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Future Generation Optical Network for Wired and Wireless Networks Based on OFDM using a Comb Source

M. Samayaraj Murali Kishanlal, A. Jawahar

Abstract: In this study it is focused to design an architecture for the future optical networks based on PON (Passive Optical Network) called as FGON (Future Generation Optical Network). The FGON improves the efficiency and reliability of optical networks in providing a seamless data transmission network by integrating the three core concepts namely WDM, PON and OFDM. The proposed network also supports ROF (radio over fiber) for extended coverage of optical signals through wireless in unfavorable domains. In the FGON the input signals are given using a unique technique of creating a dense signals using WDM by creating a uniform comb like structure by using a dual arm Mach Zender Modulator based circuit whose output has nine flat comb structures and then the modulation technique of OFDM is used for enabling the WDM-OFDM-PON We study the performance of the signals generated by the comb structure in a ROF based OFDM-PON simulation network where out of the nine generated signals seven are used for wired network and one for wireless network and one for common uplink channel the various parameters such as the received signal strength FGON network, BER (Bit Error Rate) are noted and analyzed, and the received signals propagation characteristics of the FGON is noted which will be suitable for next generation optical access.

Keywords : OFCS: Optical Flat comb source, PON: Passive Optical Network FGON: Future Generation Optical Network, ROF: Radio Over Fiber WDM: Wavelength Division Multiplexing.

I. INTRODUCTION

Recent days and future communication networks require a high speed, reliable and performing networks to provide a wide spectrum of services to the users. One such solution is the use of emerging optical networking technologies and its components for grooming, routing and restoration of the signal to its destination. The various parameters involved for proper functioning of a telecommunication network are the availability of huge bandwidth, usage of low power, low attenuation, low distortion, less material usage and low budget.

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* Correspondence Author

Samayaraj Murali Kishanlal M*, Department of Electronics and Comunication Engineering, St.Joseph's Institute of Technology,Chennai, India. Email: samayarajphdfgon@gmail.com

Dr.Jawahar.A, Department of Electronics and Comunication Engineering, SSN College of Engineering ,Chennai, India. Email: jawahara@ssn.edu.in

The speed of a telecommunication network is based on how the end user access the network, ifmore number of peoplesimultaneously access the network the speed will decrease and if the number of people accessing the network are less the speed of the network will be high. The efficiency of communication networks will be based on how the network access mechanism takes place so we need to have a balance between more number of users and speed of a network. In order to fulfill such a scenario the ON (Optical Network) and its supporting protocols should be designed. The main reason for reduction in the speed at the user end is the creation of an bottleneck at the access network. A solution to this problem is the PON which provides the speed to the last mile problem by directly connecting high speed optical fibers to the end users premises commonly called as FTTH [Fiber To Home technology]. A lot of research work has been carried on this area of finding the right combination of (PON)[1]-[3], which can support the access networks with high efficiency. The main problem faced in designing a seamless integrated hybrid network is to find the suitable modulation technique and the multiplexing technique for a PON network. In recent days WDM [Wavelength Division Multiplexing] is being increasingly used more than optical TDM and optical CDM techniques. WDM is a famous multiplexing technique that is used for long haul communication with high data rate and it also assists in increasing the electronic processing speed of a communication network. A WDM-ON can support a long range network and can also support a large number of ONU [Optical Network Unit]. One more key point about WDM architecture is that the network can be easily upgraded [4]-[5].In spite of having so many advantages the main setbacks faced by an WDM optical network is that they are not suitable for flexible sub-channel bandwidth allocation which is vulnerable at fiber level and at the wavelength level of an network. The main disadvantage of WDM-PON is that when used with high data rates it is affected by the non-linearity properties of the fiber and also by the dispersion effects associated with the fiber which makes the networks unusable at high rates. A practical solution to such problem is by adding OFDM modulation to the existing WDM-PON enhances the system by neglecting the effects caused by non linear properties and also the dispersion effects of fiber. The presence of sub carrier channels of the OFDM guarantees high data rate to the system and at the same time the presence of large guard band intervals between the subcarriers also ensures minimum dispersion in an OFDM based system.

The other advantages of an OFDM based optical network includes High Bandwidth efficiency, the network is flexible for sub-channel bandwidth allocation and also it is highly scalable with increasing number of ONU's in the network. One small disadvantage of OFDM is in SMF (single mode fiber) is that with larger distances the signal gets broadened due to positive and chromatic dispersion effects[6]-[8].

Implementing OFDM technique for an communication scheme needs a special kind of modulation and demodulation procedures of the various available forms, the frequently used techniques are QAM and PSK. The different orders of the above mentioned modulation technique namely 8 PSK, 16PSK, 16 QAM, 32 QAM are used for modulating the subcarriers of OFDM signal. In this paper a new way to combine WDM-OFDM-PON has been taken which has lot of advantages as mentioned in [9] – [12] and also the efficient way for enabling the internal technques of an OFDM based PON is discussed in [23]. The best way to do is to by using a comb source which has been discussed in detail in the optical comb generation section, we have proposed a new technique for an FGON in which is a optical flat signal is obtained using a single stage Mach-Zender modulator(MZM)which is tunable and it generates nine flat which are 6.25 GHz spaced subcarriers which have a spectral ripple off less than 1 db. With this source as input to an OFDM based ROF supporting network which modulates the subcarriers with a frequency of 12.5Gbpsusing 16QAM . From the obtained results we analyse the working characteristics of the FGON network. The organization of the remaining paper is as follows, the FGON structure is described in section II. The entire process of generating a single stage optical flat comb source is explained in section III. 16 QAM-OFDM-WDM based ROF supporting PON is explained in section IV and V . Finally the results and conclusions are given in section VI and VII.

II. FGON SYSTEM ARCHITECTURE:

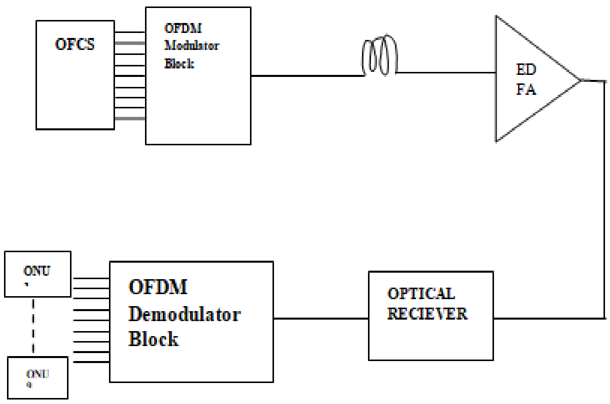

Fig. 1:Block diagram of FGON

The architecture of the FGON is shown in fig 1 which consists of the following 1.Transmitter section consisting of the OFCS and the OFDM modulator block the 2. Connecting part (the fiber part) which consists of the fiber which connects the transmitter and receiver sections and 3.Receiver section which contains the optical receiver unit, the OFDM demodulation block and the ONU [Optical Network Units]. The base architecture for the FGON is derived from the PON structure which is depicted as

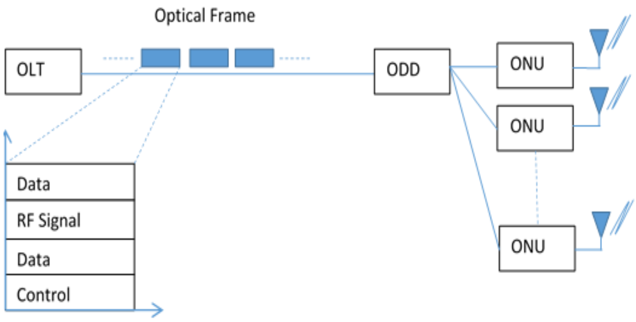

Fig. 2 :Basic structure of PON

The OLT [Optical Line Terminal] is the structure which generates the signal and sends it to the ODD [Optical Data Ddistribution] for distribution. The ODD acts as a splitter which splits the signal between various ONU. This signal from OLT via OPU to ONU is called downstream signal and the signal back from ONU to OLT is called upstream signal In the FGON which is derived from the PON structure. The signal which is generated from the OLT is done using the combination of optical flat comb signal generation and OFDM modulation block and the designed OLT is capable of generating nine user signals based in nine different set of frequencies which is the WDM part and the signal is then OFDM modulated and then it is transmitted The second part which is the connecting part of the architecture consists fiber of length 10-100 km which is tested under various lengths for different parameters and also the connecting part consists of and isolator and also EDFA-Erbium doped fiber amplifier for amplification of the signal after particular intervals. Using EDFA provides with a large number of advantages such as high gain, low noise figure, high degree of stability and vary compact in size. The OFDM demodulator acts as a ODD structure by splitting the signals an delivering to the ONU's respectively.

III. OPTICAL FLAT COMB BASED WDM GENERATION

In this paper the desired generation of the input WDM signals are uniquely generated using a novel mechanism as mentioned above by using a optical flat comb source which gives an series of uniform output signals which resemble a comb like structure that can be used as input for further processing. A number of such techniques are already in use to generate such flat signals. Wu et al [13] used a cascade shaped MZM which did not produce the desired form of signals Gheorma et al [14] used a parallel configured dual MZMs the main disadvantage in that method is the cost of MZMs used is to high also in the works of Zhou et al [15], Zhang et al [16] and Chen et al [18]used more than a single modulator for generation of optical comb signals further in the works of Sakamoto et al [17] the advantage of using a single modulator was emphasized recently in the method followed by Abir et al [21] they used a double stage dual arm MZM for generating an optical source comb which had 11 flat signals so as a betterment to the above mentioned work in this paper we generate a flat signal using a single stage dual arm MZM optical modulator as shown in the fig 3.

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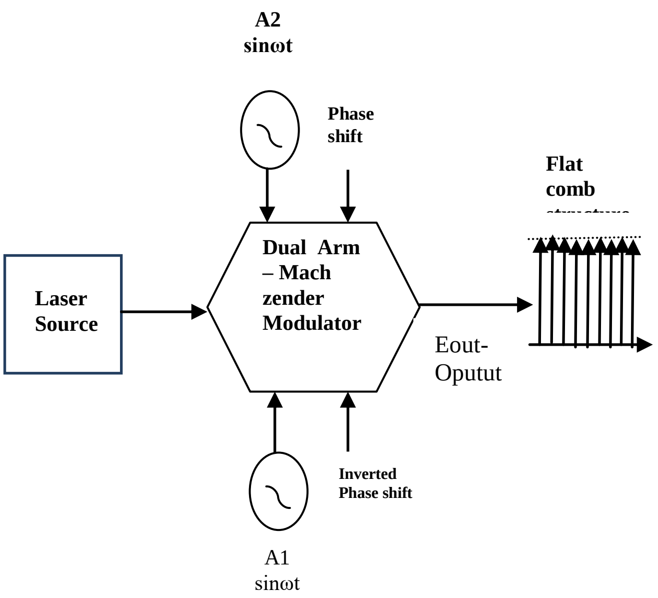

Fig. 3 :Block diagram of Comb generating structure

In the setup of the MZM dual arm the individual arms are DC biased by special RF sinusoidal signals $S_1(t)$ and $S_2(t)$ which are in phase the biasing is provided such that the arms are given a static phase shift Θ_1 and Θ_2 the amplitude of the static phase shift is V_{rf1} and V_{rf2}

$\phi_1 = \Theta_1 + V_{rf1} \sin \omega t$ (1)

$\phi_2 = \Theta_2 + V_{rf2} \sin \omega t$ (2)

The subcarrier spacing of the flat structure is defined by Δv, where $\Delta v = (\omega / 2\pi)$

The output equation of the MZM is given by

$$E_{out} = \frac{Ein}{2} \sum_{m=-\infty}^{\infty} [Jm(Vrf1) e^{j(m_{\omega}t + \Theta 1)} + Jm(Vrf2) e^{j(m_{\omega}t + \Theta 2)}] \quad (3)$$

Where the input power of the laser is ,J_m is the m^{th} orderof Bessel function, V_{rf1} and V_{rf2} are the amplitude of sinusoidal waves $S_1(t)$ and $S_2(t)$.

From the approximation equation of the laser source in harmonic mode by Sakamoto as;

$\eta = (P_k / P_{in})$ (4)

$\eta = (1/2\pi V_{rf}^{1})$ [$1+\cos(\Delta\Theta)$ $\cos(2\Delta V_{rf})$ + $(\cos(2\Delta\Theta)$ + $\cos(2\Delta V_{rf})$ cos { $2(V_{rf}^{1}) - (2m+1)/2$}

where $\Delta V_{rf} = (V_{rf1} - V_{rf2}) / 2$, $\Delta\Theta = (\Theta_1 - \Theta_2) / 2$ and $V_{rf}^{1} = (Vrf1 - Vrf2) / 2$

In order to get an flat output from the flat comb source is

$\Delta V_{rf} + \Delta\Theta = \pi / 2$ (5)

By following the above conditions we obtain a output of nine subcarriers having a spectral ripple of 1.3 db which is shown in the fig 4,

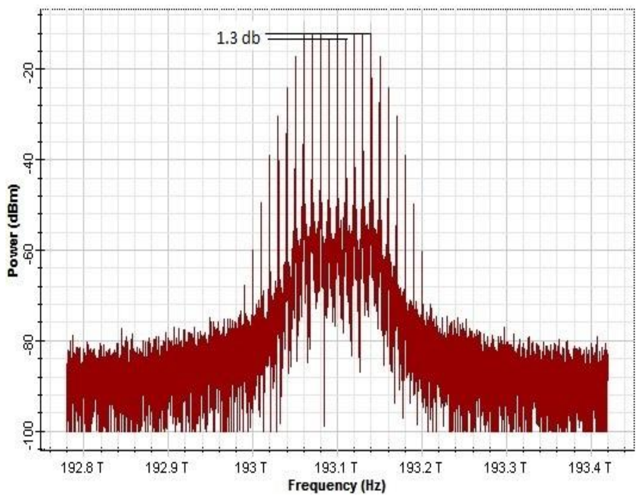

Fig. 4 :Generated Flat Comb structure

IV. OFDM-ROF NETWORK

For testing the generated nine sub carriers by the optical flat source we modulate the signals using OFDM based ROF network with different distances of single mode fiber as illustrated in figure 1. The block diagram of generation and reception of OFDM signal is depicted in fig 5 and fig 6,

OFDM Modulator block

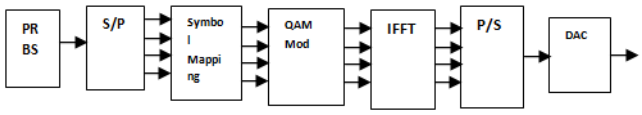

Fig. 5 :OFDM Modulator block

OFDM Demodulator Block

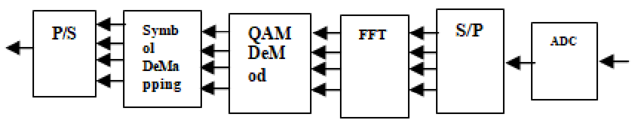

Fig. 6 :OFDM Demodulator Block

OFDM signal is generated using according to theblock shown in fig 5,which uses the concepts of DSP (Digital Signal Processing) system in which all the incoming data bits are first converted from serial form to parallel form in the serial to parallel conversion block, then the signals are combined into N subcarriers symbols in which each of the subcarrier can be modulated using any of the modulation technique such as QAM, QPSK, etc. In our work the modulation technique which is used is QAM having modulation order of 16 i.e. 16QAM modulation format, the mapped signals are then fed into a block which performsIIFT after which it creates a real valued time domain based waveform the OFDM symbol which is represented by

$$Pout = 1 + m R\, 2\{\textstyle\sum_{n=0}^{1} Xne^{(j2\pi fnt)}\} \quad (6)$$

Where

n: number is the number of sub carriers, m: modulation depth of subcarrier

Fn: nth subcarrier frequency, Xn: modulated data symbol and the modulation index . The modulation index μ = m sqrt(N/2)

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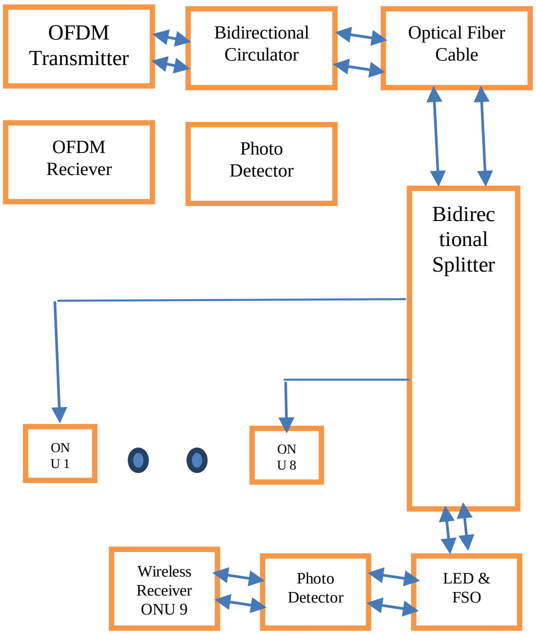

Fig. 7 :FGON OFDM ROF network architecture

Then the modulated signal is again made to convert from parallel mode to serial mode which is suited for transmission and is transmitted At the receiving end we have the demodulator block which is shown in fig 6, in the demodulator circuit the OFDM signal is supplied to the Analog to digital convertor block which converts the incoming Analog signal to its equivalent digital signal and from which the signal is fed in to a serial to parallel converter block which converts the incoming digital serial signal into parallel form and it is fed to a FFT circuit which makes the signal read for the demodulator circuit which changes the time domain signals to frequency domain signals. One limiting factor with OFDM is that when the rising amplitude is high the lower threshold based signals are clipped and in the other scenario if the driving amplitude is low the signals are not clipped but the power efficiency of the signal is affected. The FGON OFDM ROF network architecture is shown in Fig 7, which shows that the generated WDM OFDM signals are divided into two categories out of the nine signals Eight are used for wired networks and one is used for testing wireless ROF network which are tested on the basis of the BER values and the results are analyzed as follows.The generated OFDM signal is shown in the below fig 8, and the spectrum of the signal after injecting in the fiber is shown in fig 9, we can see that the signal is slightly clipped due to the above mentioned factor of high raising amplitude at the time of injecting in the fiber, but that factor is negligible and the above mentioned factor is also proved by fig 10, in which we can shows the OFDM signal after passing the Photodiode at the receiving end which is also a bit affected from the original signal which was generated in fig 7.The entire work is simulated based on the parameters given in table 1 which tells about important parameters such as sampling rate, size of FFT number of subcarriers which are used in the simulation, after simulating the designed network is tested with respect to the above parameters from which we observe the performance characteristics of the designed future generation optical network.

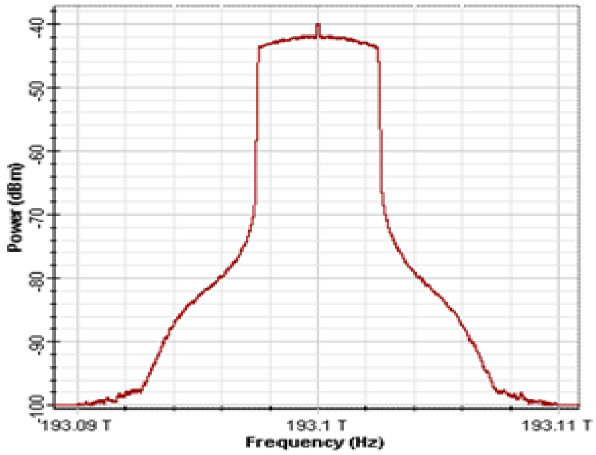

Fig. 8:GeneratedOptical OFDM Spectrum after Modulation

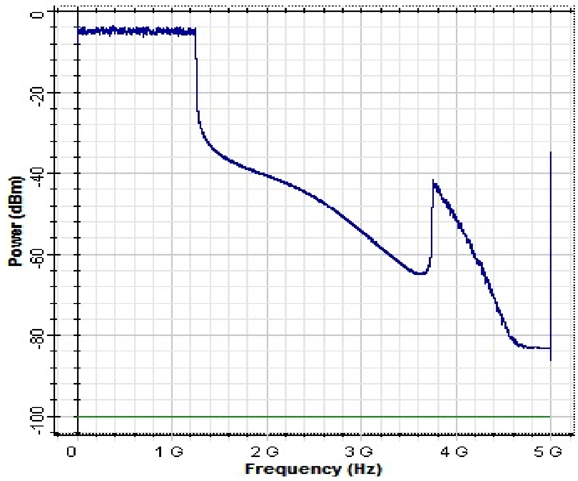

Fig. 9: OFDM Spectrum after injecting in Fiber

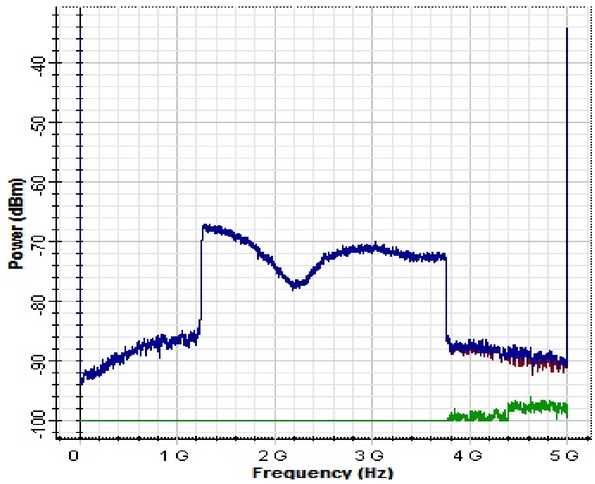

Fig. 10: OFDM Spectrum at the receiver side after passing the Photo diode

V. SIMULATION PARAMETERS

Parameter	Value
Sampling rate of ADC/DAC's	>= 12 GHz
Size of FFT	2048
Overhead of Cyclic Prefix	1.56%

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Random Data is encoded	**16-QAM**
Carrier Index	**8 to 485**
Spectral Range	**46 MHz to 2841 MHz**
Central Spectrum	**2130 MHz**
Number of subcarriers	**Up to 500**
Bit Rate of NG-OFDM is	**>10 Gb/s**
Expected Output	**>10Gb/s**

VI. PERFORMANCE CALCULATIONS

The working of the designed FGON network can be measured by analyzing a series performance calculation parameters such asSignal Power [SP] of a single sub carrier

$$Sp = [(P.m.R)^2 / 2] \quad (7)$$

Where Sp: signal power of a single sub carrier, R is the responsitivity of photodiode

$$S_{NR} = [\{Sp / (4KT/R_e)F_eB + 2qRPB\}] \quad (8)$$

Where Fe: receiver noise,K is Boltzmann's constant, T: absolute temperature, B: Receiver bandwidth, Q is electron charge

Similarly the it Bit Error Rate (BER) is also calculated using the below formula

$$BER = [2(1-1/\sqrt{M})e_rF_C (\sqrt{3S_{NR}} / 2(M-1))] / \log_2 M \quad (9)$$

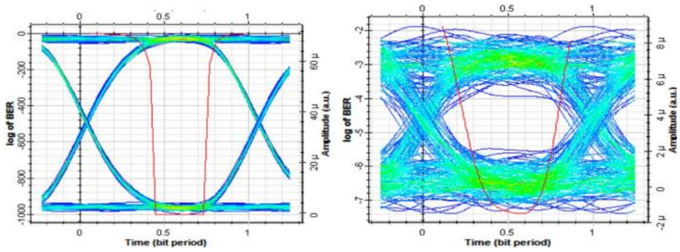

Fig 11: BER analyses for wired network at the initial and after passing through 25 km fiber.

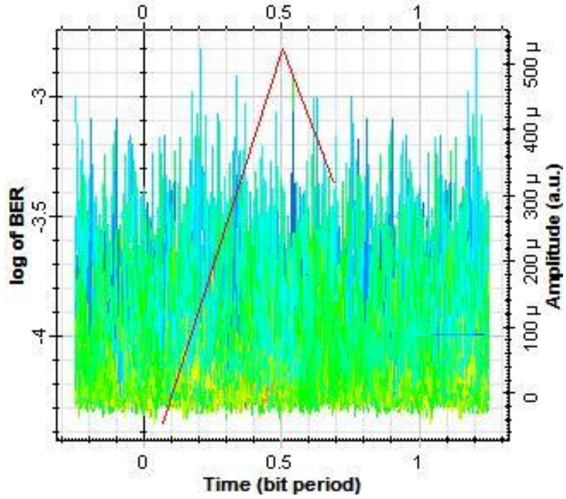

Fig 12: BER analyses for wireless network.

The designed FGON network is performance tested for these parameters by varying the length of distance between the transmitter and the receiver obtaining the values and plotting them wecan find out the performance characteristics of the proposed FGON's and also the obtained constellation diagram for the used 16 QAM OFDM modulation is shown in fig 13. By plotting the BER values of the Eight wired users we get the following graph as mentioned in Fig 14 which shows the BER achieved for wired users in both downlink and uplink traffic.in the available eight input lines, seven input lines are used for downlink channel and one for the common uplink channel for wired and wireless. BER of zero isachieved for all eight users . The Fig 15 shows the BER of 4.36881x10-5 achieved for one wireless user.

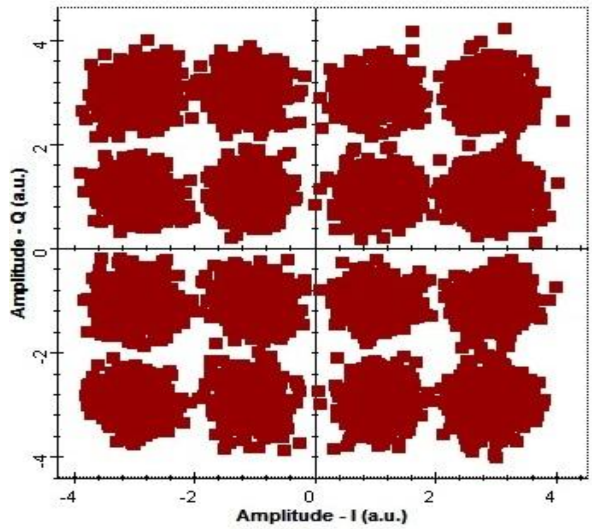

Fig. 13:Signal Constellations of 16 QAM OFDM Receiver

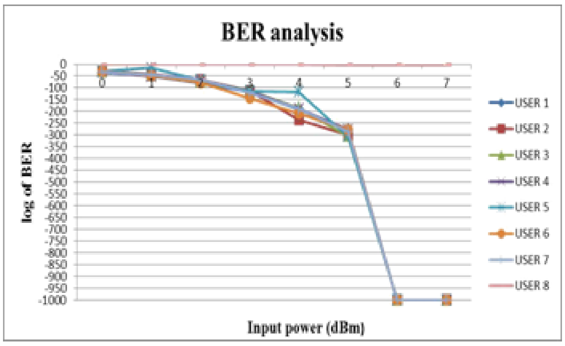

Fig. 14:Signal Constellations of 16 QAM OFDM Receiver

The above Fig 14 shows the BER analyses of various input power made for multiple users. USER 1 to USER 7 mentioned in above figure are wired users and USER 8 mentioned is the wireless user.

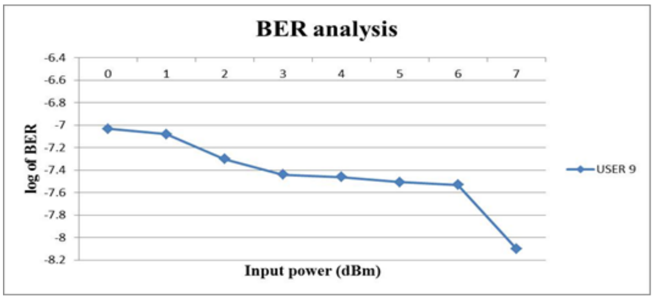

Fig. 15: BER analysis of various input power for uplink user

The Fig 15 shows the BER analyses of various input power made for one uplink user. From both the graph the best BER is achieved at the input power of 7 dBm.

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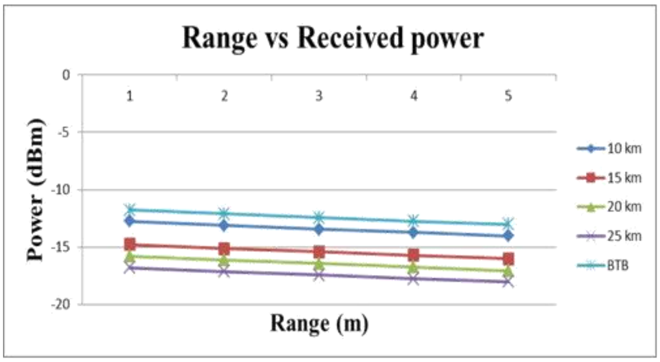

Fig. 16: Wireless Range Vs Received power for various fiber lengths

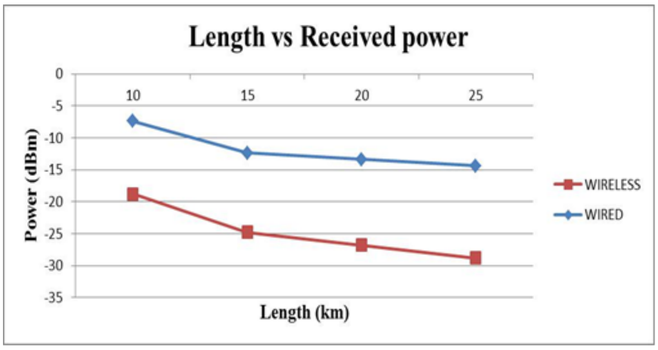

Fig. 17:Fiber length Vs Received power for various fiber lengths

From both the above graphs Fig 16 and Fig 17 it is clear that the power of the signal decreases linearly as the length increases and after 25 kms the signal quality gets decreased and noise is increased in the signal which can be seen in fig 18. It shows that the power of the system decreases suddenly after passing the 25 km mark.

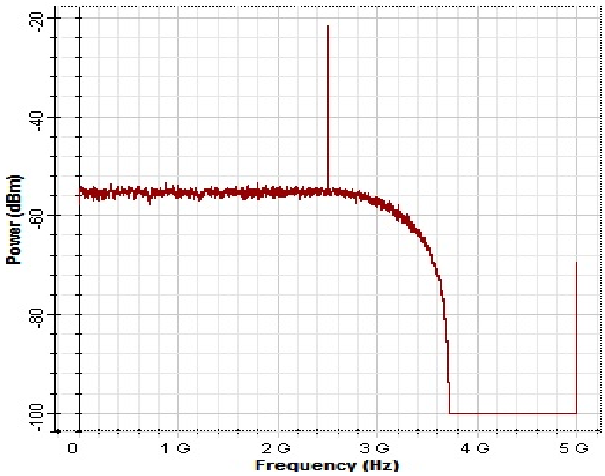

Fig. 18:Power of the signal after travelling 30 kms.

VII. CONCLUSION

In the paper an Future generation optical network is demonstrated and it has both wired and wireless connectivity. The input to this network is uniquely designed by a MZM based circuit which produces nine flat input signals which can be increased in future by changing the required parameters. Both the upstream and the downstream channels carry data and no active components are required for the entire set up and the following conclusions can be made based on the numerical results that the BER is more affected for wireless ONU and is more stable upto 25 kms for wired ONU. Thus we can conclude that the WDM-OFDM-PON offers a exciting prospect for the future of optical networks.

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AUTHORS PROFILE

Samayaraj Murali Kishanlal M, Associate Professor, St.Joseph's Instituteof Technology, Chennai. Has around 14.5 years of Teaching experience, currently pursing his doctorate in Optical networks. His areas of intrest include Optical Networks, Machine learning and artificial Inteligience..

Dr. Jawahar, Professor in the Department of Electronics and Communication has 26 years of teaching experience including 11 years of teaching for Post-Graduation Program and 10 years of research experience. The title of the research is "Studies on Hybrid Topology Management Schemes for Wireless Sensor Networks". He has received his B.E in Electronics and Communication Engineering, with first class from Government College of Technology, Coimbatore, Post Graduate Diploma in Computer Applications (PGDCA) with first class from Alagappa University, Karaikudi, M.S., in Electronics and Control Engineering with first class from BITS, Pilani, M.Tech in Remote Sensing with First class from College of Engineering, Anna University, Chennai, and Ph.D., from SSN College of Engg., Anna University.

He has published over 18 research publications in refereed international journal and 26 in the proceedings of national and IEEE explore digital library conferences. He is a member of IEEE, Life member ISTE and Life member IETE. He is teaching as well as guiding for undergraduate, graduate students and Ph.D., scholars.