An Overview of Elastic Optical Networks and its Enabling Technologies

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***Abstract*—Advanced optical communication network technologies such as Dense Wavelength Division Multiplexing (DWDM) can provide bandwidth up to 1Tbps, but these networks are not efficient in handling heterogeneous and variable traffic demands. In order to serve this huge and heterogeneous traffic efficiently there is a need for next generation optical networks. The recently proposed Elastic Optical Networks (EONs) can provide a long-term solution to handle this exponentially increasing data traffic efficiently and economically. In this review paper, we have presented the basic concept of the EONs, its properties and various design issues in EONs, which will be helpful for the researcher to understand the concept and pursue their work in this field more efficiently.**

Keywords: Elastic Optical Networks, Orthogonal Frequency Division Multiplexing (OFDM), Bandwidth variable-wavelength cross-connects (BV-WXC), Quadrature Amplitude Modulation (QAM)

I. INTRODUCTION

The recent advancements in mobile and multimedia technologies have triggered the growth of internet data traffic volume at an exponential rate. WDM technique has mainly been used in optical backbone networks in which various independent sources modulated using unique wavelength light source are combined with the help of a multiplexer and are transmitted over optical fiber [1][2].A demultiplexer separates the optical signal into appropriate detection channels for signal processing at the receiving end, as shown in Fig.1 given below.

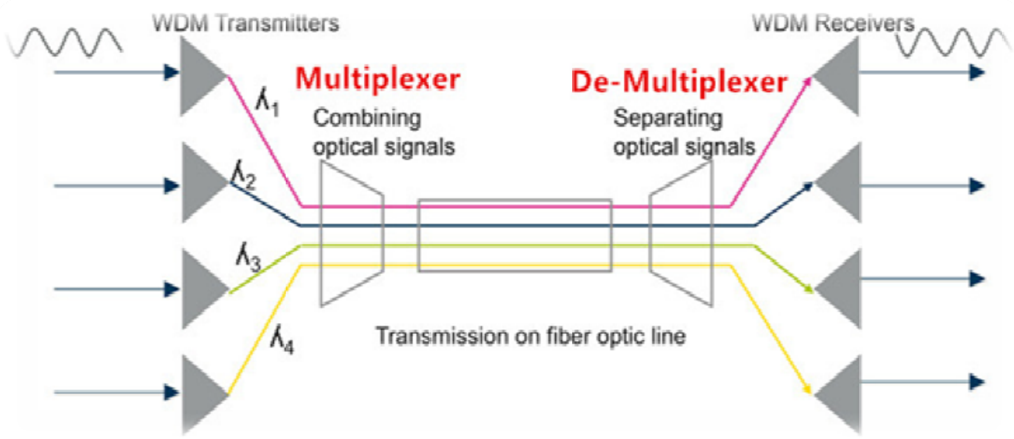

Fig1. Wavelength Division Multiplexing [2]

In order to meet increased data rate demands, modulation formats with a higher number of bits per symbol are used to accommodate heterogeneous traffic demand into existing 50 GHz fixed grid spaces standardized by International Telecommunication Union (ITU) [3]. However, with more bits per symbol, transmissions become prone to interferences and thereby suffer a higher SNR (signal-to-noise ratio) per bit, in turn, limits long distance transmissions.

Since WDM networks allocate entire wavelength to a connection even if the traffic demand is low and entire grid is not necessary as shown in Fig. 2 given below, thus this allocation for variable traffic demands leads to fragmentation of spectral resources as residual frequency parts in fixed grids limits the transmission efficiency due to inefficient spectral resource utilization [4].

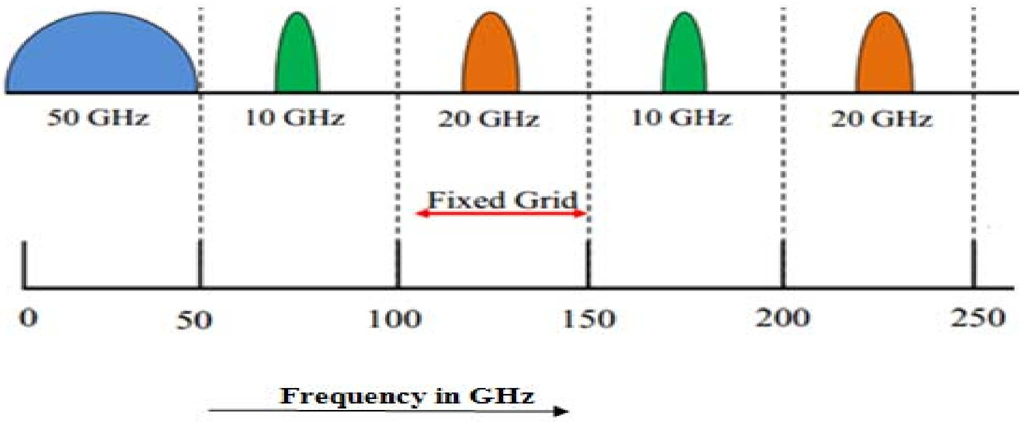

Fig.2. Spectrum allocation in conventional WDM network [3]

WDM networks waste energy when the entire grid is not used as transponders in WDM networks are unable to adapt to power consumption that depends upon the utilized percentage of the frequency grid [5]. Hence, these drawbacks of fixed grid wavelength networks require a more flexible infrastructure and network design. To accommodate heterogeneous traffic volume, recently EONs based upon OFDM have been proposed which makes the spectrum flexible and improves spectral efficiency as compared to WDM networks [6][7][8].

II. EONs

EONs are OFDM-based spectrum efficient, flexible and adaptive networks, equipped flexible trans-receiver with adaptable network elements have been proposed recently as an improvement over traditional networks. They provide an alternative to single carrier modulation technique as the data stream divided and multiplexed onto multiple consecutive low rate subcarriers and hence increase the symbol duration and provides a higher data rate [9][10].

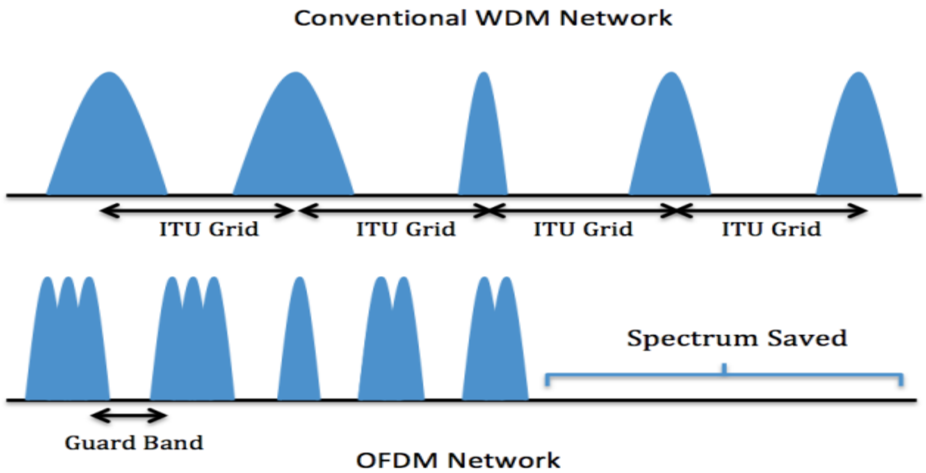

Fig. 3.Spectrum allocation OFDM network and conventional WDM network and along the frequency domain [10]

Unlike WDM systems, the use of OFDM allows subcarriers of the same light-path to overlap, thereby leading to high spectrum efficiency as shown in Fig.3 above .The term elastic in EONs refers to three key properties of the optical networks

- Flexible optical spectrum
- Bandwidth variable Transponder (BVT)
- BV-WXC.

The architecture of an EON is shown in Fig.4 given below.

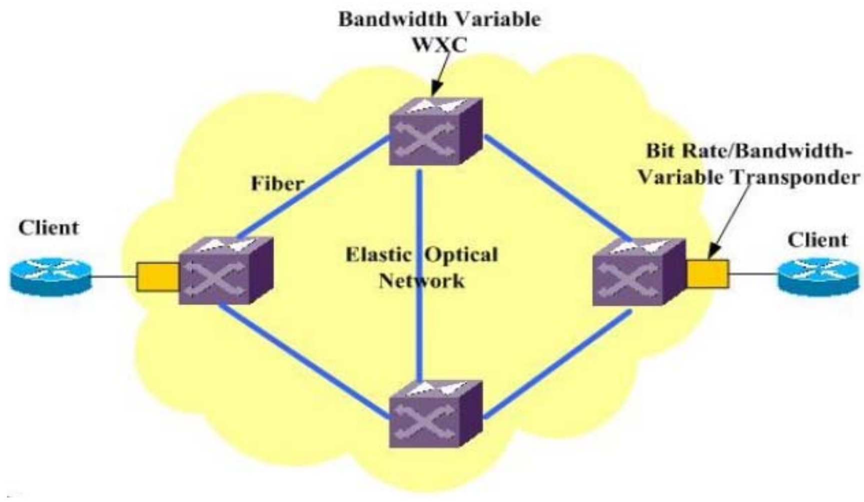

Fig 4. Architecture of EON [11]

OFDM together with BVT and BV-WXC paved the way for the elastic allocation of spectral resources.BVT generates optical signal with optimum spectrum usage and various subcarriers channels are combined into a single super-channel using OFDM and transported as an individual OFDM channel makes these networks more efficient .

III. OFDM

OFDM allocates separate information symbols onto different subcarriers which are orthogonal to each other. OFDM Subcarriers can be mathematically represented as:

$$s_k(t) = \begin{cases} \sin(2\pi k \Delta f t), & 0 < t < T, k = 1,2, \ldots, N \\ 0, & otherwise \end{cases}$$

Where Δf represents subcarrier channel spacing, N represents total subcarriers, and symbol period is given by T. The transmission bandwidth is approximately equal to $N\Delta f$. Signals are orthogonal and they satisfy the following condition:

$$\int_0^{\tau} s_i(t) s_j(t) dt = \begin{cases} C, & i = j \\ 0, & i \neq j \end{cases}$$

Each OFDM subcarrier has a $\sin c$ i.e. ($sin(x)/x$), spectrum in frequency domain, as shown in Fig. 5 given below [12].

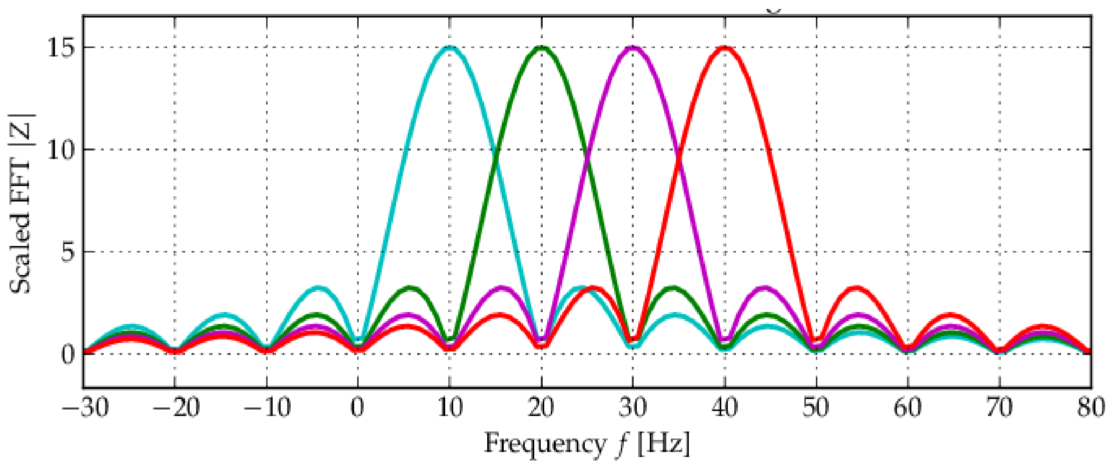

Fig 5. Spectrum of Orthogonal OFDM subcarriers [12]

The main advantages of OFDM are its high data rate conveniently implemented using IFFT and FFT operations and have good tolerance to Inter-Symbol Interference (ISI), high spectral efficiency, and low sensitivity to time synchronization errors. However the drawbacks of OFDM are high Peak to Average Power Ratio (PAPR) and its tendency to have a noise and frequency offset (Doppler Shift). Fig. 6 below shows the principle of communication of EON using an OFDM transmitter and receiver. OFDM transmitter consists of an OFDM modem that processes the signals in the electrical domain, an external cavity laser (ECL), Mach-Zehnder modulator (MZM), and an optical fiber link. The receiver is consists of a Photo-detector. Low pass filter and an OFDM receiver [13].

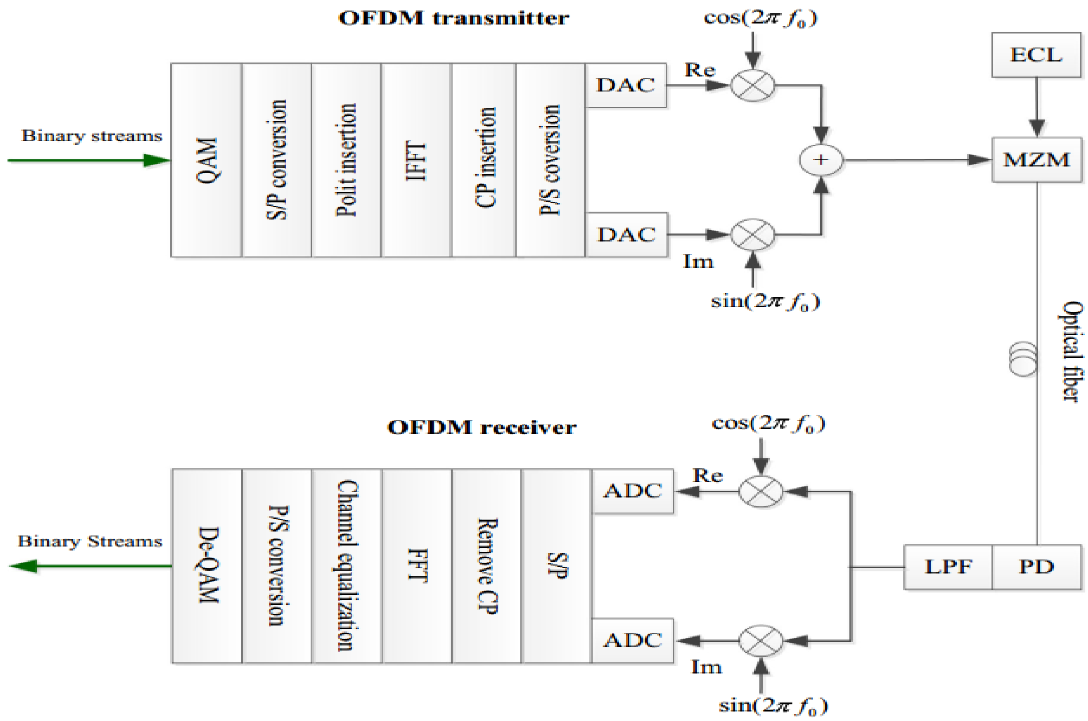

Fig. 6. An OFDM based Transmitter /Receiver System

In OFDM transmitter, the randomly generated data bits are converted into QAM symbols which are then converted into the parallel form using serial to parallel (S/P) conversion and pilot symbols are added for synchronization. These are then modulated on orthogonal subcarriers using Inverse Fast Fourier Transform(IFFT) and then a Cyclic Prefix(CP) is added to mitigate Inter-Carrier Interference (ICI) and Inter-Symbol Interference (ISI),then a discrete OFDM signal is generated using parallel-serial conversion and digital to analog (DAC) conversion is done to produce an analog OFDM signal. In-phase and Quadrature-phase (IQ) up-conversion is done to obtain an RF signal which then modulates ECL through an MZM and the optical signal thus obtained is transmitted over the optical fiber.

At the receiving end, direct detection is done using a photodetector to obtain an electrical OFDM signal which is then passed through a low pass filter and then passed through OFDM modem and IQ down-conversion, analog to digital (ADC) and S/P conversion is done. Fast Fourier Transform (FFT) is used to remove CP which is then followed by P/S conversion and QAM demodulation and binary data is obtained.

IV. BVT

BVT is used to generate optimum spectral resources by adjusting various parameters Fig.7 shows a conceptual design module of a BVT. It uses different modulation formats such as Phase Modulated 16-QAM and 64-QAM, Quadrature Phase Shift Keying (QPSK), and it provides a trade-off between spectral efficiency and transmission reach [14].

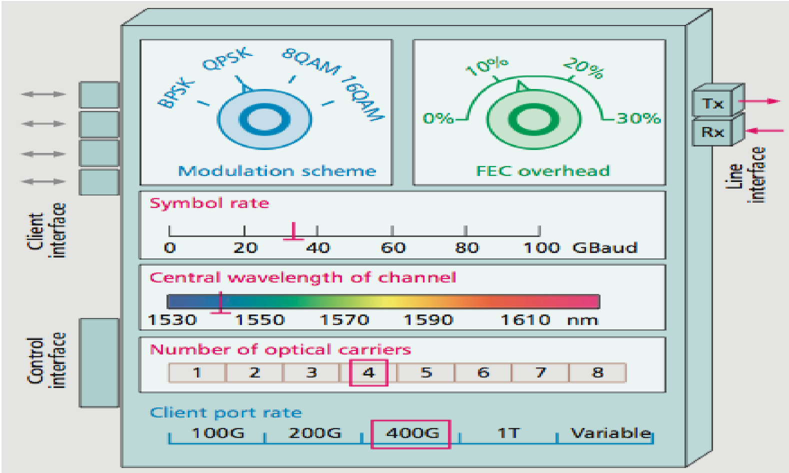

Fig. 7. A Bandwidth Variable Trans-receiver[14]

V. BV-WXC

BV-WXC uses BV-WSS at intermediate nodes to allocate a cross-connection route with sufficient spectrum from the source node to the destination node [11]. BV-WSS as shown in Fig. 8 also called as a flexible spectrum selective switch and uses an integrated spatial optics such as a diffraction grating which performs multiplexing and demultiplexing. BV-WSS splits the incoming light into discrete spectral components and then it is redirected to the desired output fiber using one-dimensional mirror array [15].

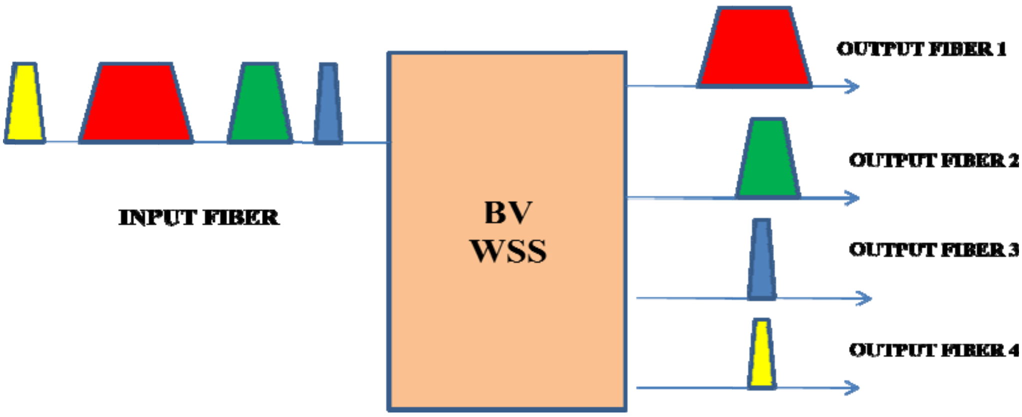

Fig 8. A Bandwidth Variable –Wavelength Select Switch [15]

An Electrical interface is used to change or to re-assign different output patterns to several output fibers. To vary the fiber connectivity between the transceiver and networks access ports for a given direction extra BV-WSS's are used in BV-WXC to allocate a cross-connect within the size of the given spectral width.

VI. CHARACTERISTICS of EONs

In EONs the central frequency of each channel has a finer granularity that enables expansion and contraction of optical paths. Hence, these networks provide several unique characteristics that are as follows [16]:

A) Flexible Bandwidth:

EONs support flexible granularity and supports fractional data rates and variable traffics by enabling the concept of sub-wavelength, super wavelength. Fig. 9 shows bandwidth segmentation in which a 100 Gbps bandwidth is segmented into sub-wavelengths of 50 Gbps, 20Gbps, and 30 Gbps respectively by using appropriate configuration of BV-WXC and BVT at each node of the optical path allocates appropriate spectrum bandwidth and provides efficient use of network resources. [17] Similarly, EONs enables bandwidth aggregation feature to create a super-wavelength optical path as depicted in Fig. 9, in which three separate 100 Gbps bandwidths are multiplexed using OFDM creating a 300 Gbps super-channel for efficient spectrum utilization.

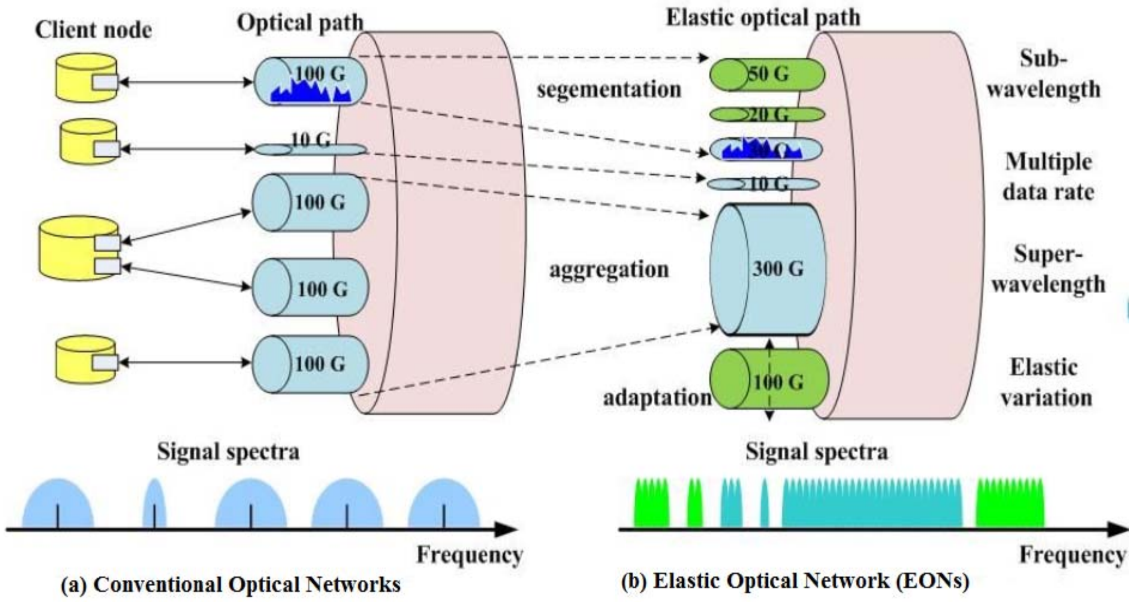

Fig. 9. Spectrum Assignment over (a) conventional optical networks with Rigid Frequency grid (b) EONs [16]

B) Multiple data rate accommodation:

As shown in Fig. 9, EONs supports multiple data rates and have the ability to provide high spectrum efficiency through flexible spectrum allocation and improves spectrum utilization over WDM networks in optical bandwidth is wasted due to frequency spacing for guards bands even for low bit rate signals.

C) Enhanced Spectral efficiency:

The use of OFDM in EONs enables efficient use of spectral resources as because of orthogonality , adjacent subcarriers may overlap in the spectrum without causing ISI and adaptable data rates, scalable path lengths and thus increases the overall system capacity by supporting spectrum reuse.

D) Energy saving:

EONs have a unique property to save power consumption as it turns off unused OFDM subcarriers while traffic demand is less and thus provides energy-efficient operations.

EONs although brings not only opportunities but also poses several new challenges to avail benefits from these opportunities such as the application of Routing and Wavelength Assignment (RWA) techniques in EONs creates several challenges due to the introduced novel spectrum flexibility. The spectrum continuity constraint in WDM networks has to be replaced with wavelength continuity constraint of RWA. In order to accommodate OFDM subcarriers, the non-overlapping spectrum constraint in WDM networks will be changed into single wavelength assignment constraint of RWA and the subcarriers should be assigned consecutively in order to exploit the spectrum efficiency brought by orthogonal adjacent subcarriers [17].

VII. RESEARCH ISSUES AND CHALLENGES

EONs are a promising concept but there are several issues and challenges such as issue of efficient hardware development, network and control plane management, intelligent management of spectral resources and post-disaster recovery and management, which need further research to resolve. In this section, we have tried to uncover these research challenges which provide interesting research opportunities in EONs for researchers.

A) Challenge of efficient Hardware Development

For designing efficient EONs a new generation of innovative and sophisticated devices and components for efficient optical switching and filtering are desired in order to have synchronization and compatibility along with efficient performance. Thus the research community has the challenge to develop new sliceable BVT, which supports the elastic allocation of spectral resources, variable bit rates, multiple modulation schemes etc [18][19].

B) Management of Network Control plane

The EONs in order to support various unique properties such as supporting multiple modulation schemes, aggregation, and segregation of bandwidth,providing flexible optical channels and supporting multi-path routing, there is need to develop and adopt several new modifications in Control Plane protocols [20]. Along with these control protocols, several intelligent energy saving mechanisms that can it turns off unused OFDM subcarriers while traffic demand is less are also anticipated [21].

C) Intelligent management of Spectral Resources

Allocation of network resources efficiently in heterogeneous traffic demand scenario in EONs is a major challenge ahead for researchers. As connection establishment in EONs is more complicated in comparison to traditional WDM-based fixed grid networks which required a single continuous spectrum path to be allocated to request but in EONs different spectrum slots are assigned in an efficient manner and in doing so the choice of selection of various transmission parameters for tunable BVT impacts the allocation of network resources and makes it further a more complicated problem.

D) Post Disaster management and recovery

Recovery of the network resources is becoming highly important after large-scale disasters and to avoid network failures and to re-establish services in a cost effective manner is a huge research challenge.

VIII. CONCLUSION

The field of EONs is a novel and compelling research area, and these are likely to become more integral part of communication backhaul platforms in future. In this review paper, we have highlighted the basic concept of the EONs , its various properties and current and future research challenges. This paper will provide the base to further study various algorithms for RSA under different traffic scenarios, their performance for efficient spectrum management to the researchers in this field.

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