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Performance Analysis of Fiber Wireless Solution in Passive Optical/Copper Restrained Areas

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Abstract ------ **With the rapid rise of optical fiber access technologies, a new networking form is emerging called fiber-wireless (Fi-Wi). Wireless part is used where laying-out of fiber is not feasible economically and its operation and maintenance is problematic. Fi-Wi offers high quality and reliability, better coverage, high signal-to-noise ratio, low maintenance and less time required for deployment. In this paper, we have simulated Fi-Wi set up and analyzed QoS parameters offered by the solution. We have also compared its results with access network with fiber only (PON). The frequency range used for wireless portion of the system is 71-76 GHz (E-Band Frequency range). We have evaluated our simulation using variable data rates, diverse fiber lengths and varying optical launch powers and their impact on bit error rate (BER) and Q-factor. On the basis of simulation results, we conclude that Fi-Wi system gives comparable results in the last mile section against access network based on PON or Copper.**

Index Terms ------ **PON, FiWi, Radio & Fiber, E-Band**

I. INTRODUCTION

Fiber technology in core network has enhanced capacity of media and bandwidths offered to subscribers have multiplied. Also there is rapid growth in bandwidth requiring services used by customers. It has forced operators to devise the innovative solution to meet the customers' expectations.

The advent of DSL (Digital Subscriber Line) in telecommunication network has given broadband access to users. Initially, charges of broadband access were quite high and out of reach of majority of internet service users. But later on, swift developments on technological front as well as reforms in telecom world in the shape of deregulation of telecom market and increasing competitive forces brought in downward slide of prices of broadband access and usage. This led to widespread usage of broadband services at competitive prices. Coincidently, the need for designing of new and re-designing of existing telecommunication networks was felt more acutely.

The biggest challenge faced by telecom operators in provisioning of telecommunication services to large number of customers was and still is the design of access part of the network. Before the start of DSL services, access network mainly comprised of copper cables. This problem was resolved with the entry of DSL and next generation network (NGN) design and network optimization techniques were adopted [1].

During last few years, demands for bandwidth and high data rate are rising in steep manner and existing infrastructure was not able to cope with the needs of end users. This issue was resolved with fiber optic communication evolution in various generations including the use of Wavelength Division Multiplexing (WDM) techniques.

Recent installation of Fiber to terminal x (FTTx) enabled to provide high bandwidth and data rates at last mile terminals. The simple architecture of FTTx is based on passive optical networks (PON). The PON does not use active devices, thus it is less complex and consumes less power and space and can be extended very cheaply to large number of customer terminals. However, the cost for laying of fiber Infrastructure upto every customer premises is very high [2].

The global recession in recent years has discouraged service providers to invest in fiber access networks. Therefore, telecommunication operators started revamping, redesigning and optimizing existing copper networks by reducing lengths of last mile access loops [3]. Shortening of local loop converts "old-fashioned" copper access network into a fully functional broadband access network, that is able to provide multimedia services to a large number of customers but even revamping of old copper network is time taking job and it also incurs substantial cost.

In such scenario, the Fiber Wireless (Fi-Wi) network as a viable alternative is gaining increasing attention. This option excludes the requirements of wired local loop to every customer terminal and reduces network deployment cost and time [4].

In the next section, we will discuss Fi-Wi architecture. Section-III describes the wireless communication network used in the research. Section IV contains details about simulation setup. In section V, results are analyzed.

II. FI-WI ARCHITECTURE

In this architecture back bone comprises of optical fiber network while access part comprises of wireless network [5], [6]. Fi-Wi set-up is shown in Fig.1. Fi-Wi networks use WDM technology for communication through optical fiber while mm-wave frequency ranges are used for communication through wireless part of the network. The wireless part of the network requires large number of antennas with high throughput to increase coverage area. The wireless signal faces many issues during optical transmission like opto-electric conversion efficiency, dispersion and non-linear effects of optical fiber which need to be overcome [7]. There are two basic architectures for transmission of wireless signal through optical fiber, RoF (Radio Over Fiber) and R&F (Radio and Fiber) [8].

In RoF architecture, RF frequency modulates light signal for transmission over optical fiber while WDM enables transmission of multiple signals through Single Mode Fiber [9], [10]. The modulated RF signals are sent to RAUs (Remote Antenna Units) where it is converted into electrical signal and transmitted through wireless path. RoF uses different wireless signals such as RF over Fiber, IF over Fiber, Baseband over Fiber and Free Space Optics [11]. Recently experimental demonstrations have been done for wireless transmission of optical signals directly by using optical antennas [12]. Latest development for implementation of RoF Architecture is for upcoming 5G Mobile Communication Networks [13] and linear cell systems connected to RoF Networks [14].

On the other hand, R&F architecture uses two separate MAC protocols for fiber and wireless parts of the network. ONU & Base station combination is used for protocol translation resulting into less traffic load on Central Office (CO). It is beneficial as wireless communication is not interrupted even after failure of optical part of the network and reduction in CO complexity is also achieved as wireless MAC frames are not always transmitted to CO for communication because purpose is served by associated access points [11].

III. E-BAND WIRELESS COMMUNICATION

Frequency ranges of 71-76 GHz and 81-86 GHz are referred to as E-bands. The use of this frequency range is controlled by FCC part 101 licensed operation. This range is ideal mm-Wave band for point to point communication due to low attenuation and availability of large spectrum of 5 GHz in each band. This spectrum bandwidth of 10 GHz exceeds bandwidth available in entire allocated microwave spectrum.

The 5 GHz uninterrupted E-band spectrum can be used as single continuous transmission channel. It can provide throughput of 1 to 3 Gbps with simple modulation techniques like on-off keying (OOK) or binary phase shift keying (BPSK) while even high throughput can be achieved with more advanced modulation techniques [15].

IV. SIMULATION SET-UP

A. Fiber Based Network Simulation

Fig.1 shows the simulation set up for Fi-Wi network at 1 Gbps bit rate, 128-bits sequence length, 64 samples per bit and total number of samples is 8192. The other simulation parameters are shown in Table I [16].

Wavelength of 1530 nm and 1550 nm have been used for downstream while 1300 nm have been used for upstream being lowest possible attenuation windows. Figs. 2, 3 and 4 show ONU, RF Transmitter and Receiver subsystems respectively.

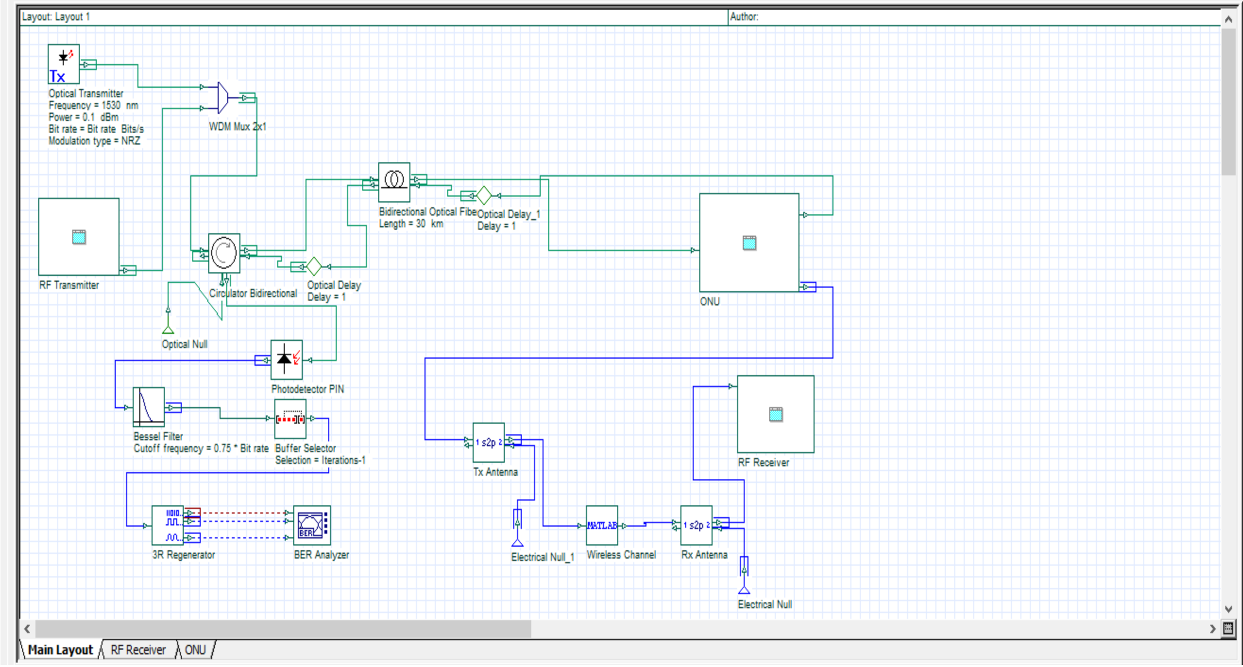

Fig. 1. Fi-Wi Simulation Setup

TABLE I: Simulation Parameters

Parameter	Value
Bit Rate	1-5 Gbps
CW Laser Frequency	1530 nm, 1550 nm
Optical Power	0-2 dBm
Fiber Length	10 - 40 Km
Fiber Attenuation	0.2 dB/Km
Wireless Attenuation	0.5 dB/Km
Fiber Dispersion Constant	16.75 ps/nm/Km
Photodetector Responsivity	1 A/W

At transmitter side, Continuous Wave (CW) laser and optical transmitter emit light at 0.1 dBm power. Mach Zehnder Modulator (MZM) modulates optical signal by 71 GHz amplitude modulated RF signal. The PON and RF modulated optical signals are multiplexed by using WDM multiplexer and are fed to standard single mode fiber. This downlink data signal is de-multiplexed through WDM de-multiplexer. The PON optical signal is passed through optical receiver, 3R generator and BER Analyzer for measurement of QoS parameters. On the other hand, RF modulated optical signal is passed through band-pass Bessel filter and then detected by PIN detector. The resulting electrical signal is then fed to transmitting antenna which is simulated by using two port s-parameter network model. The transmitted signal passes through wireless channel simulated by Optisys-Matlab co-simulation and detected by two port s-parameter network based receiving antenna. The electric signal, received by receiving antenna, is demodulated through 71 GHz amplitude demodulator and passes through low-pass Bessel filter and 3R regenerator to recover original bits. The electrical signal from 3R generator is fed to BER analyzer to test the RF transmitted signal.

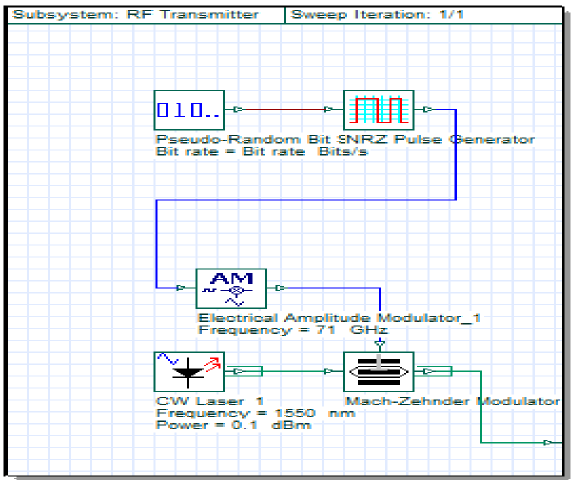

Fig. 2. RF Transmitter Simulation Setup

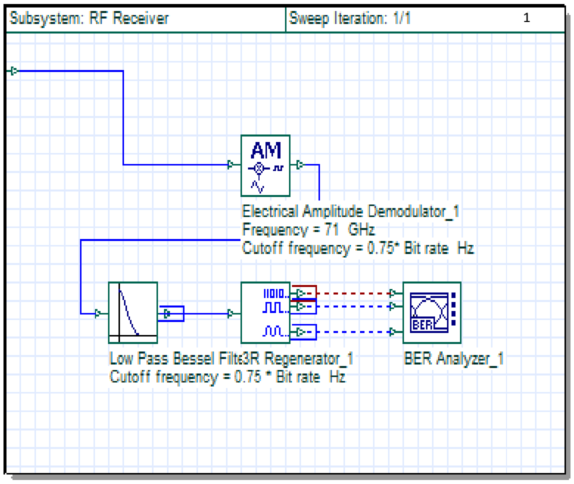

Fig. 3. RF Receiver Simulation Setup

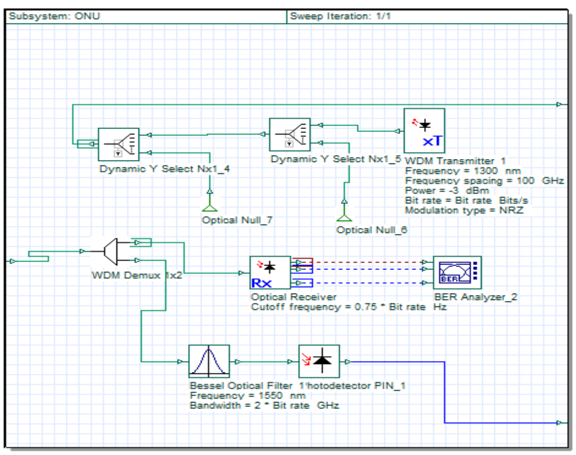

Fig. 4. ONU Simulation Setup

The multiple upstream signals are transmitted by WDM transmitter with frequency spacing of 100 GHz. Upstream utilize MAC Protocols for multiple access in order to collect data from multiple users which is simulated by using pair of Dynamic Y-selectors while at receiving end Buffer selector have been utilized to separate multiple upstream signals. The optical circulator has been utilized for isolating upstream and downstream signals and for recognizing bidirectional transmission in single fiber. The properties of the bidirectional circulator used in the simulation are wavelength dependent isolation, insertion, and return loss. Two optical delay elements have also been placed to facilitate transmission of upstream and downstream signals having different frequencies.

B. Antenna Simulation

In Optisystem, antennas and wireless channels cannot be simulated due to unavailability of frequency dependent parameters. Therefore, two port s-parameter block in optisystem has been utilized to represent transmitting and receiving antennas while Matlab block has been utilized to simulate wireless channel. Antenna simulation softwares like HFSS produce s parameters such as return loss and gain at particular frequencies. The antenna gain only includes dissipation loss, and does not include mismatched and polarization loss. The representation of antenna through this method is based on analogy between antenna and two port s-parameter network model [17], [18]. The s-parameter values for S2P file are imported from HFSS antenna designing software by designing dipole antenna for 71-76 GHz E-band frequency range. The values for s-parameters are tabulated in tables II and III for transmitting and receiving antennas.

The zero return loss is ensured by keeping load impedance Z_L equals to output impedance Z_o. S_{12} and S_{22} can have arbitrary values, but to ensure similarity, S_{12} and S_{22} should be zero for transmitting antenna while S_{12} and S_{11} should be zero for receiving antenna. Phase of S_{11} is important, but phase of S_{21} is not important. The characteristics of transmitting and receiving antennas remain same as it can be observed in tables II and III [17].

TABLE II: S2P Values for Transmitting Antenna

$\lvert S_{11}\rvert$	$<S_{11}$	$\lvert S_{21}\rvert$	$<S_{21}$
$\lvert S_{11}\rvert$ (HFSS)	$<S_{11}$ (HFSS)	$\sqrt{(G_P(1-\lvert S_{11}\rvert^2)}$	0
$\lvert S_{12}\rvert$	**$<S_{12}$**	**$\lvert S_{22}\rvert$**	**$<S_{22}$**
0	0	0	0

TABLE III: S2P Values for Receiving Antenna

$\lvert S_{11}\rvert$	$<S_{11}$	$\lvert S_{21}\rvert$	$<S_{21}$
0	0	$\sqrt{(G_P(1-\lvert S_{11}\rvert^2)}$	0
$\lvert S_{12}\rvert$	**$<S_{12}$**	**$\lvert S_{22}\rvert$**	**$<S_{22}$**
0	0	$\lvert S_{11}\rvert$ (HFSS)	$<S_{11}$ (HFSS)

V. RESULTS AND DISCUSSIONS

Eye diagrams of 1 Gbps and 3 Gbps FiWi downstream traffic are shown in figure 5 and 6 respectively. It can be observed that eye opening is large and clear which means that signal quality is good with minimum noise and distortion and logic 0 and logic 1 can be distinguished very easily. The eye diagram of PON downstream traffic at 3 Gbps is also shown in figure 7. The comparison of eye diagrams shows that QoS parameters of FiWi system are comparable to PON.

A. Q factor and BER Variation with Bit Rate

The variations of Q factor and BER with bit rate are shown in figures 8 and 9 respectively. Q factor and BER were analyzed for bit rates from 1 to 5 Gbps while optical power and fiber length were kept constant at 0 dBm and 20 km respectively. Graphs show that Q factor decreases while BER increases with increase in bit rate.

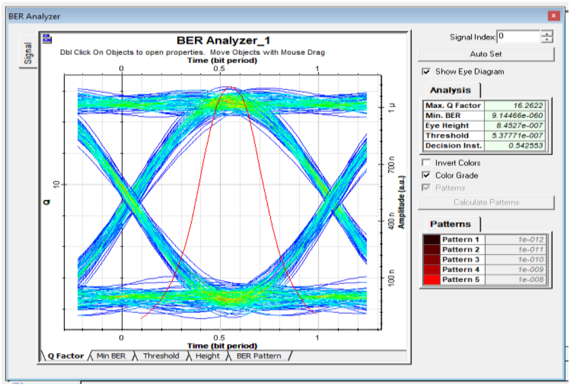

Fig. 5. FiWi Eye Diagram at 1 Gbps

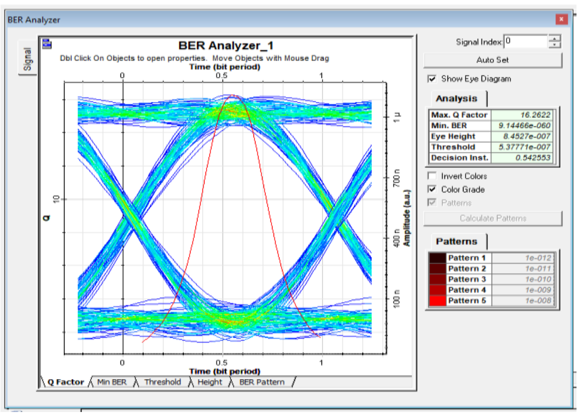

Fig. 6. FiWi Eye Diagram at 3 Gbps

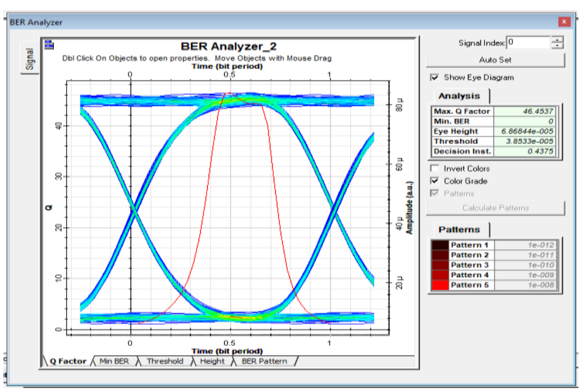

Fig. 7. PON Eye Diagram at 3 Gbps

B. Q factor and BER Variation with Fiber Length

The variations of Q factor and BER with fiber length are shown in figures 10 and 11 respectively. Q factor and BER were analyzed for fiber lengths varying from 10 Km to 40 Km while optical power and bit rate were kept constant at 0 dBm and 2 Gbps respectively. Graphs show that Q factor decreases while BER increases with increase in fiber length.

C. Q factor and BER Variation with Optical Power

The variations of Q factor and BER with optical power are shown in figures 12 and 13 respectively. Q factor and BER were analyzed for optical power varying from 0.1 dBm to 2 dBm while fiber length and bit rate were kept constant at 20 Km and 2 Gbps respectively. Graphs show that Q factor increases while BER decreases with increase in optical power.

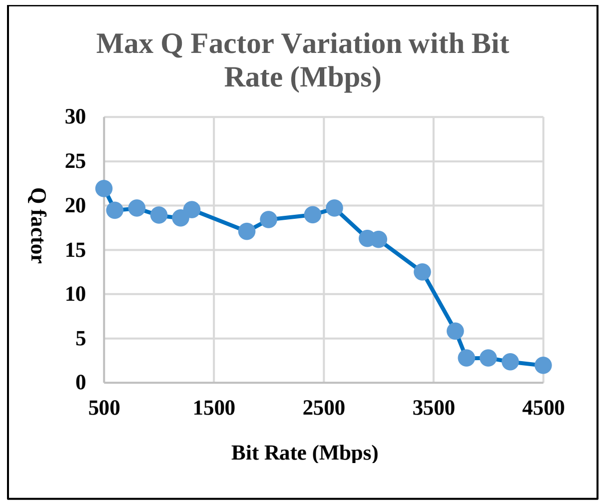

Fig. 8. Max Q factor variation with Bit Rate

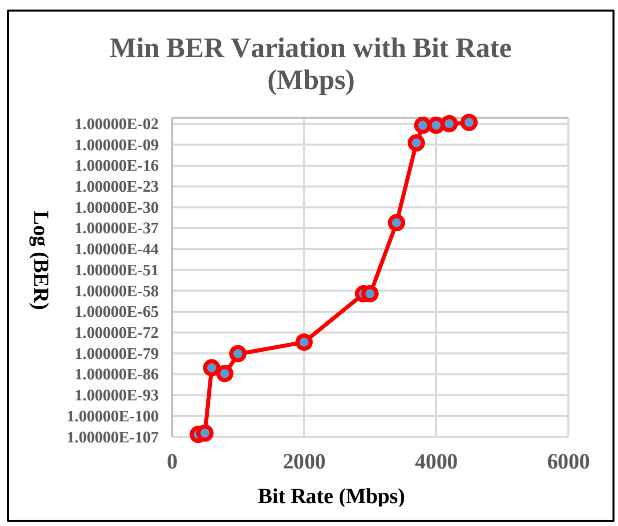

Fig. 9. Log (Min BER) variation with Bit Rate

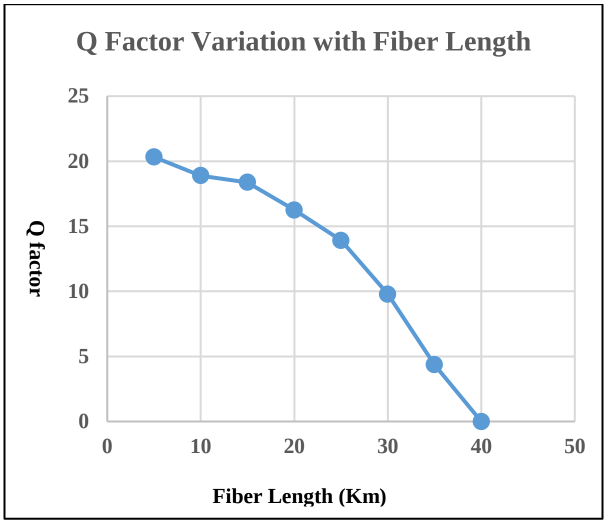

Fig. 10. Max Q factor variation with Fiber Length

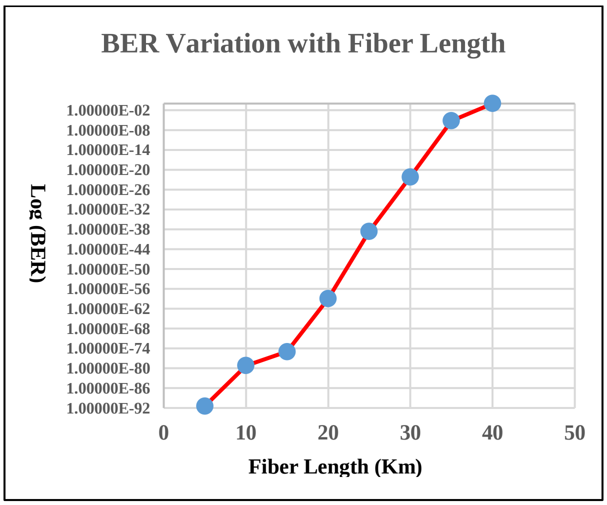

Fig. 11. Log (Min BER) variation with Fiber Length

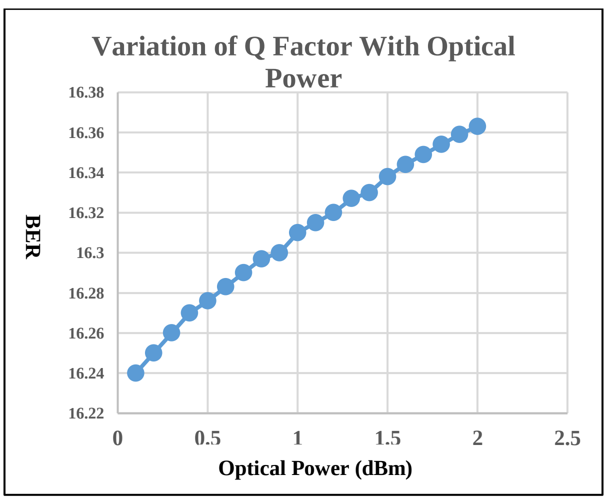

Fig. 12. Q factor variation with Optical Power

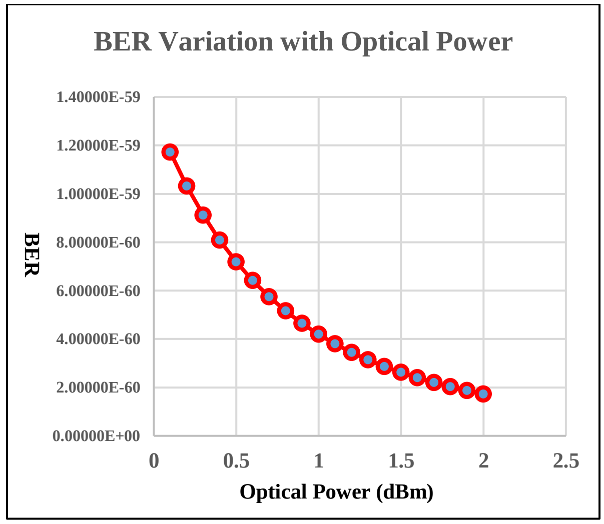

Fig. 13. BER variation with Optical Power

VI. CONCLUSION

Fi-Wi network is the potential alternative to the FTTH to meet current and future bandwidth demands of users. The proposed Fi-Wi system was simulated with data rates of 1 to 5 Gbps modulated by RF signal, for frequency range of 71-76 GHz, over varying fiber lengths. Simulation results show that this type of network can provide high data rate services to customers with minimum BER and high SNR values. WE successfully transmitted signals from 1 Gbps to 3.5 Gbps at the customer premises with acceptable levels of signal quality, eye opening, Q factor and BER. Simulation results demonstrate that F-Wi networks can be used to provide multimedia and other high data rate demanding services in the areas where optical fiber cannot be extended.

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