MIGRATION TO NEXT GENERATION OPTICAL NETWORK
OFDM based ElASTIC OPTICAL NETWORK

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***Abstract*—The rapid growth in the data traffic lead to the need of optical network that operates beyond 100 Gbps and one of the network that we are going to discuss in this paper is Elastic Optical Network (EON). The multiplexing technique efficient for EON is Optical Orthogonal Frequency Division Multiplexing because of its high spectral efficiency, robustness against inter-carrier and inter-symbol interference. In this paper, we are going to present a survey on O-OFDM based EON, Routing and spectrum assignment and Survivability in EON.**

I. Introduction

The data traffic growth in worldwide is increasing day by day so there is a requirement of optical network which can support high bandwidth, high speed data transmission, and is cost effective. To accommodate high capacity demand i.e., beyond 400 Gbps, elastic optical networks can be used. OFDM based EON is very efficient technology as it focuses on OFDM technology, and its flexible properties. OFDM based EON has various advantages as compared to previous optical networks vig., segmentation of Bandwidth, aggregation of Bandwidth, accommodation of multiple data rates, energy efficiency and virtualization.
Fig.1 shows comparison between conventional and elastic optical paths [1, 2].

II. Elastic optical network (EON) architecture

The elastic optical network is very useful in order to fulfill the need of increasing bandwidth demands because of its flexible data rate and spectrum allocation, low signal attenuation, low signal distortion, low power requirement as some subcarriers can be switched off when not required, low use of material, small space requirement and low cost. In this section we are going to discuss about architecture of elastic optical network as shown in Fig.2 [3] and its various components (sliceable bandwidth variable transponder and bandwidth variable wavelength cross-connect).

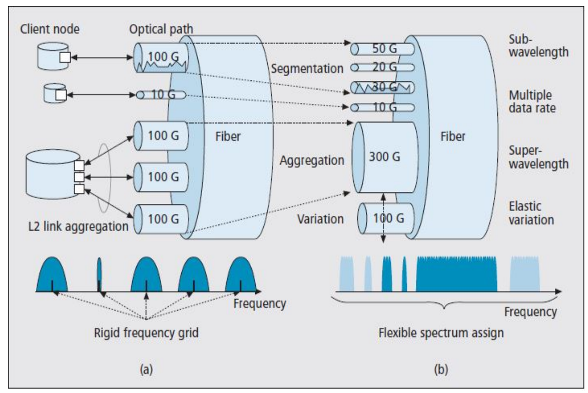

Fig. 1. Comparison between conventional and elastic optical paths reproduce from [1, 2].

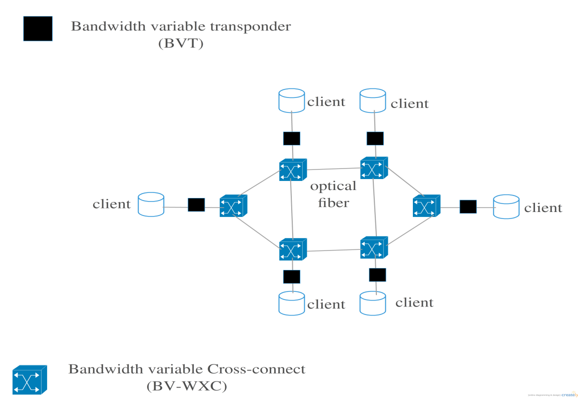

Fig. 2. Architecture of Elastic Optical network.

A. Components of EON

The two main components of EON are (i) Sliceable Bandwidth Variable Transponder (ii) Bandwidth Variable- Cross Connects.

1) Sliceable Bandwidth Variable Transponder(S-BVT): SBVT can tune optical bandwidth and transmission reach by adjusting certain parameters such as bit rate, forward error correction, modulation format, and shaping of optical spectrum [4].

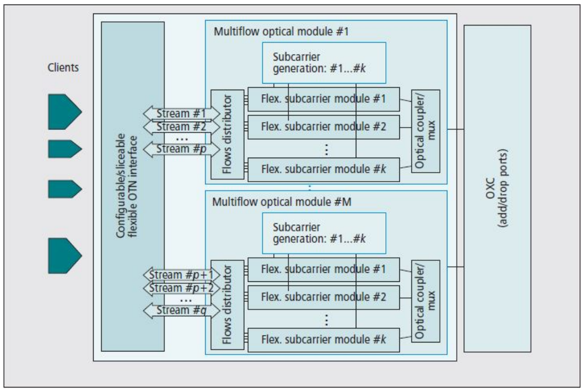

Fig. 3. S-BVT Architecture reproduce from [4].

In this bandwidth is sliced so as to serve several traffic demands to one or more destinations. Fig.3 shows architecture of S-BVT.
Configurable/Sliceable flexible Optical Transport Network (OTN) interface is used to slice high data rates to lower data rates for example as shown in Fig.4 1 Tbps is sliced into 600 Gbps and 400 Gbps [4].

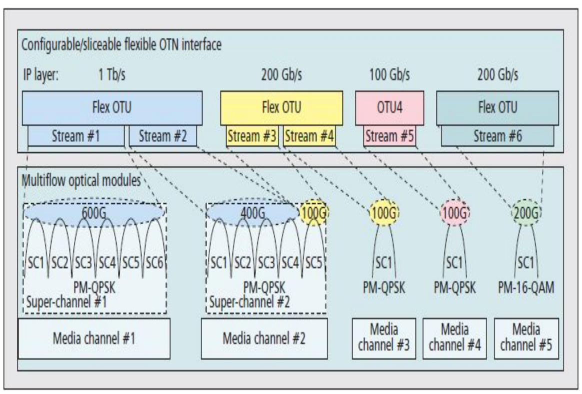

Fig. 4. OTN frames and flexible association with media channels reproduce from [4].

Each multi flow optical module is used to generate multiple sub-carriers. The p-stream from the OTN layer are used to modulate k non modulated sub-carriers where k is greater than equal to p. The modulated traffic is multiplexed via optical mux/coupler and output goes to the fiber.

2) Bandwidth Variable- Cross Connects(BV-WXC): BV-WXC is used to allocate appropriate sized cross connection with the corresponding spectrum bandwidth for elastic optical network. Fig. 5 shows architecture of BV-WXC [3]. Here BVT is Bandwidth Variable Transponder and BV-SSS is Bandwidth Variable Spectrum Selective Switch.

Whenever there is increase in traffic, the transmission capacity of transmitter increases and therefore switching window of every WXC on the route expands in a flexible way according

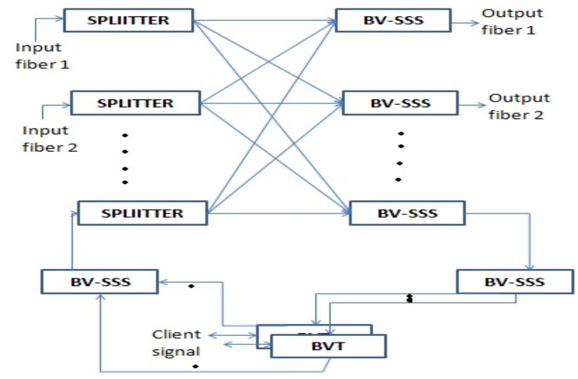

Fig. 5. BV-WXC Architecture.

to the spectral width of the input signal. BV-SSS performs multiplexing/De-multiplexing of spectrum. BV-SSS can be designed using either Liquid crystal on Silicon (LcoS) [5] or Micro-Electro-Mechanical System (MEMS) [6] that can be employed as switching element to realize an optical cross connect with flexible bandwidth and center frequency.

III. ROUTING AND SPECTRUM ASSIGNMENT(RSA) IN EON

A. Basic concept of RSA

RSA is used to find route between nodes and allocate spectrum slots to the desired demand. For RSA two constraints must be satisfied:
1. Spectrum Contiguity: contiguous sets of spectrum must be allocated for a connection.
2. Spectrum Continuity: same set of spectrum must be allocated on each link along the route of the demand [3].
The above both constraints are shown in Fig. 6

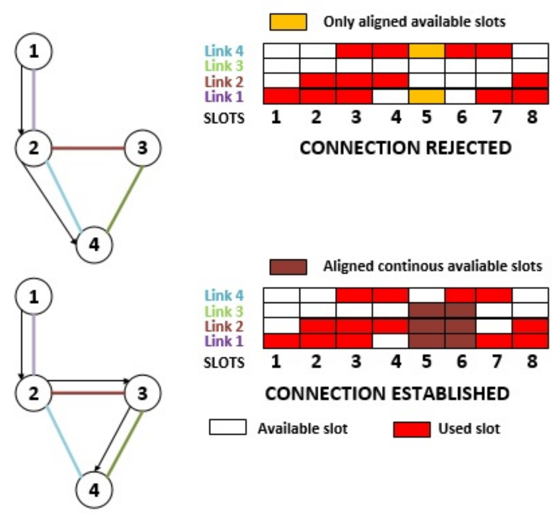

Fig. 6. Spectrum contiguity and continuity constraints.

First we are going to discuss about routing and after that about spectrum allocation.

B. Routing

There are two types of routing i.e., without elastic characteristics and with elastic characteristics. Since we are discussing about elastic optical network, we will focus on routing with elastic characteristics.

Routing with elastic characteristics: In this approach, when a connection request arrives, a group of frequency slots for a connection are allocated. In this multipath routing is used instead of single path routing because of spectrum fragmentation in single path [3].

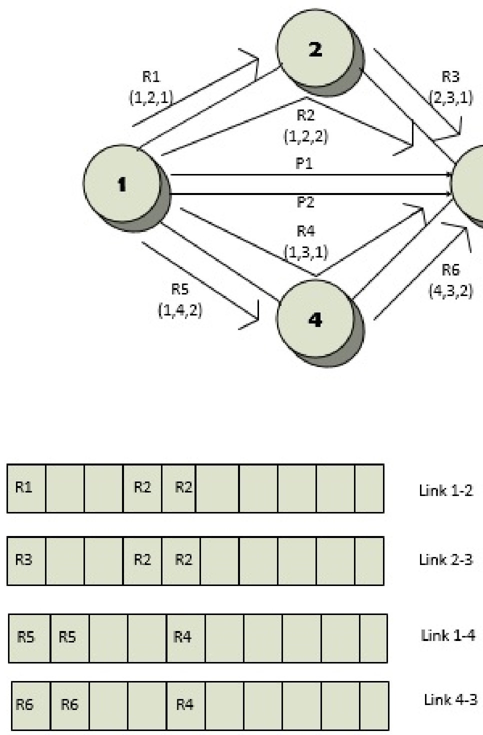

Fig. 7. Multi-path Routing in EON.

In Fig.7, R(S,D,F) is a connection request between node pairs (S: source, D: destination) with F: number of contiguous spectrum slots. In this, two slots are reserved for guard band. Let us explain this with an example as shown in Fig.7, R7 connection request arrives from node 1 to node 3 with a demand of four frequency slots. As it is unavailable the demand will be blocked. But with the help of multipath routing, two paths P1 and P2 can be generated through which connection request can be fulfilled.

C. Spectrum Allocation

In this spectrum allocation is categorized based on the spectrum range for connection groups and spectrum slot for individual connection request [3].

1) Spectrum range for connection groups: This is further categorized in three parts:
a) Fixed spectrum allocation: Central frequency and assigned spectrum width remain static as shown in Fig.8 [7, 8] Demands either utilize the whole of it or only a part of it.

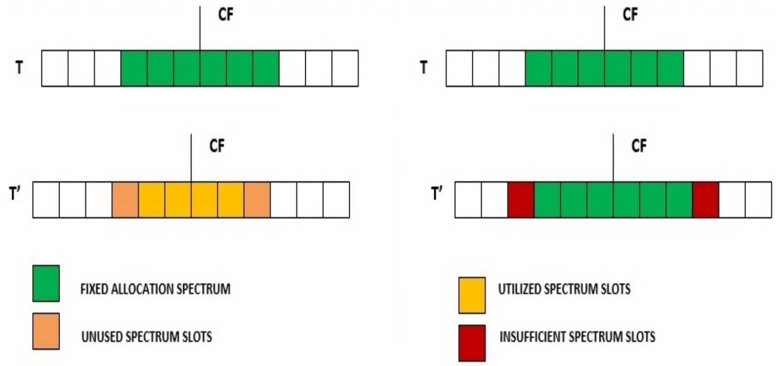

Fig. 8. Fixed Spectrum Allocation (a) underused spectrum condition, and (b) insufficient spectrum condition.

b) Semi-elastic spectrum allocation: In this central frequency is fixed but we can vary the spectrum dynamically width according to our requirement as shown in Fig.9 [7, 8].

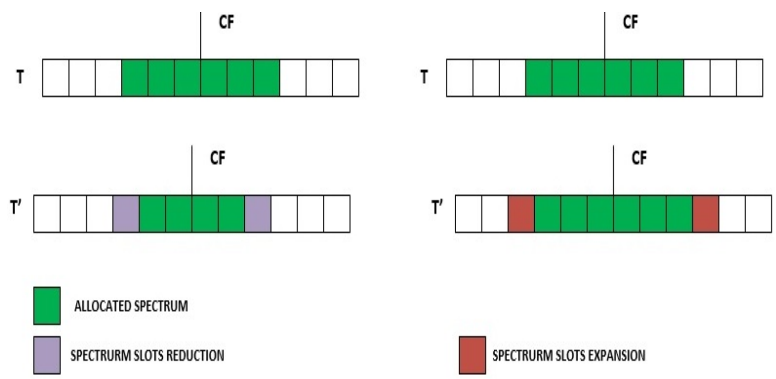

Fig. 9. Semi-elastic spectrum allocation policy with (a) spectrum slot reduction, and (b) spectrum slot expansion.

c) Elastic Spectrum allocation: The central frequency (CF) and spectrum width both can be dynamically varied. Two cases of elastic spectrum allocation are:
i) CF movement within a range
ii) Elastic spectrum reallocation.

Both the above cases are shown in Fig.10 [7, 8].

2) Spectrum slot for individual connection request: There are 7 allocation policies for individual connection request:
a) First Fit : In this spectrum slots are indexed. Whenever a connection request arrives, the lowest indexed slots from the list of available slots are allocated [3, 9, 10].
b) Random Fit : In this, a list of free or available spectrum slots is maintained. Whenever connection request arrives, from the list, any slot that available and suitable for connection, is randomly chosen [3, 9].

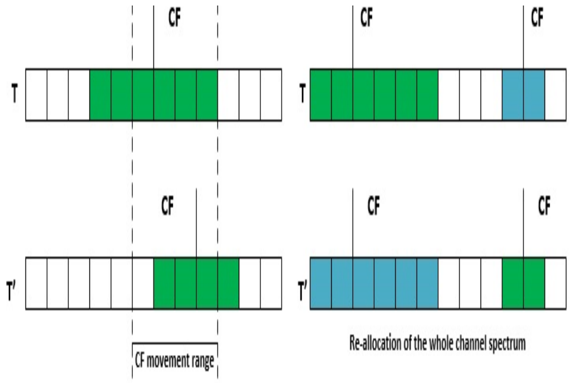

Fig. 10. Elastic spectrum allocation policy with (a) CF movement within a range, and (b) elastic spectrum reallocation.

c) Last Fit : In this, from the indexed spectrum slots, highest indexed slot is chosen for a connection [3, 11].
d) First-Last Fit: In this, all spectrum slots of each link is partitioned into odd and even numbered slots. The lowest indexed slot is chosen from from odd number of partition from the list of available slots. The highest indexed slot is chosen from even number of partition from the list of available slots [3, 10].
e) Least Used : In this, from the list of available spectrum slots least used slot is allocated to the demand. Otherwise, first fit method is used [3].
f) Most Used : In this, from the list of available spectrum slots most used slot is allocated to the demand. Otherwise, first fit method is used [3].
g) Exact Fit : In this, exact slots are allocated for a demand so that there is no wastage of slots. If not, the first fit method is used [3, 9].

IV. SURVIVABILITY IN EON

Various protection and restoration mechanisms are used for the survivability of elastic optical network. We will discuss only ring cover protection, p-cycle protection and bandwidth squeezed restoration.

A. Ring Cover Protection

Ring cover provides protection only on on-cycle span. In this whenever a link fails that is traversed through by pre-deployed rings, ring cover technique is used to find the eligible ring to provide protection to the failed link. Spectrum constraints must be considered in this scheme [12].

As shown in Fig.11 three pre-deployed rings for protection are (3-2-1-7-3), (3-7-6-5-3) and (3-2-1-7-6-5-3). If (2-1) link fails, this failure affects the two pairs of working nodes i.e., (3-1) and (2-7). So, the two pre-deployed rings i.e., (3-2-1-7-3) and (3-2-1-7-6-5-3) are used to recover the working flows. Two pair of fibers are used for working and protection.

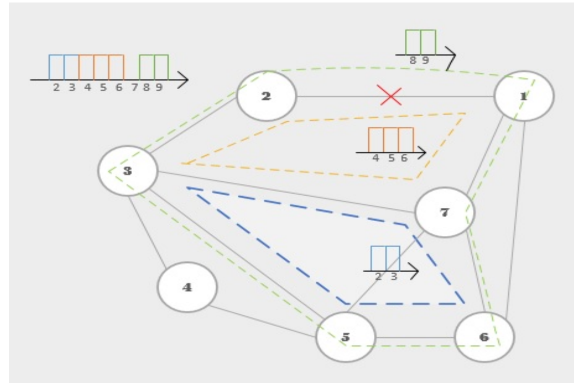

Fig. 11. Ring Cover technique.

B. P-Cycle

P-Cycle is considered significant technique for an optical network because it provides ring like restoration speed and mesh like spare capacity efficiency. P-Cycle provides protection on on-cycle as well as straddling span [13].

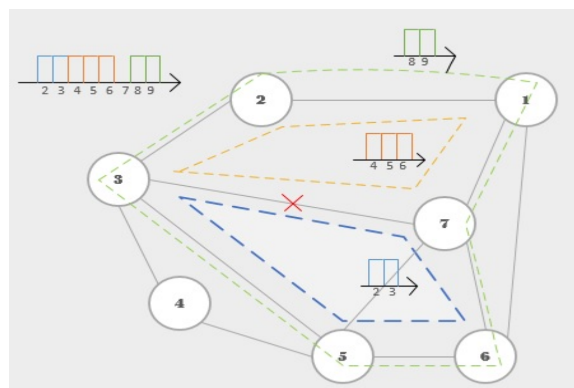

Fig. 12. P-cycle technique.

The concept of p-cycle used in elastic optical network, is shown in Fig.12. In this there are three p-cycles i.e., (3-2-1-7-3), (3-7-6-5-3) and (3-2-1-7-6-5-3) on which there are three working flows i.e., FS (2-3), FS (4-6) and FS (8-9). Let us consider span (3-7) is affected, so (3-7) is on-cycle span for (3-2-1-7-3) and (3-7-6-5-3) and straddling span for (3-2-1-7-6-5-3). In (3-2-1-7-6-5-3), there are two protection paths but due to the requirement of specturm contiguousness constraint only upper half of the cycle is used for protection. Two pair of fibers are used for working and protection in this scheme also.

C. Bandwidth Squeezed Restoration

The BSR scheme is a type of recovery scheme in which when working path is affected the bandwidth of backup path is reduced to the required minimum amount considering the client requirement when working path is switched over to backup path. This enables cost-effective restoration in terms of spectral resource utilization Fig.13. shows an example of the BSR scheme in which there are two optical paths in the network.

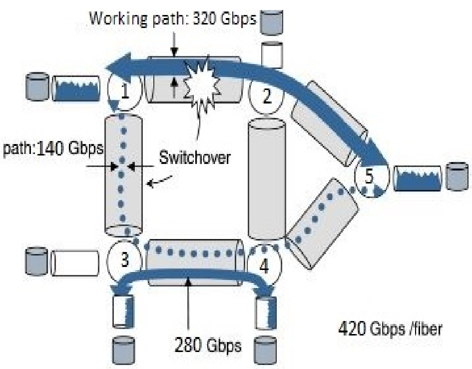

Fig. 13. Bandwidth Squeezed Restoration Technique reproduce from [14].

Two working flows one is from Node 1 to Node 5 which has a bandwidth of 320 Gbps and other is from Node 3 to Node 4 which has a bandwidth of 280 Gbps. Let us assume that each fiber has a bandwidth of capacity 420 Gbps and so the available bandwidth between Node 3 and Node 4 has 140 Gbps. As shown in Fig.13, the failure occurs in the link between Node 1 and Node 2, the optical path can be switched over to the Node 1, Node 3, Node 4, Node 5 route [14]. The path bandwidth is reduced by changing the bit rate of a bandwidth-variable transponder (BVT) from 320 Gbps to less than 140 Gbps. The recovery route can be calculated either in advance or after the failure occurs. Restoration must be done as fast as possible so as to avoid traffic loss.

V. CONCLUSION AND FUTURE WORK

The elastic optical network is a significant optical network technology for high speed transmission because of its flexible properties. In this paper different elements and aspects of EON has been discussed. We started with basic concept of EON, its architecture, and finally we covered different RSA and survivability issues in EON. Future work that can be done is instead of using optical OFDM we can use Orthogonal Wavelength Division Multiplexing(OWDM) so as to make it cost effective as there is no requirement of optical-electrical-optical converters (O-E-O) and all process will be in optical form.

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