# Routing and Allocation of Wavelengths in Elastic Optical Networks: A Survey

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### Abstract

**Objectives:** The current technologies of wavelength routing and allocation of available for WDM networks are no longer applicable in Elastic Optical Networks (EON), since all their connections are allocated in a fixed manner, as provided for ITU. Therefore, the topic concerning routing and allocation of resources in EON is relevant given the growth projected in web traffic. This survey includes the evolution, main characteristics, and the process of routing and allocation of wavelengths required by EON. **Methodology:** The processes of allocation of sub-wavelengths and those of super-wavelengths are presented, as well as the multiple storage for different transmission rates and the principle of spectral contiguity. The process of routing and allocation taking OFMD into account is explained. **Findings:** In this study, we present a survey with routing and allocation techniques of wavelengths that improve the spectral efficiency of EON. **Application/Improvements:** This survey provides a wide knowledge on the methods to improve the spectral efficiency in EON. Such efficiency can promote an advance in new routing and allocation techniques for the optical transport networks.

Keywords: Elastic Optical Networks, EON, Optical Networks, Routing, WDM

# 1. Introduction

During the last decade, the web traffic and new apps have grown to a yearly rate of more than 40%, causing the bandwidth used in the optical fiber to rapidly approach its maximum limit, glimpsing the possibility of the saturation its capacity<sup>1</sup>. Such growth lies in the demand of high-definition video by the final users, hastened by the high demand and usage of Smart phones, tablets and mobile devices that require connection every time, everywhere. Plus, users demand services for the massive storage of information in the network. All these events lead to increasing cloud storage, an additional increase. This new consumption and storage paradigm is an opportunity for the main service suppliers in tele communications; however, new functionalities in transport networks are required to provide the best experience to the users, which will turn into additional costs for operators. Given this situation, optical networks face difficulties such as the technological heterogeneity and strict efficiency demands of the optical spectrum<sup>2</sup>.

Nowadays, there has been a great advance in a new concept in transport technologies for optical networks, such as Elastic Optical Networks (EON). In a near future, network operators will require new transport networks to take an increasing volume of traffic that considers the cost-benefit ratio and efficiency. When exceeding the limits in the spectral allocation of the fixed network WDM, the EON increase flexibility in connection provisioning. Nonetheless, and depending on the traffic volume, an optical spectrum of right size is allocated to the network connections. On the other hand, and unlike the optical channels implemented on WDM networks, a light path or optical path can be expanded or contracted in order to meet the different needs of bandwidth in EON. Thus, the incoming connection requests can be served with the efficient spectrum management.

The concept of EON poses great challenges in the network, mainly in assuring efficient connections. Like in networks WDM, a connection uses a spectral portion in each one of the network links to be working in. This is due to the spectral continuity principle. Likewise, the connection bandwidth through the network must be fixed contiguously, assuming the restriction of spectral contiguity. The principle of contiguity generates complexity challenges to the wavelength routing and allocation problems. The proposals of wavelength routing and allocation available for WDM networks are directly applicable to EON due to the fact that all their connections are allocated in a fixed manner as stated on the ITU<sup>3</sup>. Therefore, the topic of routing and resource allocation in the flexible networks is relevant given the projected.

# 2. Survey

Nowadays, the evolution in the transmission systems to 100 Gb/s has aroused a great motivation and interest on implementing technologies of next-generation optical fiber transmission with transmission rates up to 400 Gb/s and 1 Tb/s. Those systems can use and seize modulation formats of higher level, spectral configuration, and transmission devices with densely concentrated, accepting a super channel implementation, in order to increase global capacity of the system regarding current technology, and thus improving the energy consumption so that it is still profitable to industries suppliers of the telecommunications service.

# 2.1 Evolution of Optical Networks

In the last 10 years, the implementation of optical networks has undergone an extremely fast evolutionary process, taking into account the high traffic demand in the network exponentially in order to supply the needs of capacity<sup>4</sup>. This type of networks must find itself obliged to adapt to superior capacities, such as 100G by cannel, along the increase of spectral efficiency.

It can be said that the pioneers on implementing a system of optical transmission go way back to the late 70ies, where a new thinking in the way of transmitting information through optical fiber began. The first method of optical transmission entered the market in taking into account a transmission rate of 45 Mb/s<sup>5</sup>. This simple design of wavelengths, composed by multiple optical links, an optical transmitter/transceiver, optical fiber and receiver, each one spliced to an electronic regenerator in order to mitigate the loss of signal distortion presented in the fiber. In such period, the need of implementing transmission systems to higher velocity and higher capacity rates demanded new designing of faster transmitting devices and detectors.

In the early 90's, after a long struggle for improving and innovating optical network devices in telecommunications, there was an upgrade to optical transmission systems of approximately 2 Gb/s in the network The design of such networks focused on transport of voice traffic; nonetheless, certain services of data information and fax implementation made traffic increase in the network. Such technological booming made that some of the big companies want to have this implementation and want to be interconnected globally. This fact demanded the submarine transoceanic installation of the transmission being transferred to optical fiber in the submarine system TAT-8<sup>6</sup>. Monetary issues of that time affected in some way the implementation of this type of optical technologies due to the fact that the investment for this optical transmission was very high. Thus, the first thing in mind was the improvement and allocation of more capacity to satisfy demands and decrease the transmission expenses.

The evolution to the optical transmission systems with transmission rates higher than 10 Gb/s, along with problems signal transmission inefficiency due to linear and non-linear phenomena, was an aim for research. When allocating a transmission wavelength near to the window of 1500 nm, it was possible that effective detections of transmission to high rates took place in this region due to the low percentage of doped silicon (chemically) in the fiber. Unfortunately, this wavelength region did not adjust to the minimum requirements of the dispersion window applied only in standard mode. For that reason, one of some solutions attempted to be implemented was to create a fiber containing such a design that would match the loss offered by the wavelength with the minimum dispersion window. Such phenomenon is nowadays known as Dispersion Shifter Fiber<sup>z</sup>.

The growth in traffic and possible migration to optical transmission systems with greater higher transmission rates to electronic devices posed serious problems. The design of optical transport networks did not seem to be very effective if thought in terms of such transition. Scientific community was, undoubtedly, aware of the fact that the WDM networks could increase the fiber capacity. Rod C. Alferness<sup>8</sup> describes how the microwave transmission systems with multiple wavelengths work. Such development led to the proposal of WDM systems as the evolution of optical transmission systems. This new technology showed that the entire spectrum to be used in the fiber is divided on a series of wavelengths that do not meet, also known as frequency bands. Here each wavelength carries only one communication channel working to any transmission rate. Thus, WDM does not allow certain inefficacies in transmissions, caused by the high transmission rates. Next, the implementation of unique frequency lasers and multiplexing devices of passive wavelength took place. Those devices allowed optimal and robust wavelength multiplexing according to the needs and requirements of high transmission<sup>8</sup>.

Implementing TDM would allow less complexity and energetic consumption due to the activation of its electronic device. This causes the WDM process to be independent and not affected by transmission rate<sup>9</sup>. Following the evolution of this type of technologies, a drawback for the economic viability of transmission systems WDM before the availability of optical amplifier, was the cost of electrical regenerators. In the first WDM systems, the compensation of loss in the optical transmission was accomplished by means of electrical converters, used in systems on one channel. Here, each wavelength in the WDM system has to be de-multiplexed and electrically changed; this process INS known in the field as optical-electronic-optical conversion. Certain converters were required in order to restore the electrical signals. In that sense, the implementation costs to update the transmission system would increase taking into account the increase of network capacity<sup>10</sup>.

A new and more complex model of optical switches is the implementation of a switching matrix called Optical Cross Connect (OXC). This switch uses a commutation matrix to change one particular wavelength, taking into account a given number of fiber inputs in order to route such waves to each of the fiber outputs for example, a ROADM (Reconfigurable Optical Add/Drop Multiplexing<sup>11</sup>). This means that the model is a mix of de-multiplexed wavelengths, optical-spatial commutation, and the wavelength multiplexing. The type of optical switching device used in optical networks is a space division; the physical route switching device is the one that changes the optical wavelength carrying the coded signal between one and several paths. Optical electronic commutation generates thermic and electro mechanic effects, which are implemented for the effective commutation function. Once the optical trajectory being rearranged on a specific wavelength, such channel allows to carry out information sending, regardless the transmission rates; this is why the cross-connect techniques of optical insertion and extraction connect network elements taking into account any transmission rate taken by a wavelength. This represents a great advantage for the optical commutation in transport network. Likewise, in scientific literature, great capacity matrixes are presented, which are able to improve the performance of E.O commutation. Controlled by a great variety of inlet fibers and a cluster of outlet fibers, optical switching devices based on niobate lithium or chemically represented as L<sub>i</sub>N<sub>b</sub>O<sub>3</sub> and directional couplers were used to demonstrate the possible applications of optical commutation<sup>12</sup>. This research showed a different way of thinking when comes to comparing and mounting the optical cross connects. In the last years, electrical cross connect has been implemented for channel transmission of maximum rates of approximately 45 Mb/s, making it necessary to set great changes in designing electrical commutation and electrical wiring for the articulation of new commutation technologies. Hence, optical commutation displayed advantages in terms of energy and space consumption, mainly because the signals are turned on to several hundreds of Mb/s. Such advantages provided a very useful opportunity to develop commutation grids achieving an understanding with applications to connect transport networks in general.

# 2.2 Elastic Optical Networks

Currently, it is intended that the transport optical networks are transformed as flexible, adaptive or elastic networks; reconfigurable and heterogeneous networks. Elastic or flexible networks are possible by means of the implementation of techniques allowing the division of optical spectrum in a flexible fashion, and also the dynamic allocation of transmission data in the nodes<sup>13</sup>. The concept of flexibility states that the network is able to adjust dynamically the available resources in accurate manner, according to the variations in traffic conditions; that is wavelength channels, bandwidth, transmission format, data speed, power<sup>14,15</sup>. In a transport network, this new concept will permit new network architecture beyond the physical connection between the nodes, in order to make it possible to connect such nodes using different paths, depending the required bandwidth, either by means of the allocation of wavelength clusters or the connectivity with all the capacity of the super channel. In reconfigurable optical networks, the rate and the modulation formats are fixed, and the network adjusts the transmission according to the changes of the net physical conditions such as: optical power, wavelength, chromatic dispersion of the fiber, among others. In this type of networks, it is very important the Quality Of Transmission (QOT)<sup>16</sup>. Additionally, a new concept called heterogeneous optical networks appears. Such networks introduce new models in designing the network carrying a higher complexity. In this context, according to the user's traffic demands the bits' route, transmission route and modulation format are adjusted. Having these conditions clear, it is necessary to implement algorithms for routing and spectrum allocation, applicable for the allocation to each node<sup>17</sup>.

The concept of flexible optical networks has been introduced as a way of offering the efficient usage of available optical resources, as it adapts at the same time high data transmission speeds<sup>18</sup>. Such solutions offer a limited flexibility and cannot surpass the foreseen capacities of future transmission systems. Recent advances in Optical Frequency Orthogonal Division Multiplexing (OFDM), coherent transmission and Nyquist WDM (N-WDM) have established the scenario so that the totally flexible optical networks can adapt dynamically to the needs of each connection.

In order to obtain a clear vision of the flexible optical networks, it is necessary to migrate the configurations and analysis of the fixed grid in frequency established by ITU-T to one flexible configuration<sup>3</sup>. The flexible analysis allows the usage of ranges in finer, more compact frequency, while the case of the inferior analysis, or technically known as "Inferior grid" allows total flexibility that carry a great spectral efficiency and spectrum conservation. X. Cao highlights that when increasing the number of optical carriers, that is increasing the number of wavelengths for one fiber, an evolution to WDM takes place<sup>19</sup>. This is a successful technology, as fiber resources for several channels are seized, and the only necessary changes are in their ending points. In some cases, the traditional regeneration as optical amplification is simplified, being this simpler and more profitable process. Depending on the network application, WDM is divided into two main different branches of information transport, each with its own complexity, specifications and cost structure: WDM dense (DWDM), with more than 80 channels of wavelength by fiber, and y CWDM with less than 40 channels of wavelength by fiber.

In presents three mathematical formulations for the design of robust network allowing the flexible traffic, developing an iterative algorithm to solve routing problems and spectrum allocation<sup>5</sup>. Thus, it is possible to optimize in a great manner the designs for the next generation, so that the effective network consumption is improved. Also, a dynamic planning scheme is presented where the reserves in bandwidth work efficiently; allowing minimizing bandwidth fragmentation problem, as well as taking into accounts the wavelength resources. Such results brought an improvement in the performance of the dynamic network and an easier process in the reserves of bandwidth.

In the scientific literature, it was possible to reach the conclusion that two technologies allow to work efficiently the high traffic volume, enhancing its spectral technology in the optical network. The first is the advance of Optical technology OFDM<sup>20</sup>. Here, the data are transmitted through multiple orthogonal sub-carriers. Such technology has been largely used in several communication systems such as wireless networks LAN and Asymmetrical Digital Subscriber Line (ADSL). The great research centers aimed their efforts to develop an optical version of OFDM as a tool to overcome the transmission inefficiencies<sup>21,22</sup>. Likewise, that development shows great advantages due to its low transmission rate for symbols for each sub-carrier and coherent detection. All this allows mitigating the effects of physical inefficiency in the net. The technique OFDM allows certain unique benefits in terms of spectral efficiency, making the spectrum of nearby sub-carriers not to overlap to one another due to its orthogonal modulation. Consequently, the technique aims for flexibility in bandwidth by means of the allocation of a variable number of low-speed sub-carriers for a transmission.

Another technology that permits to give a new course to the optical transport network is that of the Cross-Connect (WXC) BV-Wavelength<sup>23</sup>. The WXC allows that the signal, spread through the optical route with the spectrum given by the traffic volumen, can be routed towards the receiver device. Each BV WXC in the route allocates a Cross Connect with the provided spectrum in order to create an optical route of adequate size from end to end. For that purpose, the BVla BV WXC has to configure its change/shift window in an adjoining manner, taking into account the spectral width of the incoming optical signal. The electromechanics based on liquid crystals or wavelength of selective shifters (Wss) can be used as BV WXC. With the aim of not allowing that the interference phenomena damaging the signal quality of each sub-carrier, the nearby optical routes require separating the correct and just spectrum, implemented by spectral guardbands. For that reason, in Figure 1, as it is the representation of a BV WXC for a node, the process of spectrum selection and allocation is shown here. The incoming spectrum for each divisor carries out a commutation process as far as the outlet ports reserved by the network; for the usage of the allocated spectrum, such spectrum is filtered by the different BV-Wss to form spectrum applicable or desirable in each outing port.



Figure 1. Variable Bandwidth Cross-Connect BV WXC.

EON depends on the traffic volume and the adequate spectral size, allocated to each connection<sup>24</sup>. That is that, unlike the fixed bandwidth with a fixed optical trajectory (which is actually applied in WDM networks for a flexible optical network) an optical route is expanded and contracted taking into account the request of volume traffic

and user. This special characteristic of flexibility in the allocation of optical spectrum that EON networks offer, allows making the most of the spectrum efficiency and its growth in the network. EON technology provides unique parameters, such as the segmentation and aggregation to the spectral resources, efficient allocation of various transmission rates, as well as the elastic variation of the allocated resources. Consequently, Figure 1 and 2 shows the way how the shift from WDM to EON is represented.

# 2.3 Principal Characteristics of EON

#### 2.3.1 Storage of Sub-wavelengths

As shown in Figure 2, the current WDM networks allocate a capacity of fixed and complete wavelength to an optical route, regardless if the traffic demand supported by means of this wavelength is not enough to. That is, a connection with sub-wavelengths is given at this point. Here, this implementation mechanism is no efficient as the usage of spectral resources in the network is wasted, and is not fully used.

EON provides a new mechanism for the management of sub-wavelengths, taking into account its cost-benefit relation; that means segmenting or dividing the bandwidth. In Figure 2, only the bandwidth allocation needed to store the user's traffic is shown, each node in the route of the optical trajectory allocates a cross connection with the spectrum bandwidth in order to create an accurate optical trajectory from beginning to end of the network. That is why that by means of an effective implementation of the network resources, the effective allocation of connections can be obtained.



Figure 2. Spectral Allocation in WDM.

### 2.4 Storage of Super-wavelengths

This feature is very important and fundamental for optical transport networks since it requires greater wavelength capacity. In WDM networks, various autonomous channels are assigned to serve this type of connections requests; that is to connections with super-wavelengths but taking into account that the spectral guardbands are necessary to be implemented between nearby channels for commutation. Such process increases even more the spectrum overload. In order to provide a better spectrum usage, EON networks adapt the spectrum allocated to the specific demand requirements, regardless the total bandwidth that is needed Figure 3.



Figure 3. Spectral Allocation in EON.

# 2.5 Multiple Storage for Information Transmission Rates

As visualized in Figures 2 and 3, EON allows efficient spectrum storage for different transmission rates in the optical domain; this happens due to the spectrum flexibility allocations. On the other hand, WDM networks with fixed grid can lead to modifications and variations of optical bandwidth due to the frequency separation for signals of low-transmission rates. Consequently, the optical flexible networks support various rates of information speed and showing an efficient spectral.

# 2.6 Principle of Spectral Continuity Restriction

Despite the fact that the EON provides several benefits, their incorporation represents great challenges at the level of networks, mainly in the setting of efficient connections. The same way as to the WDM networks, an elastic optical connection must occupy the same spectrum portion between its final nodes, assuring the principle of spectral continuity. Likewise, the whole connection bandwidth must be allocated contiguously, assuring the principle of spectral continuity restriction. This las principle aggregates a new complexity degree to the conventional wavelength routing and allocation problem. It is very important to state that the wavelength routing and allocation proposals available for WDM networks are no longer directly applicable to optical flexible nets. Thus, new schemes of resource allocation and routing must be designed. The problem of spectrum routing and allocation has gained a lot of relevance in the scientific and academic community in the last years, with a special focus on scenarios of dynamic networks. Here, the arrival of output processes and connections take place randomly where the network accommodates the input traffic in real time. This problem and its possible solutions will be detailed in next chapter.

Most of the work that implements the concept of flexibility or flexible network analysis is focused on the analysis of the improvement and upgrading of bandwidth, spectral efficiency and flexible dynamic traffic, aiming to minimize the energy consumption and cost resources in the net<sup>25</sup>. The Passive Optical Network (PON) is described as an attractive solution to service provision with numerous applications, such as videoconference high definition and data traffic. Here the author develops models of tele traffic taking into account the losses for the estimation of the connection failure probabilities. The identified problem happens due to the lack of a wavelength and blockage probabilities, product of restricted bandwidth capacity of a wavelength that takes into account TDM-PON WDM with dynamic allocations for a flexible traffic. The proposed models result from one dimension in Markov chains that describe the service system in PON networks. The wavelength occupation in PON networks is also provided. The accuracy of the proposed models has been validated by simulations and has been found to be quite satisfactory.

# 2.7 Routing and Allocation of Wavelengths

Besides the articles mentioned in this document, it has been found that EON have been used as resource improving and upgrading techniques for the optical networks. Patel implements a heuristics for the routing and storage problem in the allocation of variable bandwidth<sup>26</sup>. The author proposes that the proposed heuristics minimizes

the latency for each request and reduces greatly the blockage possibility in comparison to traditional approaches in circuit commutation of the optical network. It is possible to obtain a better usage of the bandwidth, taking into account multiple sub-carriers, and this mitigating the effects of delay and propagation. On the other hand, in the last years, other types of solutions to the spectral efficiency problem for long-range transmission have been searched. Thus, the article proposes to solve such problems by means of modulation techniques. The mathematic statement attempts to adjust and solve the number of modulation levels. That is demonstrated by means of the optical routing of 40 Gbit per second, using low-range routes, 16 APSK of reduced spectrum and QPSK of longrange. Nonetheless, the obtained results are only presented for a small topology of 6 nodes in MESH configuration, and do not indicate its scalability. In such article, the author bears in mind that this is a totally optical network, avoiding the massive usage of amplifier and repeating devices. In more recent studies algorithms incorporating dynamic RMSA with a hybrid routing single-path/multipath (HSMR) scheme are proposed. The authors analyses two kinds of HSMR schemes; that is (HSMR-OPC) for different routes and HSMR using a fixe route (HSMR-FPS), which analyses the route selection problems for an optimal design. The authors assess proposed algorithms with numerical simulations using a traffic model by Poisson and two typologies with MESH configuration. The simulations outcomes showed that the proposed HSMR schemes can reduce effectively the bandwidth and blockage probability by taking into account dynamic RMSA, compared to the two reference algorithms, which use only one routing path and spectrum segmentation. The simulation results suggest that HSMR-OPC can reach higher efficiencies among all the BBP HSMR regimes; this can be attributed to the fact that HSMR-OPC optimizes the routing paths for each request over the process with considerations of using bandwidth and lengths in two links. The impact of the proposed algorithms on other networks, including the metrics of network performance, and performance considering bandwidth, will permit to consider dynamic RMSA for diverse selection routes for the provision of multiple trajectory in O-OFDM networks. All this will allow strengthening flexible networks taking into account the dynamic Routing, Modulation and Spectrum Allocation (RMSA).

In analyzed the existence of a great variety of factors that bring uncertainty in the demands and needs of traffic. The authors identified that the flexibility problem in the optical network is related, or linked, to the bandwidth granularity. For that reason, it is necessary to improve the spectral efficiency for the enhancing of the bandwidth and system capacity. The method proposed by the authors allowed them, to generate mathematical models to improve optical node flexibility, commutation systems and optical system architecture. Implemented architectures support continuous heterogeneous signals and subwavelength with rates going from 190 Mb/s per second for a subwavelength channel to 555 Gb/s for a super channel with multi-carrier. The results show a great performance and viability of the application in the concept of low-demand architecture.

# 3. Conclusions

This study provides information on the optical networks evolution, mainly until reaching Elastic Optical Networks. Information about the techniques on wavelength allocation and routing in order to optimize the efficiency of EON. Those networks allow decreasing costs to support the Internet traffic growth.

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