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A Comprehensive Review of Recent Advancement in Optical Communication Networks

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Abstract— Optical fiber communication along with the advanced optical networking technologies and advanced modulation formats is an evolving field of research. The enormous bandwidth and long distance reach of optical networks makes them a suitable candidate to be used in backhaul networks. This paper presents a comprehensive review of various advanced optical networks: Wavelength Division Multiplexing (WDM) based networks, Radio over Fiber (RoF) networks, Passive Optical Networks (PONs) and recently proposed Elastic Optical Networks (EONs) along with recent work reported in literature. A briefs description of optical amplifiers and several architectural advancements in these optical networks is also discussed in a holistic manner .

Keywords**:** WDM, RoF, PON, EONs, Orthogonal Frequency Division Multiplexing (OFDM), Bandwidth variable-wavelength cross-connects (BV-WXC).

I. INTRODUCTION

An Optical Fiber is a thin fiber of glass or plastic that carries light from one end to the other. Optical Fiber is a flexible, transparent fiber made by drawing glass or plastic to a diameter slightly thicker than that of a human hair. Optical fibers are used to transmit information in optical domain over longer distances and at higher bandwidths as compared to wire cables. Fibers are used instead of metal wires because signals travel along them with lesser amount of loss. Figure 1 shows a generic block diagram of a typical optical communication system. It consists of a transmitter, a communication channel, and a receiver, the three elements common to all communication systems [1].

The optical transmitter converts the electrical signal into optical form and launches the resulting optical signal into the optical fiber. It consists of an optical source, a modulator, and a channel coupler. Semiconductor lasers or light-emitting diodes are used as optical sources. The optical signal is generated by modulating the optical carrier wave. An optical receiver converts the optical signal received at the output end of the optical fiber back into the original electrical signal [2].

It consists of a coupler, a photo detector, and a demodulator. The coupler focuses the received optical signal onto the photo detector. Semiconductor photodiodes are used as photo detectors because of their compatibility with the whole system.

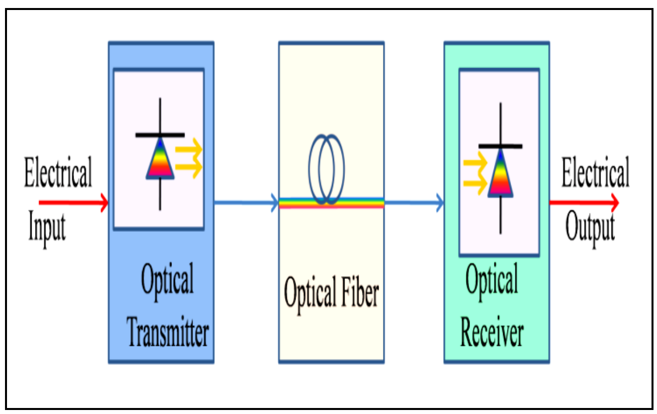

Figure 1: Block diagram of an Optical Communication System.

The design of the demodulator depends on the modulation format used by the light wave system. This paper presents a systematic review of state of art recent work in optical networks. Section II gives a comparative description of various channels (mediums) used in optical communication, Section III gives a brief description of optical amplifiers, Section IV describes the recent work in WDM based networks. Section V contains the advancements in RoF networks. Section VI gives a brief description of next generation PON networks and Section VII contains description of OFDM based elastic optical networks followed by conclusion in section VIII.

II. OPTICAL CHANNELS

Optical communication can be classified into guided and unguided communication on the basis of medium used during transmission of information. In guided communication a dedicated fiber link is present between the transmitter and receiver. In unguided optical communication systems, the optical beam emitted by the transmitter propagated through space, similar to Optical Wireless Communication (OWC) systems and free-space optical communication (FSO).

In FSO communication, the collimated light beam is transmitted from one location to another by using low power infrared lasers. The light from a FSO channel is intercepted by system of lenses, capable of focusing photons on highly sensitive detector receivers. The enough transmitter power is guaranteed as long as there is a clear line of sight between the source and the destination. FSO data rates, comparable to optical fiber transmission, and can be carried with very low error rates, while the extremely narrow laser beam widths [3].

FSO systems are used in disaster recovery applications and for temporary connectivity while cabled networks are being deployed. Free space optical communication is simply effected by atmospheric distortion hence FSO become most secure and high speed medium of data transmission.

OWC uses light at near-infrared frequency to communicate. Transmitter, propagation channel and receiver are three main communication parts of OWC system. OWC channel is considered to be outer space where it is assumed to be vacuum and free from atmospheric attenuation factors and provides high security, low cost, low power, and high rates due to the unregulated bandwidth.

The authors in [3] analyzed the performance of different channels viz. single mode fiber (SMF), FSO link and OWC link. Figure 2 shows the proposed block diagram for performance evaluation of different channels. For SMF and OWC, the communication range of 25, 50, 75 and 100km is taken. For FSO, the performance is evaluated at transmission range of 250, 500, 750 and 1000meter. From simulative results, OWC and SMF channel give the best results i.e. reduced the value of minimum bit error rate the best channel and increased the values of signal output power and the quality factor when compared with other channels FSO channel for long distance communication.

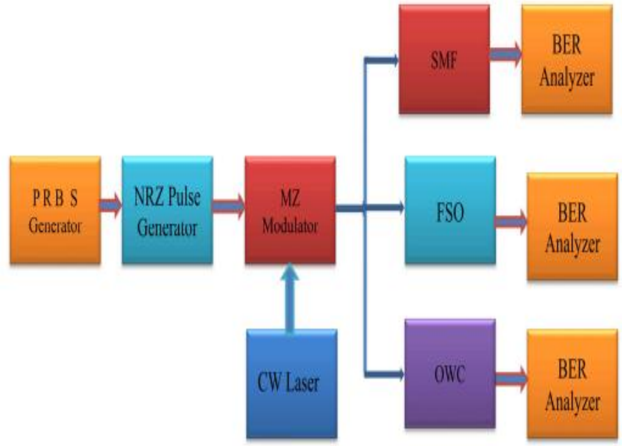

Figure 2: Proposed block diagram for performance evaluation of different channels.

III. OPTICAL AMPLIFIERS

In optical fiber communication the signal suffers various losses such as fiber attenuation losses, fiber tap losses, fiber splice losses, etc., and the detection of the original signal at the receiver becomes difficult. In order to transmit signal over a long distance it is necessary to compensate all losses in the fiber either by using optoelectronic repeaters or optical amplifiers. The optical amplifiers are classified based on their application into two categories: Semiconductor optical amplifier (SOA) and fiber amplifiers: Erbium Doped Fiber Amplifier (EDFA) and Raman Amplifiers [4].

SOAs are semiconductor lasers without the optical cavity feedback and have anti –reflection coating such that the population inversion is generated in the active region by an electrical current. The stimulated emission of photons occurs via electron-hole recombination processes induced by the signal photons at wavelengths included in the amplification band of the semiconductor material.

Erbium-Doped Fiber Amplifier was the first optical amplifier widely used in optical communications systems; it has become a key component in many optical networks because it provides efficient, low-noise amplification of light in the optical fiber low-loss telecommunications window near 1550 nm. EDFAs are used to provide amplification in long distance optical communication with fiber loss less than 0.2 dB/ km by providing amplification in the long wavelength window near 1550 nm.

In a Raman amplifier, the signal is amplified due to stimulated Raman scattering (SRS). Raman scattering is a process in which light is scattered by molecules from a lower wavelength to a higher wavelength. When sufficiently high pump power is present at a lower wavelength, stimulated scattering can occur in which a signal with a higher wavelength is amplified by Raman scattering from the pump light.

Optical amplifiers can be used in different hybrid configurations to boost the performance of optical link as well as to minimize the limitations of existing amplifiers. HOA's have advantages of wide gain bandwidth, high power gain and more flat gain profile over individual amplifiers.

The author in [5] proposed a model of hybrid optical amplifier (HOA) using EDFA and Raman amplifier to obtain optimized gain over different frequency range. The performance of proposed HOA is evaluated at pumping power of 300 mW and pumping wavelength of 1400 nm in backward direction. The length of EDFA and Raman is taken 13.5 m and 8.05 m respectively. Simulative results shows that the proposed design of HOA works faithfully and using hybrid configuration, it is possible to reduce gain variations by optimizing erbium fiber length and using gain flattening technique and provides a high gain .This HOA design used in the optical communication system with a reach of 1120 km and provides a good Bit Error Rate performance.

IV WDM NETWORKS

Wavelength Division Multiplexing is the technique that allows several different signals to be carried along a single fiber at the same time. It achieves this by using different wavelengths for each transmission and can be employed on single mode or multimode fibers using lasers.

The authors in [6] presented a comprehensive review of WDM based optical communication link. The authors have also given a detailed working of EDFA along with its different pumping techniques, pumping wavelength and operating regions. The authors further described advanced modulation formats viz. Non Return to Zero (NRZ) and Return to Zero (RZ) format along with their comparative advantages and applications.

In [7], the authors used WDM technique to improve the transmission capacity and needed bandwidth requirement of backbone networks using Optical fiber cable networks. OADMs, OXCs and Convertors have been used for utilizing the bandwidth optimally. In backbone networks Reactive and Pro-active approach has been strengthen for a desirable QoS.

The authors in [8] analyzed the working of a designed DWDM based 32 channel optical link using EDFA. The working of the designed optical link was evaluated for different modulation formats (RF and NRZ) at variable data rate of 5, 10 and 15 GHz over a transmission range of 60, 80 and 100km at a pumping wavelength of 980 and 1480nm. The performance of the designed link was evaluated in terms of variations of Q-Factor and BER with increase in transmission range. Simulative result shows that the designed link works optimally. The values of Q-factor are obtained as 11.217, 9.855 and 8.209 for RZ modulation and 5.420, 5.159 and 2.986 for NRZ modulation for fiber lengths of 60km, 80km and 100km respectively. The designed system depicts significant improvement and works optimally for RZ modulation format at100 km fiber length.

The authors in [9] evaluated the performance various dispersion compensation techniques for EDFA based 32 channels DWDM network. The performance of different dispersion compensation techniques: pre, post and symmetrical compensation are evaluated using NRZ modulation format. Comparative analysis shows that Pre-DCT is much better and provides greater Q-factor than post and symmetrical DCT's. From simulative results it is found that by varying the number of input channels in a DWDM system, the quality of signal received at the receiving end remains almost same showing marginal degradation and the designed system works faithfully even at higher transmission ranges.

The authors in [11], evaluated the working of EDFA based 32 channel DWDM network using different pumping techniques at variable pumping power of 40,60,80,100 and 120mW at EDF length of 4,6and 8m. Simulative results show that with increase in pump power, the Q-factor increases for both the pumping techniques but the increase is greater in bidirectional pumping. In counter pumping, since the transmission is acceptable up to 6m length of EDF, we have analyzed the values of Q-factor at 6m EDF length and for bidirectional pumping the values of Q-factor are analyzed at 8m of EDF length. The system depicts a considerable improvement and works optimally for bidirectional pumping with Q Factor of 12.413 and 11.432 at 8m of EDF at 120mW of pumping power.

Further, the author in [12] evaluated the performance of DWDM based system using different hybrid configurations of optical amplifiers viz EDFA-EDFA, SOA-EDFA using NRZ and RZ modulation format. Simulative result shows that the values of Q-factor and BER are obtained for different lengths of optical fiber- 80,100,120,140 km. The values of Q-factor for EDFA-EDFA are 8.42, 7.69, 6.35 and 3.80 with RZ modulation and 4.34, 4.32, 4.14 and 3.68 with NRZ modulation for fiber lengths of 80km, 100km, 120km and 140km respectively. The values of Q-factor for EDFA-SOA are 2.85, 3.02, 4.33 and 3.86 with RZ modulation and 2.84, 2.62, 3.44 and 3.27 with NRZ modulation for fiber lengths of 80km, 100km, 120km and 140km respectively. Based on the results obtained, it is concluded that EDFA-EDFA hybrid optical amplifier produces better results than

EDFA–SOA hybrid optical amplifier. Moreover, Q-factor of hybrid optical amplifier using RZ format is more as compared to NRZ format and long distance communication is achieved using RZ modulation format.

V. RoF

Radio over Fiber is basically an analog optical link which transmits modulated RF signals. Radio-over-fiber technology uses the optical fiber links to distribute RF signals from a central location to the remote antenna units (RAUS). It transmits RF signal downlink and uplink. It transmits RF signal to central station (CS) from base station (BS) and vice versa**.** The demand for network bandwidth is large due to the growth in traffic such as video on demand, internet usages, and voice over IP, steaming video and voice. This can be provided by RoF system because of its advantages as, large bandwidth, immunity to radio frequency interference, reduced power consumption, multi-operator and multi-service operation, dynamic resource allocation etc [13].

As shown in Figure 3, Control Station is used for the generation of signal. In this, RF signal is transmitted with the help of optical fiber link. At Control office modulation and signal processing is used in order to build the baseband signal. There is negligible Attenuation loss in this transmitted signal then, this transmitted signal is detected at the BS. At the Base Station Unit (BSU) the operations of both the electrical to optical (E/O) and optical to electrical (O/E) conversion take place.

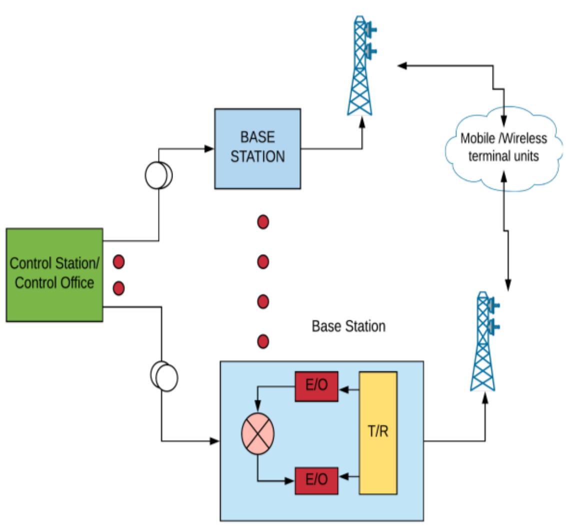

Figure 3: A general RoF system

The signal transmission between Wireless Terminal Unit (WTU), BSU and user take place with the help of antenna which is placed at the base station unit. Communication between BSU and CS takes place with the help of optical signal. Therefore cost of transmission equipments such as antenna, amplifiers are getting reduced. Hence, RoF system looks a more efficient system than the conventional wireless networks. Several authors have work in isolation for designing an efficient RoF system.

The authors in **[**13] studied dispersion losses and degradation of signal due to power fading which a signal experiences while travelling through an optical fiber, various optical devices. Authors used Mach Zehnder modulator (MZM) in the RoF system. The proposed RoF system was analyzed for switching bias voltage and extinction ratio of Lithium Niobate (LiNbO3), MZM and from all the observations and findings it can be concluded that for the proposed system the appropriate switching bias voltage is 4V and the extinction ratio is 30 dB so as to achieve the optimum results that is maximum Q –Factor with minimum BER.

In [14] the authors have proposed a method to establish a millimetre-wave photonic up-converter, a frequency doubled OEO, or a low interference dual-direction RoF links. There may be more potential applications using such kind of manipulation. Carrier phase and amplitude modulation is an important signal processing technique in microwave photonics. The authors also proposed a series of work by realizing such modulation with a single drive dual-parallel Mach-Zehnder modulator (DPMZM).

In [15], the authors presented two WDM system based on Dual Electrode Mach Zehender Modulator (DE-MZM) and Optical Phase Modulator (OPM) having effects of the Raman crosstalk are compared, and a simulative investigation is presented. The output performance is improved with OPM based systems. Hence by selecting minimum value of Raman crosstalk according to transmission distance and modulation frequencies, the WDM system can be optimized.

In [16] the authors investigated Crosstalk effects due to cross phase modulation (XPM) in wavelength multiplexed subcarrier multiplexing radio-over-fiber (RoF) system. The system performance degrades with increase in separation between wavelengths, and with increase in the separation between pump and probe wavelengths. As modulation frequency and transmission distance increases it increases the XPM-induced crosstalk. Hence by carefully selecting the walk-off parameter, dispersion and pump and probe wavelengths, the overall system performance can be optimized.

The authors in [17] theoretically investigated the transmission performance of the optical millimetre (mm)-wave generated by a structure of optical modulation dedicated to Radio-over-Fiber (RoF) system**.** A radio over fiber system was planned and simulated using the Optisystem software. Its various parameters (such as Q factor, BER, Eye height, etc) were compared for different categories of coding (such as NRZ and RZ coding). NRZ may suffer from more nonlinearity due to higher peak power, whereas RZ may suffer from more dispersion which is due to shorter pulse width. Study shows that in general we can operate better by using RZ modulation in high power regime than NRZ coding.

The authors in [18] presented the generation of optical carrier suppressed signal for RoF system. Signal modulation and optical carrier suppression are made by using a Dual-Drive Mach-Zehnder modulator (DD-MZM). In this paper, the carrier suppression and performances of RoF system are investigated by simulation. The various values of optical carrier suppression ratio can be obtained by adjusting the extinction ratio of the DD-MZM. The performances of RoF system and optical carrier suppression were investigated with the simulation. The performance of RoF system and the optical carrier suppression using DD-MZM was theoretically studied.

The authors in [19] studied the performance analysis of two channel RoF link using MZM modulator. The performance was evaluated in terms of variation in Q Factor and BER at a transmission range of 10,20,30,40 and 50 km. Simulative result shows that he values of Q-factor for channel 1 are 21.2355, 16.771, 16.3341, 15.6513 and 15.4905 at distances10, 20, 30, 40 and 50 km respectively. The values of Q-factor for channel 2 are 18.075, 15.07883, 15.9469, 13.6047 and 11.1546 for 10, 20, 30, 40, and 50 km respectively. It was concluded that the designed RoF link works optimally and improved performance as achieved. The performance of the designed link was further evaluated for different values of extinction ratio of MZM modulator in [20]. The Extinction ratio was varied from 10 to 30 dB insteps of 5dB. From simulative results it was found that concluded that for the proposed RoF system the Q-factor decreases and BER increases with increase in optical fiber lengths, and Q-factor increases with increase in Extinction ratio and the designed system works optimally at extinction ratio of 30db.

The authors in [21] studied the effects of four wave mixing (FWM) crosstalk; a wavelength division multiplexed based radio over fiber system. The effects of FWM power is compared for different fibers to show that FWM crosstalk reduces significantly. Performance for standard single mode fiber (SMF), True Wave (TW), True Wave Reduced Slope (TWRS), corning large effective area fiber (LEAF) and Alcatel Teralight fiber has been investigated. It has been observed that FWM crosstalk power increases with the increase in channel input power and transmission distance while decreases with increase in channel spacing. A simulative model has also been designed and it has been found through simulation that Corning LEAF posses minimum BER of 10-35 and minimum FWM optical power of -12 dBm at dispersion of 12 ps/nm-km among various fibers. Hence it is concluded that Corning LEAF emerges out to be a better option to mitigate the FWM induced crosstalk effects in WDM RoF system.

In [22] the author analyzes the impact of modulation index on the Stimulated Raman Scattering (SRS)-induced crosstalk. The crosstalk levels are enhanced by 5 dB(approx) when modulation index is increased from 0.3 to 0.9. It is observed that the crosstalk is decreases with increasing modulation frequency and increases with optical power. And with increasing transmission length a minor increase in crosstalk levels. Hence by selecting the appropriate depth of modulation carefully, the performance of WDM RoF system can be optimized.

In [23] the authors presented a single channel RoF system has been designed for simulative investigation & comparison of Mach Zehender Modulator (MZM) and Optical Phase Modulator (OPM). Different ranges of dispersion and input channel power is used for the analysis. It is shown that the SPM induced pulse broadening increases with increase in dispersion modulus and channel input power. The performance of MZM and OPM has been analyzed beneath the impact of SPM effect. It has been concluded that SPM effect is better mitigated by MZM based transmission when dispersion modulus is increased beyond 2 ps/nm/ km. It is also reported that SPM affects MZM based signal heavily at higher input power levels beyond 15 dBm while OPM output is 3 dBm better than of MZM output at these power levels.

The authors in [24] used different modulation and amplification techniques to evaluate the output performance of Sub Carrier Multiplexing (SCM) based on RoF system under the influence of inter modulation distortions and harmonic distortions. EDFA and SOA are used for the amplification of SCM based RoF transmission system. Amplification through EDFA provides an improvement in output power signal as compared to SOA. The performance of system is improved considerably by suppressing 2nd & 3rd orders inter-modulation distortion terms. In term of comparison with MZM and DM, it has been concluded that non linear distortions are better suppressed in OPM based signal. OPM emerge out to be a better technique for SCM based RoF systems. The distortions is increases with increasing spacing between RF signals, hence optical signal subcarrier spacing has considerable impact on the distortions.

VI. PASSIVE OPTICAL NETWORKS

Current Fiber to home networks provides broadband and other multimedia services to consumers effectively. But for handling ever increasing bandwidth hungry services, the capacity of traditional fiber to home networks must be enhanced in a scalable manner. PONs designed by FSAN working group is the converged infrastructure standardized by ITU and IEEE [25]. PONs supports services such as traditional telephony, VoIP and various other multimedia services. PONs uses passive network elements that reduce deployment costs and power consumption. However, the maximum logical reach of PONs is upto 60km with a split ratio of 1:128 [26]. Figure 4 shows the basic PON architecture.

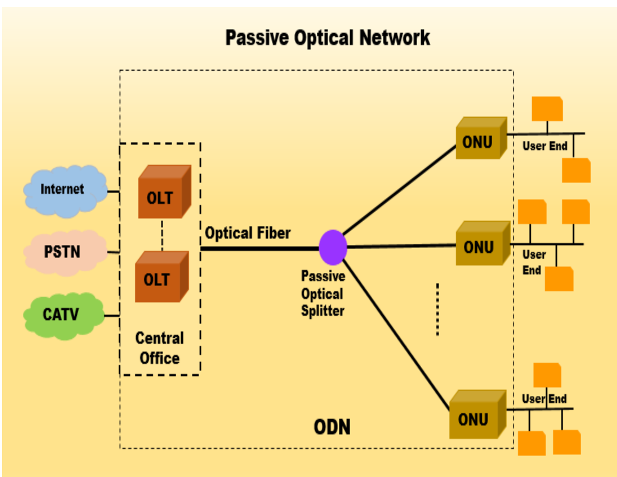

Figure 4: Passive Optical Network Architecture

The PON architecture consists of three main units OLT, ONU and ODN. OLT located in CO is the interface between PON and the optical backbone network. OLT distributes PSTN, Internet and CATV services to as many as 16 to 128 end users per fiber line. Passive optical splitter divides an optical signal into multiple equal low power signals and distributes them to end-users during downstream and in case upstream transmission these acts power combiners. ONU provides service interface to end users. ODN connects OLT and end users using optical fibers.

Figure5 shows the evolution of various standards for PONs. ITU-T G.984 series specifies GPON standards. GPON supports two different data rates for both upstream and downstream links. It can provide symmetrical data rate of 622 Mb/s or 1.244 Gb/s in both downstream and upstream links. It can also support a data rate of 2.488 Gb/s and 1.244Gb/s in downstream and upstream links respectively. GPONs along with supporting multiple data rates, provides high efficiency and also incorporate real-time suggestions from service provider. XG-PON or 10G PON is the recent standard for GPON standardized by ITU-T G.987.It provides a data rates of 10Gbps for downstream and 2.48 Gbps for upstream link. XG-PON supports advanced multimedia applications requiring higher bandwidths such as high definition video transmissions.

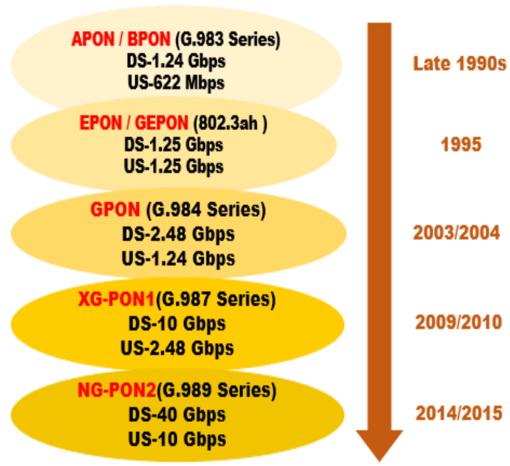

Figure 5: PON Standards

The evolution of NG-PON is divided into two phases: NG-PON1 and NG-PON2. NG-PON1 depends on PON technologies that show compatibility with GPON standards (ITU-T G.984 series).NG-PON 2 provides backward compatibility with previous standards and supports traditional video services along with new generation multimedia applications on existing optical distribution networks.

In [26], the authors have presented a model of 4 TDM-PON using SOA-Raman amplifier over CWDM wavelength plan serving 128 end users. In [27], the authors have presented model of TDM based PONs with multiple channels that use different coding schemes and transmit data over nonlinear fiber in an efficient manner with optimum use of resources. The Simulative result shows that for both upstream and downstream links, reach extension of 60 km is achieved with a bandwidth of 75 nm is obtained.

In [28] the authors have presented and analyzed a hybrid model of WDM/TDM PON at variable data rates and the proposed model supports upto 48Gbps with better performance in terms of BER. In [29], the authors have provided a detailed description of G-PON and E-PON and their architecture and their adaptability to ever increasing bandwidth requirements. In [30], the authors have presented a model of 4 TDM-PON with a symmetric data rate of 2.5GHz using SOA-Raman amplifier over CWDM wavelength plan serving 128 end users. The Simulative result shows that for both upstream and downstream links, reach extension of 60 km is achieved with a bandwidth of 75nm is obtained. In [31], the authors have proposed a CWDM PON for 2.5Gbps data rate with a fiber length of 20km.Simulative result shows that designed system works optimally and provide better SNR performance and can accommodate higher bandwidth applications.

In [32] the authors have designed a passive GPON using Raman amplifier with a split ratio of 1:64 at 2.5 Gb/s data rate. Simulative results show that the designed network works optimally and link losses of 43dB and 36.6dB were obtained for 1310 nm and 1490 nm signals, respectively without any error floors. In [33] the authors have proposed an all-optical virtual private network (VPN) based OFDM – PON using 16QAM and a data rate of 10Gbps. The use of VPN in OFDM –PON works optimally and enhances the security. In [34] the authors have proposed a reliable WDM PON architecture for protection against feeder fiber failure. In proposed architecture, in case of fiber failure the OLT and ONU switches can switch automatically to protection link.

In [35] the authors have presented a designed model of model of bidirectional Time Division Multiplexing (TDM) PON using hybrid optical amplifiers configuration (Semiconductor Optical Amplifier (SOA), Raman Amplifier and Erbium Doped Fiber Amplifier (EDFA)) is presented. The performance of the designed system is evaluated for variation of Q Factor with transmission distance using (i) SOA-Raman (ii) SOA-EDFA and (iii) EDFA-EDFA hybrid configuration. Simulative result shows that the hybrid amplifier configuration has been found to be effective in enhancement of range by approx 16% while maintaining the optimum Q factor and data rates. Also the simulative results shows that the PON model using EDFA-EDFA configuration works more efficiently and optimally and an improvement in Q Factor is obtained as compared to SOA-EDFA and SOA- Raman even at higher transmission range of 70 Km.

VII ELASTIC OPTICAL NETWORKS

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 [36].

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. The term elastic in EONs refers to three key properties of the optical networks: Flexible optical spectrum, Bandwidth variable Transponder (BVT) and BV-WXC [37]. Figure 6 shows the basic architecture of EONs.

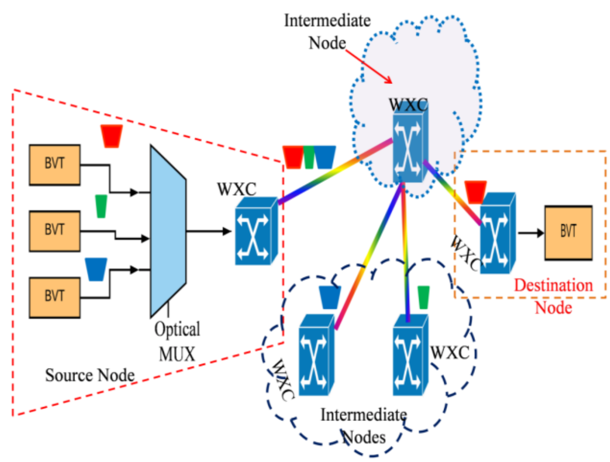

Figure 6: Architecture of Elastic Optical Network

BVT is used to generate optimum spectral resources by adjusting various parameters. 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 [38].

EONs support flexible granularity and supports fractional data rates and variable traffics by enabling the concept of sub-wavelength, super wavelength. 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[39]. 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[40].

While assigning spectral resources, each adjacent orthogonal subcarrier in OFDM must be consecutive for better spectrum efficiency. All these complexities and constraints in selecting a route along with an efficient spectrum allocation strategy are termed as Routing and Spectrum Assignment (RSA) [41][42]. Spectrum Assignment (SA) aims for better utilization of spectral resources and can be used in parallel with route selection process. There are three types of spectrum allocation methods used for establishing a lightpath [43].

The authors in [44] provide a comprehensive review of EONs and their enabling technologies and the several research issues in EONs. The authors have presented a designed network model of OFDM based optical communication network and analyzed its performance for Quality Factor and BER at different fiber length with different modulation formats. Upon simulation it was found that OFDM based optical networks were successful in handling higher data rates and extended communication reach was achieved over traditional WDM based networks.

In [45], the authors have presented the designed framework for performance evaluation of existing RSA algorithms by carrying out simulations. Simulative results show that the First Fit spectrum assignment strategy works optimally and provides lesser network blocking probability as compared to random fit and last fit strategy. The simulation framework was extended to evaluate various routing algorithms and it was found that the PSR routing algorithm works efficiently and provides minimum NBP. The authors in [46], proposed an efficient spectrum assignment strategy for EONs and the performance of the proposed strategy was evaluated by carrying out simulations and it was found that the proposed strategy works optimally and provides less NBP as compared to FF and RF strategy.

The frequent setup and release of SS over spectrum paths leads to unused, isolated non contiguous SSs. These isolated and unused SS becomes unusable for future connections and causes significant fragmentation of spectral resources [47]. Fragmented spectrum has a degrading effect in network performance, as increased fragmentation leads to increased NBP and reduced spectrum usage efficiency [48].

In [49], the authors have presented a comprehensive description of various fragmentation metrics and state of art technology in spectrum defragmentation. Authors have also proposed Access Blocking Probability (ABP) as a performance metric in evaluation of spectrum fragmentation problems in both static and dynamic traffic environment. The authors evaluated the performance from the context of operator network considering transponder granularity and result shows improved performance as compared to FF strategy. In [50], the authors have analyzed the effect of bandwidth fragmentation on NBP and identified that the availability of spectrum blocks on lightpaths and the sizes of available spectrum blocks as a major constraint in resource utilization in EONs. From theoretical and numerical analysis, the authors concluded that relation among bandwidth fragmentation, bandwidth distribution, NBP and spectrum utilization must be considered for designing an efficient defragmentation strategy.

The authors in [51] presents a spectrum assignment (SA) strategy that allocates SS based upon the relative difference between the required SS width of incoming traffic demand and available SS width. The performance of proposed SA technique is evaluated in terms of Network Blocking Probability (NBP) by carrying out simulations under variable load conditions. The comparative analysis shows that the proposed strategy reduces spectrum fragmentation effectively as compared to existing SA strategies.

VIII. CONCLUSION

This paper presents a comprehensive review of the latest advancement in the field of optical networks along with the recent work reported in literature. The paper starts with the description of optical communication network and performance of various optical channels was compared for different transmission reach in section II. Various optical amplifiers used in optical communication links are described in section III. The WDM based optical networks are discussed followed by advancement in RoF networks in section IV and V respectively. The PONs along with updated literature review is described further in section VI. To overcome the limitation of traditional WDM based network and for efficient utilization of spectral resources are described in section VII. This paper will serve as a beacon for the researchers for better understanding of concepts related to optical networks and to pursue their research in an efficient and holistic manner.

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