Dynamic Traffic Grooming With Spectrum Utilization in Elastic Optical Networks

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Abstract: **The massive growth of Internet and communication modes has made the networking technology a promising solution that provides services in a cost effective manner and with better scalability. The traffic in backbone networks is ever increasing. Future networks must be stuffed with advanced resources to meet the increasing traffic demands, the evolution of bandwidth hungry services, like video on demand, e-learning and grid computing applications. Optical networking provides an efficient solution to satisfy the requirements of today's communication revolution, since it provides massive advantages in terms of bandwidth, which could be exploited to meet the performance requirements.**

Optical networks based on Wavelength Division Multiplexing provide wavelengths firmly allocated throughout the optical spectrum which is parted by 50 or 100 GHz. The Elastic Optical Network helps to improve the overall performance of the network by allotting multiple sub channels to future connection requests with smaller bandwidth granularity (hence the term elastic) by the use of a flexible spectrum grid.

We compare three cases, including traditional coarse ITU-T wavelength grid and spacing, mini-grid and grid-less. Though grid-less is the most flexible of all, it is also equally important to evaluate the mini-grid case that lies between the cases of coarse grid and grid-less. This is because today most of optical components cannot really achieve fully grid-less tunability.

The working of flexible-grid EONs to that of fixed-grid WDM networks under dynamic traffic, with and without grooming capability, in cases of blocking probability and overall spectrum occupation is compared, thus determining quantitatively the benefits of EON in comparison to grooming based WDM networks.

Index Terms—Elastic Optical Networks (EON), Flexible SA, Gridless, ITU-T Grid, Mini Grid

I. INTRODUCTION

The rapid advancement in the field of Internet and related communication services has made the networking technology to quest for a promising solution that could provide better services with scalability in a cost effective manner. Scalability is the ability of the network to handle the growing amount of traffic. The traffic in backbone networks has increased manifold all over the world in the past decade. Future networks will have to be equipped with sufficient resources to meet the ever increasing traffic demands, and the evolution of bandwidth hungry services, like video on demand, e-learning and grid computing applications. Optical networking is the right solution to satisfy the unprecedented expectations of today's communication revolution, since it provides a massive breakthrough in terms of bandwidth, which could be exploited to meet the performance requirements. In network designing, the vital factor of concern for the service providers is the cost of the network that includes both the capital and operational expenditures. Optical networks should be configured to provide different services to increase the revenue, and be scalable to the ever growing traffic demands.

To meet the challenges of the current communication scenario, two fold approaches are to be employed. The first approach is the advancements to be considered to increase the bandwidth utilization of the fiber and the associated equipment's. The other approach is the architectural advancements, where the configuration of the network can be done effectively, aiming at reducing the network cost and the complexity. An optimal planning strategy in optical networking is to honor all the demands in the given traffic matrix. The planning process consists of designing the topology, routing, wavelength assigning and network dimensioning. For a given set of traffic requirements, the network dimensioning problem considers cost optimization. It is the problem of provisioning hardware resources in a way that minimizes the cost while meeting the performance requirements. The dimensioning of the network can be done either with or without protection. Various communication services have begun to emerge, with a wide range of bandwidth demands making the network design difficult. The upgrading of optical networks is an expensive process and should be made infrequent. Therefore, when the traffic evolves, it is very important to efficiently utilize the network resources to yield fewer upgrades. In optical networks, the light paths have a long duration and the cost of setting up a light path is high, when compared with the non-optical networks. It is doubtful that the service provider will reject a new light path request due to the higher cost. Rather, it is more proper to enhance the network by the addition of more capacity on the existing links to honor the new light path demands. Rerouting and forestalling requests and connections becomes undesirable as the data loss per unit time is directly proportional to the network bandwidth. Therefore, the dimensioning process should focus on assigning additional resources to the network, without disturbing the existing framework.

II. OPTICAL NETWORKS

Communications using fiber optics have supported us with high-speed data transfer assisted by enormous bandwidth potential. While fibers can support very high data rates (almost 50 terabits per second), the associated electronic processing hardware won't be able to keep up with such high speeds. Hence, electronic handling of data at network nodes chiefly reduces the overall turnout of the network. Moreover, electronic processing is required because optical storage and processing technologies are not developed fully. Therefore, data that has to be stored or processed at an intermediate node has to be converted into its electronic form and this converted form has to be stored in an electronic buffer memory. Finally a routing decision is made and the data is sent to the output port, where conversion back to optical form takes place and then transmitted

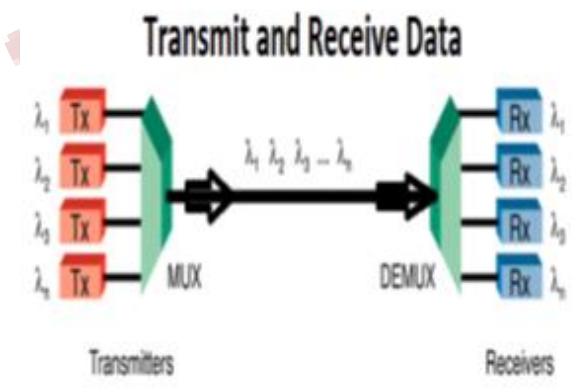


Figure 1: Communication through a medium

Towards its final destination. The currently used networks can be categorized into three different generations based on the technology used at the physical level. The networks which come under first generation category worked on copper based technologies. Second generation networks used a combination of copper and optical technologies. Third generation networks are all optical networks. The third generation networks (fully optical) are yet to become practical because of the difficulties faced during routing process and buffering process in the optical domain without an intermediate conversion to the electronic domain.

The present networks make use of a mix of copper and optical based technologies. To reduce the transmission delay and to improve the overall turnout of the network the network architecture must both reduce the number of times a message is processed by the intermediate nodes (and thus reduce the number of times an optical signal is converted back and forth between the electronic and optical domains) and must streamline the processing at each node. The irregular nature of most existing networks doesn't necessarily allow this. Hence complex routing tables are often used to make routing decisions less complicated and less time-consuming. If the network could be connected in a regular uniform pattern, the complexity involved in finalizing the routing decisions can be notably made easier thereby reducing the processing times at the intermediate nodes. But due to the effect of real world constraints, a systematic uniform pattern in building a network may not be feasible. Additionally economic reasons compel reuse of prevailing fiber connections in networks which restricts the physical topology options.

III. TRAFFIC GROOMING

It is the process of allocating low bit rate tributary streams to a light path with high bandwidth is referred to as traffic grooming. The high speed data streams to low rate traffic demands are multiplexed to share a wavelength channel. The multiplexing and de-multiplexing is known as traffic grooming .The maximum number of low-rate traffic demands that can be multiplexed into a wavelength channel is called grooming factor. The maximum number of low speed connection that can be multiplexed onto a wavelength defines the multiplexing factor.

The traffic grooming problem in optical networks can be posed as an optimization problem: given the constraints of the optical devices and network equipment, sub-wavelength traffic demands are aggregated onto light paths such that some objectives can be minimized. The traffic grooming problem has been of practical interest because of its importance in reducing the network cost, as well as research interest because of its complexity. The complexity of the traffic grooming problem partly comes from different variations of its definitions.There are two categories of traffic grooming problems

A. Static Traffic Grooming

In static traffic grooming, set of all connection requests are given in advance. It can be formulated and solved as an optimization problem. Traffic grooming was first proposed to increase spectrum efficiency in static traffic model.

B. Dynamic Traffic Grooming

Connection requests are given one at a time. It requires the use of additional techniques. Traffic is generally dynamic, i.e., it may vary with time. The traffic grooming problem under dynamic traffic is discussed only in a few papers. There are three different models that have been used to characterize dynamic traffic: Stochastic Model: In this model, traffic requests (between a pair of nodes) arrive according to a stochastic point process and each request may last a random amount of time. Deterministic Model: In deterministic model, traffic is illustrated by a group of varying traffic requirements that the network must fulfil, but at different times.

C. Advantages of Traffic Grooming

- The maximum number of light paths is minimized.
- The overall network output is maximized.
- Connection-blocking probability is minimized.
- The maximum congestion level is minimized.

IV. CONCEPTS OF ITU-T GRID, MINI-GRID AND GRIDLESS

Fig. 2 depicts different wavelength grid and spacing scenarios. They are ITU-T standard grid, Mini-grid, and gridless. The ITU Telecommunication Standardization Sector (ITU-T)grid maintains regular wavelength separations among adjacentconnection mediums or channels. In the case of dense wavelength division multiplexing (DWDM), usual wavelength separations vary between 200 GHz, 100 GHz, 50 GHz, and 25 GHz. In Fig. 2(a), a wavelength separation of 50 GHz is maintained throughout the medium. According to ITU-T grids, the wavelengths of light paths through the medium must fallexactly on the central grid wavelength. Additionally, every single light path will be provided with a permanent optical spectrum (according to condition of fixed grids) without considering the total amount of bandwidth required foreach of the light path. In Fig. 2(a),althoughthe optical spectrum occupied by the initial two wavelengths is smaller when compared to the allotted spectrum of 50 GHz between adjacent wavelengths, a total of 50-GHz bandwidth is allotted to the traffic requirements on the initial two wavelengths. Whereas, the gridless case depicted in Fig. 2(c) is a different case where we can randomly or manually allocate wavelength and spectrum for each of the incoming light path. Consider the exact initial two light paths, here the central optical carriers can be moved farther or closer since there is noneed to follow the strict ITU-T grids and wavelength spacing rules. Moreover,there is need for allocating, only the required optical spectrum or bandwidth for each of the incoming request. So this is the most spectrum-efficient technique as we are able to move two adjacent optical carriers closer so as to only provide the bandwidth that is demanded by the incoming connection light requestalong with the required guard-band to be provided between two wavelengths. When we compare ITU-T grid and gridless case, it is obvious that the gridless case consumes less optical spectrum compared to the strict ITU-T grid. Therefore, the gridless wavelength assignment scheme is advantageous in terms of efficient spectrum usage.

Fig. 2(b) depicts the mini grid case. It is a transitionalcase between strict ITU-T grid and gridless. The mini-grid case, when compared with the strict ITU-T grid and random gridless case, still demands the wavelength of each connection or light path, to maintain a particular range of distinct fixed frequencies. Unlike standard grids, mini-grids maintain a smaller frequency granularity, which is also known as*grid granularity*. Moreover, when the bandwidth requirement for the light path is high, mini-grid case permits the light path range to stretch numerous mini-grids. We can understand from Fig. 2(b) that, the spectrum of third light path is large enough to cross three mini-grids. It is better to consider the mini-grid (transitional) case because of the finite tuning ability of optical elements. Some of the optical elements like tunable transmitters and Wavelength Selective Switches are having finite tuning capabilities; it is not possible to manually or continuously tune their wavelengths. Therefore, we can compare the other two cases with respect to the mini-grid case. Finally the strict ITU-T grid case can be judged as a particular case of mini-grid which maintains a 50-GHz wavelength separation in between and thegridless case can be judged as another case of mini-grid having random small wavelength separation and also having an infinite number of grid frequencies.

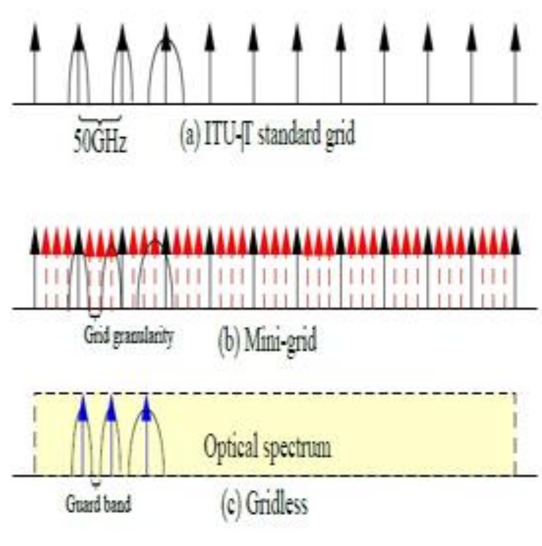


Fig. 2: (a) ITU-T grid, (b) mini-grid, (c)gridless.

V. EXISTING WORK

To efficiently utilize the spectrum resources, gridless networks were considered which has higher spectrum efficiency than WDM networks. However, due to the restrictions of optical elements, fully gridlesstunability cannot be achieved. A more practical version of spectrum elastic optical networks is mini-grid networks in which the grid granularity is much finer than the coarse ITU-T grid and a light path's spectrum can span several mini-grids. It was shown that mini-grid optical networks with small grid granularity (e.g., 3 GHz) can achieve similar performance as ideal gridless networks. In the recent works, traffic grooming was not considered. Provisioning each connection by a separate light path leads to high spectrum wastage by guard bands and low utilization of high-capacity transponders. Traffic grooming can increase transponder utilization and achieve higher spectrum efficiency by saving the spectrum usage of guard bands. Traffic grooming was proposed to increase spectrum efficiency of elastic optical networks, for a static traffic model without considering the spectrum-continuity constraint and bandwidth variability of transponder.The existing paper of traffic scheduling provides inefficient usage of spectrum resources due to wavelength division multiplexing. The approach of auxiliary graph is applicable for only static traffic model and spectrum-continuity constraint is not considered. This also reduces the blocking probability and increases the efficiency of the system but network performance must be improved further for efficient spectrum sharing. Spectrum reservation is inefficient since the arrival of request is unknown.The complexity of EON operation is increased when the flexibility degree of network is increased.

VI. PROPOSED METHOD

A. Spectrum Allocation Schemes

Elastic flexgrid optical network (FG-ON) is an optimal choice for future-generation optical networks.In the case of flexgrid optical network (FG-ON) the total availablebandwidth is divided into smaller frequency slices. The optical path (lightpath), which consists of a flexibly assigned subset of slices, is decided by the routing algorithm.In the flexgrid, each slice occupies the space between two nominal CFs.In a network, each incoming connection request will be allocated a channel, where the bandwidth depends on the required bit-rate, modulation scheme used, the (fixed) slice width, and the width of guard band used between adjacent spectrum connections.One of the main advantages of FG-ON is the ability to allot bandwidth elastically, according to incoming traffic demands. The resources are used in an efficient manner, because of the higher granularity of the flexgrid which allows to fit closely the allocated spectrum and the signal bandwidth, and also, due to the elastic (adaptive) allocation of spectrum in response to traffic variations.

Here two elastic SA schemes are defined, focusing on the changes allowed to the allocated spectrum of light paths.

B. Fixed SA

The Fixed-SA scheme, as shown in Fig 2.1, mentions the condition in which elasticity is not allowed. Under this scheme the CF and allotted bandwidth remains permanent throughout. The issue associated with Fixed SA is that, the bandwidth allotment for incoming request is not dependent on the variations of bandwidth requirements. When comparing the required bandwidth and the amount of bandwidth allotted, two conditions have to be discussed

a) When the requested bandwidth is lower than the total capacity of the bandwidth allotted: In this case thetotal spectrum used for carrying traffic is thus lower than the allotted one, therefore leading to an inefficient usage of network capacity. This is shown in fig. 2.2 where the required bandwidth is lower than the capacity of the assigned spectrum in time t'.

b) When the required bandwidth for the incoming connection request, is higher than the capacity of allotted bandwidth, some bandwidth is not served. This is shown in fig.2.3 where the represented lightpath has some bandwidth that is not served.

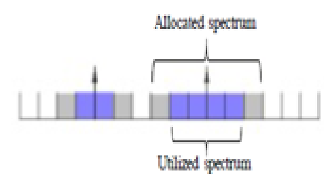


Fig 2.1 Fixed spectrum allocation scheme

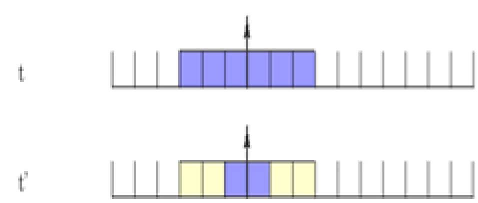


Fig 2.2 Unused bandwidth – lower requests

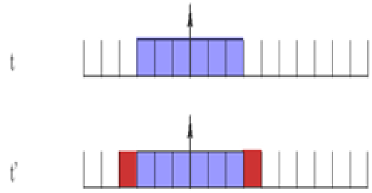


Fig 2.3 Un served bandwidth–Higher request

C. Elastic SA

The Elastic-SA scheme when compared to the Fixed SA scheme offers more flexibility by altering the number of slices per lightpath, and also by changing the CF. ForElastic-SA scheme, by the variation of CF, two conditions can be analyzed. They arespectrum expansion and reduction.

Spectrum expansion/reduction: In this case, the CF movements are limited to a certain range. Therefore, spectrum reallocation is restricted to neighboring CFs with respect to the previous one.

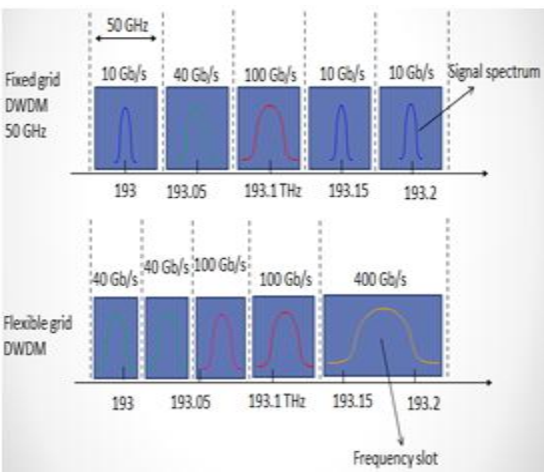
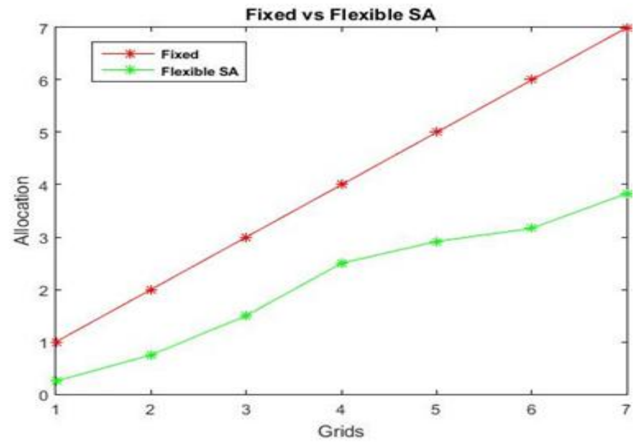


Fig 3. Fixed grid vs flexible grids

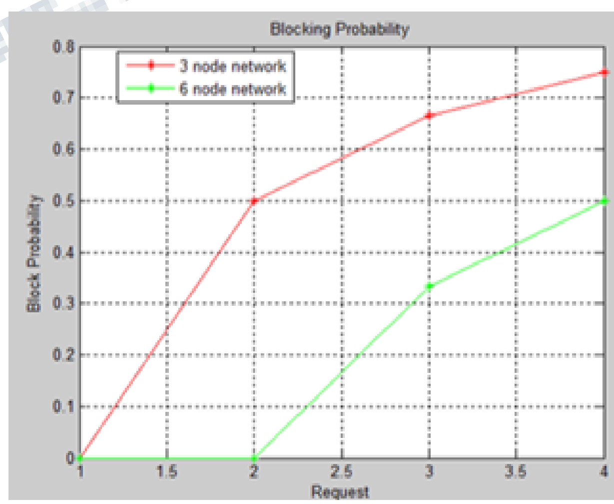
VI. SIMULATION RESULTS

1. Fixed Spectrum Allocation vs. Flexible Spectrum Allocation



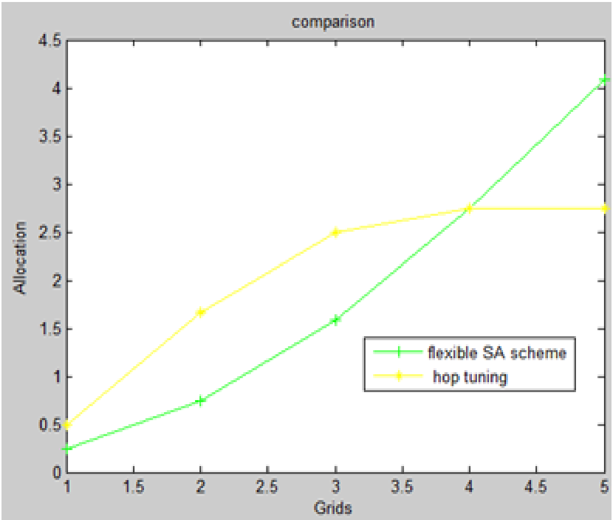
In optical transmission medium, request arrives randomly. Bandwidth is allotted for each of the incoming request in both fixed and flexible allocation scheme. In the case of Fixed SA scheme the bandwidth is allotted rigidly and when the request exceeds 12 GHz, it is blocked in fixed method, whereas in Flexible SA scheme slots are expanded or reduced as obtained in simulation graph.

2. Blocking Probability



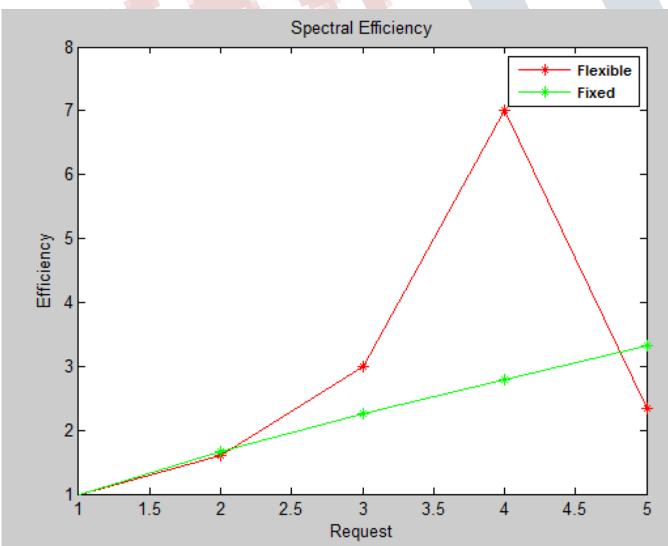
The blocking probability for a 3 node network and 6 node networks is compared. The blocking probability is reduced for 6 node network compared to 3 node network due to traffic grooming process

3. Comparison between fixed and flexible method



Here, when any of the request drops out in a particular time period, hop tuning occupies that slot if it satisfies the channel conditions.therefore spectrum is efficiently utilized.

4. Spectral efficiency graph



VII. CONCLUSION

Flexible Spectrum Allocation scheme provides flexible central frequency and bandwidth assignment for lightpaths or incoming connection request. The flexibility provided by elastic optical networks makes it suitable for accommodating dynamic traffic. Also, with the help of elastic optical networks, the spectrum reservation scheme can be efficiently utilized(by making use of the unused bandwidth) for future connections and groom them. When multiple connection request arrives, available bandwidth is fully utilized among the request and thus blocking occurs for further connections. Blocking probability is calculated for multiple node networks. Because of the use of traffic grooming process, the blocking probability is reduced. Also the spectral efficiency is increased.

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