frequency domain, is modulated and composite signal can be transported through an optical fiber. Here, reconfigurable optical add-drop multiplexers (*ROADMs*) with bandwidth variable Wavelength Selective Switches (*WSSs*) are required to implement optically switched and spectrum varying lightpath.

The remainder of this paper is organized as follows. Section 2 discusses previous works especially the light-trail and Routing and Spectrum Assignment. Next, Section 3 focuses on the prime objective of the proposed work. In Section 4, we formulate the problem such that the proposed algorithm can be explained. Section 5 presents existing traffic grooming algorithms based on fixed grid optical network and elastic optical network. Section 6 discusses working principles of the *MELT* algorithm. Evaluation of this algorithm using a series of simulations has been done in Section 7, and finally, Section 8 concludes the entire research works.

2. Related studies

In addition to those discussed so far, some other related works on the elastic optical network have passed through rigorous research activities. In [7], static Routing and Spectrum Assignment (*RSA*) has been discussed as a set of integer linear programming and a heuristic searching algorithm is also proposed. A distance adaptive spectrum allocation to a lightpath is proposed in [9] based on its physical condition (i.e. distance of the lightpath, number of hops encountered along with it). In [4], several dynamic *RSA* algorithms are presented to achieve efficient spectrum resource utilization for elastic optical networks. Survivable traffic grooming, adaptive bandwidth property and restoration of elastic optical fiber networks are discussed in [10–13].

However, while an elastic lightpath is expanded and contracted according to traffic volume (in frequency domain), entire spectrum of a fiber link may be fragmented over non-contiguous spectrum bands. Now, any one of these bands may not be sufficient to carry a traffic demand, whereas collective summary of these bands is a necessary and sufficient condition to carry over certain traffic request. This fragmentation is studied in [13] to consolidate spectrum usage.

In the works referred so far traffic grooming was not considered. A connections's required spectrum may be much smaller than the high spectrum lightpath capacity and hence spare bandwidth capacity provisioning must be implemented. On the other hand, when multiple lightpaths go through one or more common fiber links, these must be separated by guard bands to avoid severe interference. So, programming each connection request by a separate lightpath leads to wastage of bandwidth resources by interleaved guard bands and inefficient utilization of high capacity lightpath. Therefore, entire spectrum of a fiber link could have been utilized efficiently by eliminating guard bands and multiplexing several low-speed traffic demands into a high capacity lightpath. In [13], traffic grooming was proposed for the elastic optical network to maximize spectrum efficiency in a static traffic model. However, in this paper we have studied different perspectives of the elastic optical network and proposed a novel light-trail based dynamic traffic grooming algorithm that enhances spectrum utilization significantly.