A study on blocking ratio reduction for Elastic Optical Networks through the use of wavelength converters

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***Abstract*— The use of Frequency Slot Units (FSUs) with variable width in Elastic Optical Networks can improve spectrum usage, but has a side effect of introducing spectrum fragmentation, what can decrease its efficiency and cause blocking even when there are available slots due to the spectrum continuity constraint. This study explores the use of minimum wavelength converters in strategic locations in the EON topology to reduce fragmentation effect, blocking ratio and improve spectrum allocation. Results of this study will be achieved through simulation using optimization techniques and linear programming to define routing and wavelength assignment as well as converter placement, which is expected to demonstrate that correct the use of wavelength converters in selected nodes in the EON architecture can reduce the blocking ratio in a relevant percentage.**

Keywords - Elastic Optical Network; fragmentation; wavelength converter;

I. INTRODUCTION

Wavelength Division Multiplexing (WDM) optical networks brought telecommunications to a next level by sharing optical fibers with multiple independent links. Through the use of multiple carriers, each with different wavelengths, that are aggregated (or multiplexed) in one end of the fiber, and separated (or de-multiplexed), on the other end, they can share the same path without any interference from one to another. But the fixed grid channel allocation of 50Ghz each used by WDM had room for improvement on effective use of the spectrum, as not all channels were not using the entire reserved spectrum, besides the need for large band guard slots to separate them. That led to the development of flexible grid concept also known as Elastic Optical Networks (EON), where the channels do not use a fixed spectrum width – their width is variable and dependent on the required bandwidth, distance and modulation to be used.

But just like in a file system where continuous allocation and deallocation of space used by files with variable size causes fragmentation issues, the EON is subject to fragmentation of the light spectrum that can lead to lower efficiency and block of requests even when there are available slots.

There are several studies being made since 1990's such as [1] on how to reduce fragmentation effects through Routing and Wavelength Allocation (RWA) algorithms and de-fragmentation techniques. Also, some of the approaches to reduce blocking ratio make use of wavelength converters in some or all routing nodes in an optical network. But due to the high cost involved in adding the capability of wavelength conversion in all network nodes, this study will verify how much improvement the use of wavelength converters can bring to a network environment by comparing the results of RWA simulation on a pure optical network versus the use of wavelength converters at the minimum number of network nodes.

Through the use of a specific simulator to be developed as part of this work, given a network topology, saturation will be simulated and the results (number of created links, fragmentation metrics, wavelength allocation and some other metrics) will be compared with the same experiment on the same network, but this time using converters installed at specific point that will be defined automatically by the simulator through defined criteria, that might be: first fiber experiment wavelength allocation block, most used fiber (in terms of wavelength allocation) or most fragmented fiber (in terms of spectrum fragmentation).

The use of wavelength converters is known to help decreasing blocking ratio by bending the wavelength continuity constraint and allowing links to move to a different wavelength in a specific fiber in case the original wavelength used for the link is already allocated to another link. Although its benefits are known, there is no real data on how much of improvement they can bring when used in one core node in the network, nor how much benefit converters in more than one location can help improving the wavelength allocation.

This study will help to understand, through experimentation and real numbers, how much the use of converters will improve spectrum allocation efficiency through comparing metrics of the exact same network, with and without wavelength converters.

II. EON FUNDAMENTALS

Elastic Optical Network is the name given to optical networks that implement the concept of flexible spectrum

A. Routing and Wavelength Assignment (RWA)

The determination of the assigned route for a lightpath can make use of different approaches and algorithms depending on the scenario where the allocation will take place, and the concept behind it is to enable the creation of lightpaths using the best route and the minimum number of different wavelength allocation. Fig.2 demonstrate a graphical representation of the RWA process reusing wavelengths for different links that do not share the same fibers. For static scenarios, as known as Static Lightpath Establishment (SLE), where all links with its details (sources, destinations, bandwidth requirements, modulation and so on) are previously known, usually the routing problem is solved as a Integer Linear Program, while the wavelength assignment is based on the graph coloring algorithm. The reason for such approaches is that, by knowing all the lightpaths that need to be established and their technical requirements without no specific order, the solution can be found using optimization techniques.

For incremental scenarios (where new connection requests are received in an unknown or random sequence, and established lightpaths are not to be deactivated), or dynamic scenarios (where the lightpaths can be deactivated and resources deallocated), other solutions are used, such as the Dijkstra’s algorithm (also known as Shortest Path First Algorithm – SPF) and Bellman-Ford, for best routes, but studies such as [2] and [3] have shown the best approaches to reduce blocking probabilities are “fixed-alternate routing” and “adaptive routing”.

The former makes use of static routing tables with multiple routes from each endpoint to other endpoints, so in case the best route cannot be used due to the lack of continuous wavelength, the second route can be attempted, and so forth until a route is found or a block decision is made. The latter will dynamically calculate routes based on the network status at the time of the request and look for the best route where wavelength assignment can be performed with lower cost.

Even more complex routing and wavelength allocation algorithms that consider distance and modulation techniques can be found, such as the “Distance-Adaptive Spectrum Slot Allocation Algorithm” described in [4] and different approaches to handle spectrum allocation such as Orthogonal Frequency Division Multiplexing (OFDM) for Optical Networks detailed in [5], but such approaches are out of the scope of this study.

B. Spectrum Fragmentation

Every time resources with variable size are allocated and deallocated, as it happens in computer memory and file system, fragmentation can occur and that can reduce the efficiency use of the entire system. Sometimes, even when there is enough space to accommodate a new allocation request, the allocation cannot be performed because the available space is not continuous. That is exactly what happens with the light spectrum used for EONs as illustrated in Fig. 2.

The use of variable width of wavelength allocation and the allocation/deallocation sequences will fragment the spectrum and due to the continuity and contiguity constraints, the blocking probability can rise unless some defragmentation procedure takes place. In [6] and [3] there are extensive explanations and studies about most important strategies for proactive and reactive defragmentation, using re-routing and without re-routing techniques.

C. Wavelength Converters

One of the possible solutions to minimize fragmentation and the number of required wavelengths for a defined network scenario is the use of wavelength converters. Some details of the development of wavelength converters and testing can be seen since early 2000’s in [7] with information about the development of Periodically Poled Lithium Niobate (PPLN) based converters and testing its use in optical networks. PPLN converters creates a converted signal through the use of tunable pump lasers as graphically demonstrated in Fig. 3.

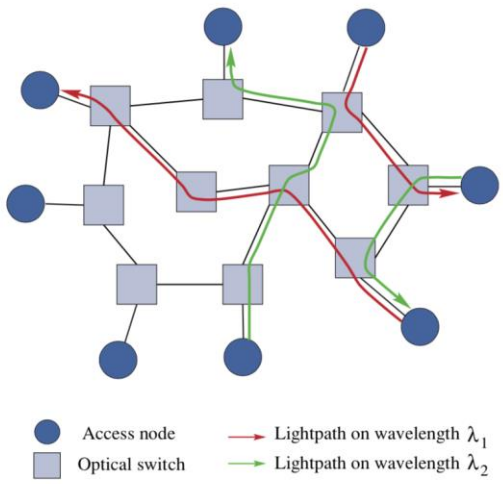

Fig. 1. A wavelength-routed optical WDM network with lightpath connections. Source: [10]

The idea behind the use of wavelength converters is to bend, or even remove the wavelength continuity constraint on optical networks, by allowing a link to change its frequency whenever it crosses a routing node equipped with a wavelength converter. An easy way to define a wavelength converter to a computer network professional would be to compare its function to a NAT (Network Address Translation) device, as the wavelength converter "translates" the frequency being used by a lightpath.

III. Methodology

Considering the focus of this study being the comparison of blocking ratio of networks with and without converters, the use of multiple routing or wavelength assignment algorithms would add complexity to the study and would not help understanding the value of using converters in the routing nodes. In fact, comparisons of the variation of algorithms would replicate several other results already published comparing RWA/RSA algorithms such as in [8], [9] and [10]. For that reason, it was decided this study would use a single and defined RWA approach in all scenarios and variations would only be used when relevant to the study: the number of wavelength converters being deployed, criteria for its placement on the network, and how routing and wavelength assignment processes sequences will be triggered in the iterations in the assignment process.

A. RSA/RWA Simulator

Since there is no RSA simulator that addresses the defined requirements, a new simulator will be developed to address the needs of this study.

Its priority is to be able to calculate routes and wavelength assignment for SLE scenarios in an environment without converters, and based on the results and blocking probability, the simulator will assign a defined and configurable amount of converters to network nodes based on different and selected evaluation criteria, and process the entire SLE allocation again in the environment, but now considering the use of the wavelength converters and the defined costs for their usage, and compare the final results and blocking ratios.

The objective is to evaluate how much the use of the converters can improve network allocation, compare the different converter placement criteria and different routing/wavelength assignment iteration sequences.

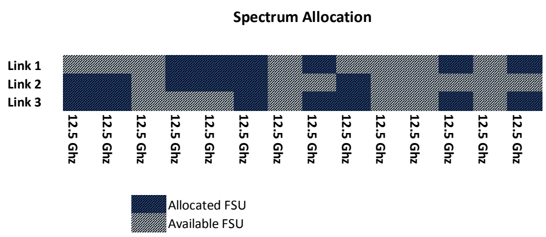

Fig. 2. EON Spectrum Fragmentation Graphical Representation

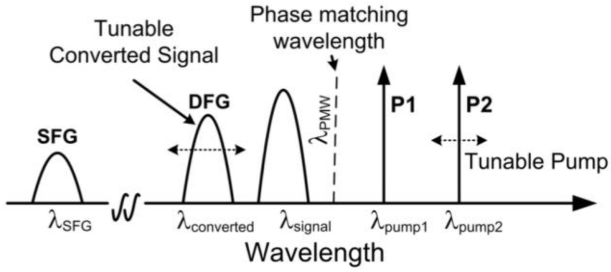

Fig. 3. Operating principle of cSFG-DFG process in PPLN for phase-transparent wavelength conversion. Source: [11]

IV. Expected Results

Published studies on the use of wavelength converters have already demonstrated it can help reduce blocking probability on EON such as in [12], but the expectation for this study is to map the difference of placement criteria and how they change the blocking probabilities and also map whether or not the sequence of routing and wavelength assignment processes during the iterations will vary those results.

It is expected, though, that we will see different results whenever we change the used criteria for wavelength converters placement and how the algorithms will use them to allocate resources in the network regarding iteration sequences.

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