Modeling and Performance Analysis of RoF System for Home Area Network with Different Line Coding Schemes Using Optisystem

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***Abstract*— Home Area Network (HAN) is deployed and operated within the close vicinity of a home to enable communication and interoperability among digital devices. With the advancement of technology, consumers' aspiration is to have a stable and high throughput broadband access with lower latency for applications like online gaming, Video on Demand (VoD), video conferencing, Voice over Internet Protocol (VoIP), HD data exchange. Key expectations from broadband accessibility are wireless access and higher data rate. All most all of the wired and wireless HAN access technologies are suffering from problems like immobility, inflexibility, complexity of installation, higher loss and relatively lower data rate. In these circumstances, Radio over Fiber (RoF) offers potential solution for increasing capacity, mobility and reducing cost. This paper proposed and simulated a simple, competent and cost effective RoF system using interferometer. Simulation results from Optisystem 12 have been included to show the comparative performance evaluation of parameters like maximum Q-factor, minimum BER, eye height and threshold with respect to bit rate and fiber length for different line coding schemes. Simulation results show that the proposed system exhibits desired performance with Gaussian line coding scheme. This paper also suggested optimal tradeoff between bit rate and fiber length for the particular system.**

***Keywords* – Home Area Network, Radio Over Fiber, Line Coding and Optisystem**

I. INTRODUCTION

Home Area Network (HAN) establishes communication of a person's digital devices with telephones, VCRs, televisions, video games, home security systems, fax machines and other smart appliances that are wired into the network [1]. In order to meet the ever increasing demand for larger transmission bandwidth, higher data rate with minimum degradation of signal quality, better wireless broadband accessibility is required for HAN. Future trends and necessity of HAN is to raise the threshold of data rate to multi Gbps. However, much research has been done previously to provide HAN with wired and wireless accessibility. Existing wired technologies of HAN, such as, Ethernet (IEEE 802.3), Power

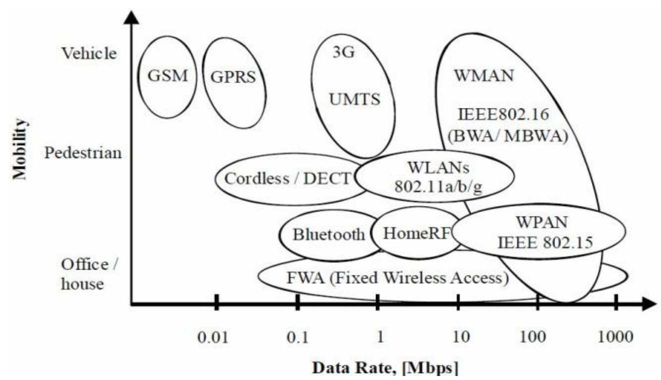


Fig. 1. Mobility Vs Data Rate for different wireless standards [2]

Line Communication, optical fiber can not provide mobility and flexibility. Whereas, wireless technologies, Wi-Fi (IEEE 802.11), Bluetooth, ZigBee (IEEE 802.15), UWB are suffering from the problem of complex installation, higher loss yet relatively lower data rate.

In such condition, a wireless and optical integration technique, Radio over Fiber (RoF) has attracted much attention recently to compensate the limitations of existing technologies. Radio over fiber (RoF) refers to a technology whereby light is modulated by a radio signal and transmitted over an optical fiber link to facilitate wireless access, such as 3G and WiFi simultaneously from the same antenna. In other words, radio signals are carried over fiber-optic cable.

Thus, a single antenna can receive any and all radio signal carried over a single-fiber cable to a central location where equipment then converts the signals; this is opposed to the traditional way where each protocol type requires separate equipment at the location of the antenna. Radio over Fiber (RoF) with extensive use of digital signal processing can be used to provide wireless broadband accessibility with higher data rate. Radio coverage in WLAN environment can be expanded using RoF [4].

Table I: Maximum data rate and range of existing wired and wireless technologies of HAN [3]

Technology/ Standard	Maximum Data rate	Range
Wired		
Ethernet (IEEE 802.3)	100 Gb/s (IEEE 802.3 bj)	
Power line Communication	10 Mb/s	
Optical Fiber	40 Gb/s	~100 Km
Wireless		
Wi-Fi (IEEE 802.11)	866.7 Mb/s (IEEE 802.11ac)	~10 meter
Bluetooth (IEEE802.15)	24 Mb/s (Version 3 +HS)	~10 meter
ZigBee (IEEE 802.15.4)	250 kb/s (IEEE 802.15.4)	~30 meter
UWB	675 Mb/s	~10 – 20 meter

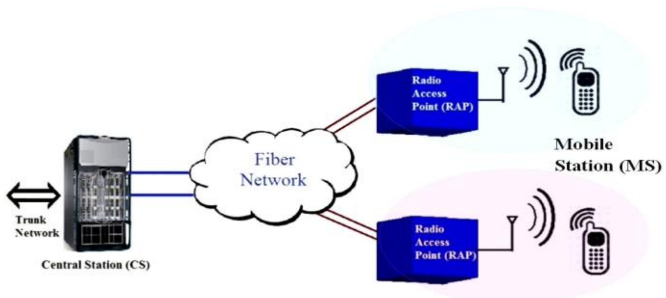


Fig. 2. RoF System Concept

RoF system consists of Central Station (CS) and Base Station (BS) connected by an optical fiber link or network. RoF system distributes the radio-frequency (RF) signals by optical transmission to Radio Access Point (RAP) so that RAP does not require performing functionalities like modulation, coding, up/down conversion and multiplexing. RoF for HAN requires higher data rate transmission over relatively short distance from Central Site (CS) to Remote Site (RS) connected by an optical fiber link. [5]

In this paper, we have proposed and simulated an adept, cost effective RoF system for HAN using single mode fiber operating at 1550 nm which fall under C-Band, which is also known for its lowest attenuation losses and hence it achieves the largest range and greater data rate. 10 GHz and 15 GHz RF are utilized to achieve higher data rate. Moreover, delay interferometer with lower insertion loss and better frequency chirp characteristics is used to separate two optical signals at the receiving end. This paper also investigated the performance evaluation of the system for different performance metrics for Return to Zero, Non Return to Zero and Gaussian line coding schemes with varying data rate and fiber length. Simulation results from Optisystem 12 shows optimum performance regarding data rate (maximum of 2.5 Gbps) and dynamic range (maximum of 60 km) can be obtained using Gaussian line coding.

II. ADVANTAGES OF ROF SYSTEM

RoF system offers following advantages:

A. Lower Attenuation loss

In RoF system, transmission of radio-frequency occurs through optical fiber thus the losses are much lower than those encountered in the free space propagation and copper wire transmission of high frequency microwave.

B. Better Coverage and Increased Capacity

With the use of densely deployed Radio Access Points dynamic range of RoF system can be increased. Furthermore, low attenuation operating windows of optical fiber communication are 850, 1310 and 1550 nm that offer enormous bandwidth and thus higher capacity.

C. Resistance to RF Interference

Since the RF signals are transmitted through the fiber in the form of light they are immune to electromagnetic interference.

D. Reduced Engineering and System Design Cost

In RoF system, Central Station performs complicated operations, like modulation, coding, up/down conversion and multiplexing. Instead of using traditional approach of densely deployed complex and expensive RAP, simple and cost effective RAPs are used with Intensity Modulated Direct Detection (IM-DD).

E. Reduced Power Consumption

Reduced power consumption is the consequence of having simple RAP with reduced equipment [6].

III. METHODOLOGY AND SIMULATION SCHEMATIC

One of the main objectives of this paper is to design a RoF system based on Intensity Modulated Direct Detection (IM-DD) which leads to simple and cost effective system implementation. Fig. 3 depicts the principle and the configuration of the proposed RoF system.

Central System (CS) composed of two microwave signal generators of 10 GHz and 15 GHz, one continuous wave (CW) laser, two pulse generators, two pseudo-random binary sequence (PRBS) generators and one Mach-Zehnder Modulator (MZM). The central wavelength of CW laser is 1550 nm. In our proposed system, we have used wavelength which falls under C-Band where attenuation is minimum and hence it achieves the longest range. In this system, 1 Gb/s data streams are mixed with 10 GHz and 15 GHz microwave signals and supplied to the MZM along with the optical carrier from the laser diode. Amplitude Modulated (AM) optical carrier is fed into the fiber transmission link i.e., Single-Mode fiber. Modulation can be done in two ways, direct and external modulation. In direct modulation, RF signal varies directly with the bias of a semiconductor laser diode, whereas external modulators are integrated with Mach-Zehnder Modulator

(MZM) or Electro-Absorption Modulator (EAM). Intensity Modulation is done mainly due to the simplicity of the corresponding optical detector that is based on a photodetector which operates as a simple amplitude threshold detector [7].

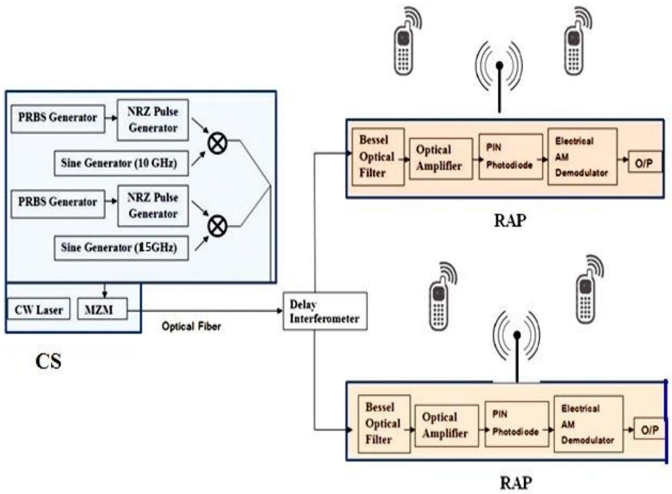


Fig. 3. Simulation model of our proposed RoF system

In our system, we have used delay interferometer to split two amplitude modulated optical carriers. Delay line interferometer have some beneficial characteristics, like, low insertion loss, better frequency chirp characteristics and fairly insensitive to slight misalignment. In delay interferometer, one beam is time-delayed by an optical path difference corresponding to 1-bit time delay. After recombination, the two beams interfere with each other constructively or destructively. The resultant interference intensity is the intensity keyed signal [8].

After that signals are filtered using 4th order Bessel Filter having center frequency of 193.1 THz and demodulated in the AM demodulators for getting back the electrical signals.

RoF HAN is modeled using simulation software, Optisystem 12. Fig. 4 shows the simulation schematic drawn in Optisystem 12 window using various in-built blocks.

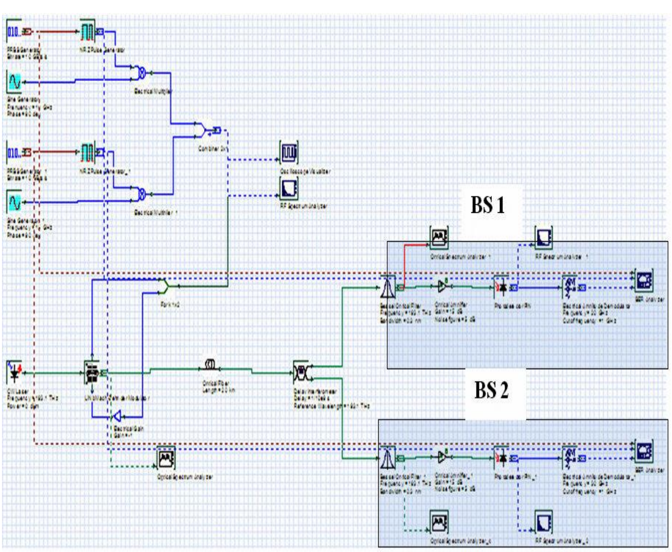


Fig. 4. Simulation schematic of proposed RoF HAN

IV. PERFORMANCE MEASURES

Characterization of an optical transmission link which is one of the main criterions for the effective modeling of RoF system depends on the proper choice of performance metrics. Performance metrics should present a precise determination of system's limitation and measurement to improve the performance of the system. The most widely used performance measures are the Q-factor, BER and eye opening.

A. Q-factor

Q-factor represents the optical signal-to-noise ratio (SNR) for a binary optical communication system and allows simplified analysis of system performance. It combines the separate SNRs associated with the high and low levels into overall system SNR. Q-factor is also helpful as an intuitive Figure of Merit (FoM) that is directly tied to the BER. BER can be improved by either a) increasing the difference between the high and low levels in the numerator of the Q-factor or b) decreasing the noise terms in the denominator of the Q-factor.

$$\text{Q-factor, } Q = \frac{V_H - V_L}{\sigma_L + \sigma_H}$$

V_S is the voltage sent by the transmitter and if we assume that V_s can take on one of the two voltage levels, V_H and V_L.
σ_L and σ_H are the standard deviations of the noise [10].

B. Bit Error Rate (BER)

BER is the number of erroneous bit divided by the total number of transferred bits during a studied time interval. In digital transmission, data stream can be altered due to noise, distortion or synchronization errors. The BER gives the upper limit for the signal because some degradation occurs at the receiver end. The bit error probability, P_e is the expectation value of the BER. The BER can be considered as an approximate estimate of the bit error probability. In a noisy channel, the BER is often expressed as a function of the normalized carrier-to-noise ratio (E_b/N_0), (energy per bit to noise power spectral density ratio), or E_s/N_0 (energy per modulation symbol to noise spectral density).

$$\text{BER} = \frac{1}{2}\operatorname{erfc}(\sqrt{E_b/N_0})$$

C. Eye Pattern

Eye pattern or diagram is used to visualize how the waveforms used to send multiple bits of data can potentially lead to errors in the interpretation of those bits. Vertical eye opening indicates the amount of difference in signal level that is present to indicate the difference between one bit and zero bit. The bigger the difference the easier it is to discriminate between one and zero. Whereas, horizontal eye opening indicates the amount of jitter present in the signal. An open eye pattern corresponds to minimal signal distortion. Distortion of the signal waveform due to intersymbol interference and noise appears as closure of the eye diagram [11].

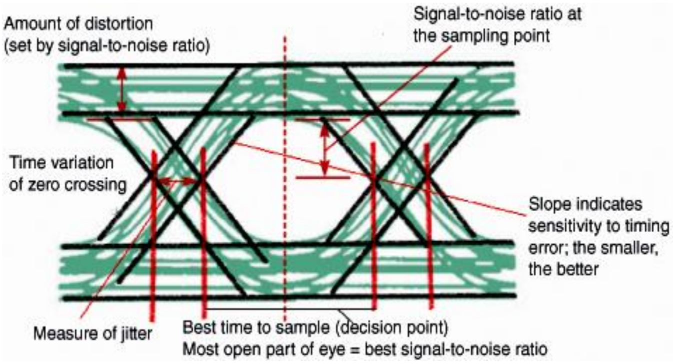


Fig. 5. Eye pattern

V. LINE CODING AND PULSE GENERATOR

Line coding consists of representing the digital signal to be transported by an amplitude and time discrete signal. Binary data can be transmitted using a number of different types of pulses. The choice of a particular pair of pulses to represent the symbol 1 and 0 is called line coding. Better line coding scheme should exhibit a number of desirable properties for particular application, such as -

Signal Spectrum: Spectrum occupancy should be small to ensure good spectrum efficiency.

Minimum DC Component: Minimum DC component is desired.

Clock signal: Spectrum of line coding scheme should contain a frequency component at the clock frequency to permit clock extraction.

Signal interference and noise immunity: Line code should have a low probability of error for a given transmitted power.

Error detection: Error detection facility should be provided.

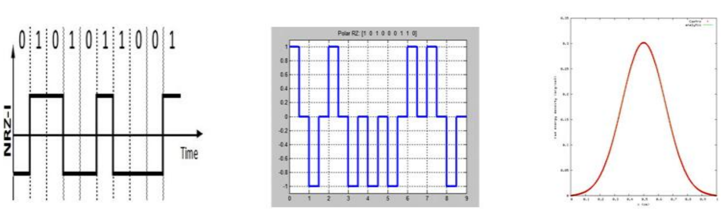
Transparency: Performance of line coding should be independent of the data.

In this paper, three types of pulses are employed, Non Return to Zero, Return to Zero and Gaussian pulse.

Polar NRZ occupies narrow bandwidth thus more spectral efficient but have significant dc component and there is no clock component in the spectrum.

Polar RZ occupies larger bandwidth thus relatively less spectral efficient than NRZ. It also suffers from problems like significant dc component and no clock component.

Gaussian pulse is shaped as a Gaussian function. It has the properties of maximum steepness of transition with no overshoot and minimum group delay [9].



a) b) c)

Fig. 6. a) Polar NRZ b) Polar RZ and c) Gaussian Pulse

VI. SIMULATION RESULTS AND ANALYSIS

Proposed RoF system was successfully modeled and simulated using Optisystem 12. After that Optisystem file was loaded to Optiperformer 12 to extract simulation results. In this specific design, we have employed four types of visualizers, oscilloscope visualizer, RF spectrum analyzer, BER analyzer and optical spectrum analyzer.

Oscilloscope visualizer allows us to calculate and display electrical signals in the time domain. It can also display the signal amplitude and autocorrelation. RF Spectrum Analyzer allows us to calculate and display electrical signals in the frequency domain. It can also display the signal intensity, power spectral density and phase. Whereas, BER Analyzer displays the eye diagram, Q-factor, Minimum BER, threshold, Eye height and BER pattern of the received signals. Optical Spectrum Analyzer allows us to calculate and display optical signals in the frequency domain. It can display the signal intensity, power spectral density, phase, group delay and dispersion for polarizations X and Y.

Output of oscilloscope visualizer is shown in figure 7. Figure 8 shows the transmitted optical signal and Figure 9 and Figure 10 illustrated the received optical signal after 20 km fiber length at BS 1 and BS 2 respectively. Figure 11, Figure 12 and Figure 13 showed the RF spectrum before transmission, received RF spectrum at BS 1 and BS 2 respectively. Figure 14 and Figure 15 showed the eye diagram of data received at BS 1 and BS 2 respectively.

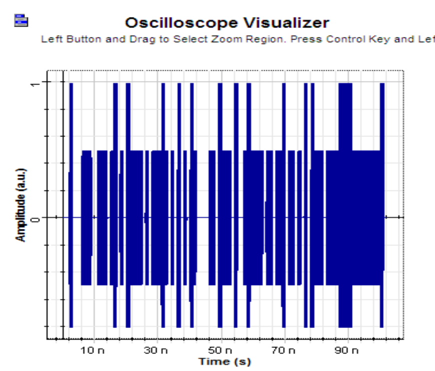


Fig. 7. Output of Oscilloscope Visualizer for 1Gbps for NRZ

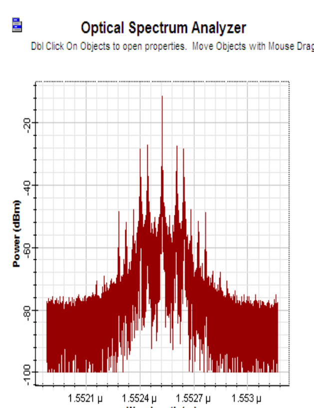


Fig. 8. Transmitted signal at BS 1

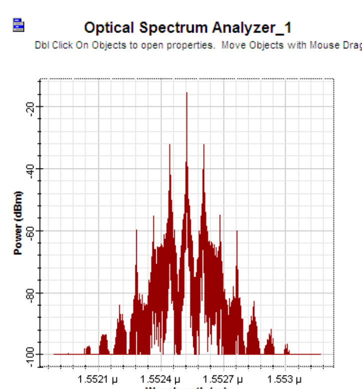


Fig. 9. Received optical optical signal at CS

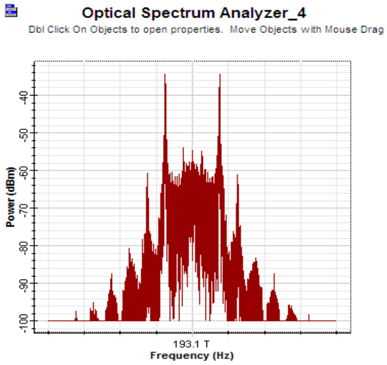


Fig. 10. Received optical signal at BS 2

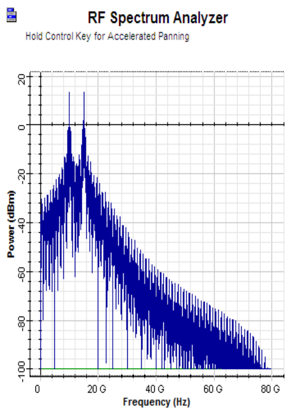


Fig. 11. Transmitted signal at BS 1

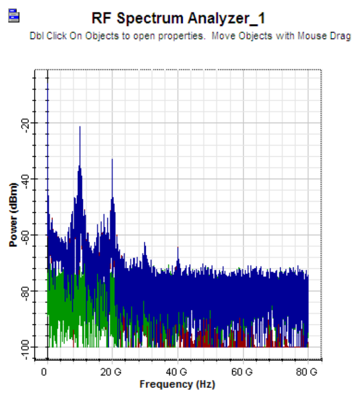


Fig. 12. Received RF spectrum at CS

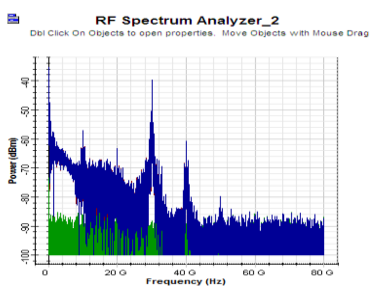


Fig. 13. Received RF signal at BS 2

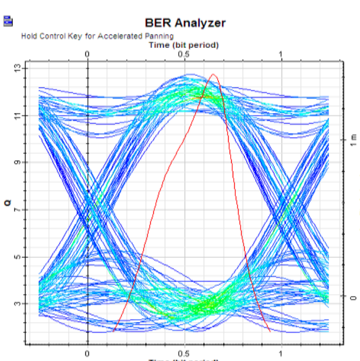


Fig. 14. Eye diagram of data received at BS 2

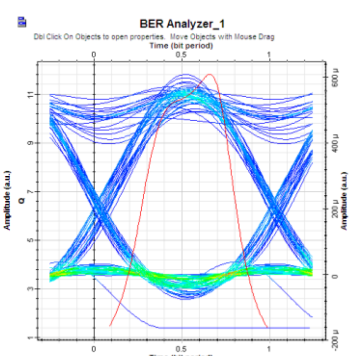


Fig. 15. Eye diagram of data received at BS 1

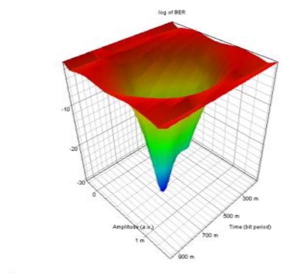


Fig. 16. 3D BER graph at BS 1

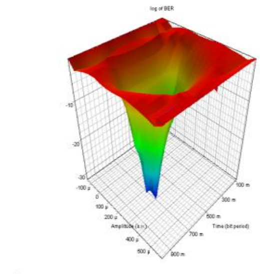


Fig. 17. 3D BER graph at BS2

Table II: Q-factor, Threshold, Minimum BER and Eye Height for Different values of Bit Rate for NRZ Line Coding Scheme

No. of Samples	Bit Rate (Gbps)	Q Factor	Threshold	Minimum BER	Eye Height
1	1	10.8684	0.000616249	9.7105*10^-34	0.000974458
2	1.5	8.95712	0.000561527	1.6658*10^-19	0.00089176
3	2	6.27743	0.000579991	1.72089*10^-10	0.000686619
4	2.5	3.97794	0.00055022	3.46098*10^-5	0.000296745
5	3	3.72178	0.000636222	9.87492*10^-5	0.000234902

Table III: Q-factor, Threshold, Minimum BER and Eye Height for Different values of Bit Rate for Gaussian Line Coding Scheme

No. of Samples	Bit Rate (Gbps)	Q Factor	Threshold	Minimum BER	Eye Height
1	1	16.3023	0.000555544	4.74326*10^-60	0.000853125
2	1.5	10.5837	0.000491375	1.76614*10^-26	0.000688038
3	2	10.1201	0.000448296	2.22313*10^-24	0.000448296
4	2.5	6.36934	0.000402491	9.36142*10^-11	0.000460962
5	3	4.15815	0.000149856	1.60243*10^-5	9.22734*10^-5

Table IV: Q-factor, Threshold, Minimum BER and Eye Height for Different values of Bit Rate for RZ Line Coding Scheme

No. of Samples	Bit Rate (Gbps)	Q Factor	Threshold	Minimum BER	Eye Height
1	1	12.033	0.000778325	1.6514*10^-33	0.000976492
2	1.5	11.3635	7.088*10^-5	2.2369*10^-30	0.00348746
3	2	8.2436	0.000528	8.20137*10^-11	0.0003270
4	2.5	5.03	5.267*10^-5	7.8088*10^-7	0.0002248
5	3	1.809	0.0001138	0.0343	-0.00179973

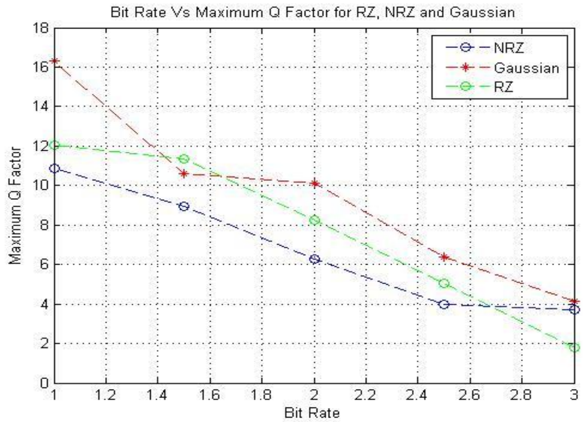


Fig. 18. Performance of Bit Rate Vs Maximum Q-factor for RZ, NRZ and Gaussian

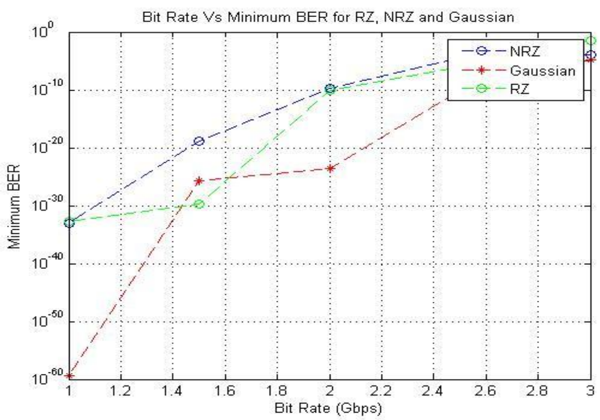


Fig. 19. Performance of Bit Rate Vs Minimum BER for RZ, NRZ and Gaussian

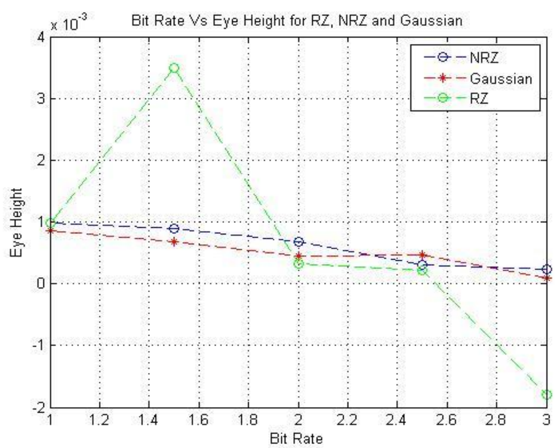


Fig. 20. Performance of Bit Rate Vs Eye Height for RZ, NRZ and Gaussian

Based on the simulation data extracted from Table II, Table III and Table IV, Figure 18, Figure 19, Figure 20 and Figure 21 have been drawn. The results shown in Figure 18, Figure 19, Figure 20 and Figure 21 depict the performance of the effect of varying bit rate on maximum Q-factor, minimum BER, eye height and threshold for RZ, NRZ and Gaussian line coding.

Table V: Maximum Q Factor, Minimum BER, Eye Height and Threshold for different values of Fiber Length for NRZ line coding scheme

No. of Samples	Fiber Length (km)	Q Factor	Threshold	Minimum BER	Eye Height
1	20	10.4368	8.4049*10^-26	0.000391424	0.0002167
2	30	11.7379	3.79*10^-32	0.0002493	9.18*10^-5
3	40	8.52152	6.0219*10^-18	0.000124769	3.66824*10^-5
4	50	8.9311	1.88869*10^-19	8.32*10^-5	3.12*10^-5
5	60	4.93	2.76*10^-7	2.79*10^-5	9.67*10^-6

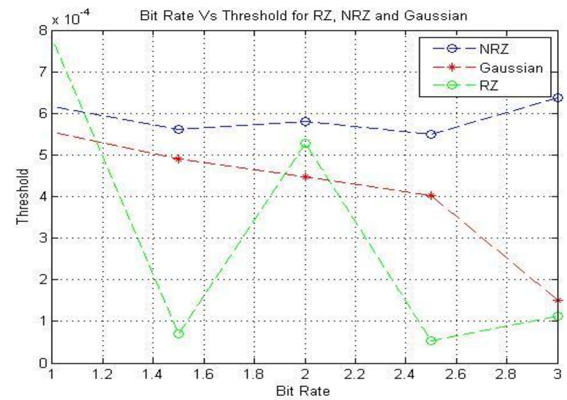


Fig. 21. Performance of Bit Rate Vs threshold for RZ, NRZ and Gaussian

Table VI: Maximum Q Factor, Minimum BER, Eye Height and Threshold for different values of Fiber Length for Gaussian line coding scheme

No. of Samples	Fiber Length (km)	Q Factor	Threshold	Minimum BER	Eye Height
1	20	11.1591	3.1868*10^-29	0.000312966	0.000245723
2	30	17.5426	3.02233*10^-69	0.000218427	5.842*10^-5
3	40	11.6541	6.90325*10^-32	0.000115171	1.88896*10^-5
4	50	12.6963	2.3045*10^-37	7.57697*10^-5	2.200066*10^-5
5	60	8.63577	1.94214*10^-18	3.7142*10^-5	9.2798*10^-6

Table VII: Maximum Q Factor, Minimum BER, Eye Height and Threshold for different values of Fiber Length for RZ line coding scheme

No. of Samples	Fiber Length (km)	Q Factor	Threshold	Minimum BER	Eye Height
1	20	13.78	1.22*10^-43	0.000396745	0.000106894
2	30	10.3496	1.16838*10^-25	0.000224766	2.72148*10^-5
3	40	8.68704	1.1508*10^-18	0.000118562	1.15552*10^-5
4	50	6.5917	9.015*10^-18	7.375*10^-5	1.6624*10^-5
5	60	4.3175	5.54*10^-6	1.78229*10^-5	5.76*10^-6

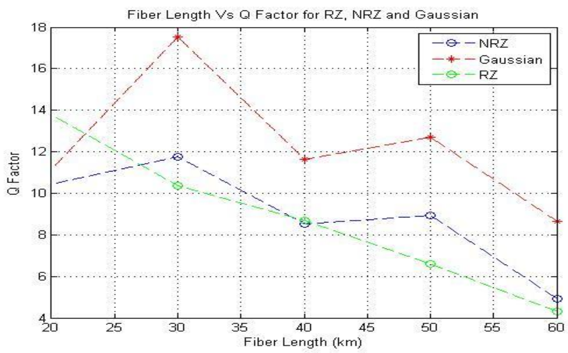


Fig. 22. Performance of Fiber Length Vs Q-factor for RZ, NRZ and Gaussian

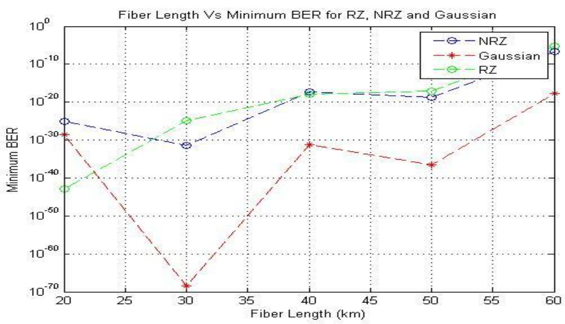


Fig. 23. Performance of Fiber Length Vs Minimum BER for RZ, NRZ and Gaussian

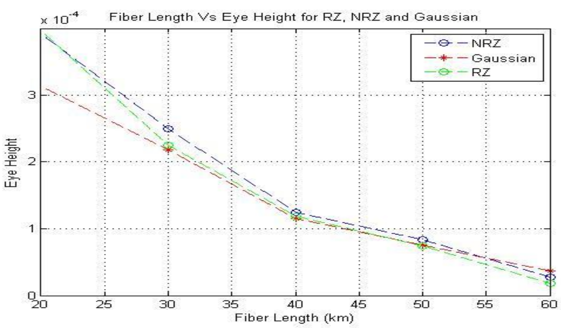


Fig. 24. Performance of Fiber Length Vs Eye Height for RZ, NRZ and Gaussian

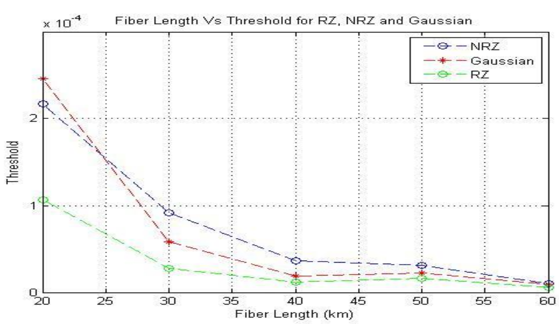


Fig. 25. Performance of Fiber Length Vs Threshold for RZ, NRZ and Gaussian

Based on the simulation data extracted from Table IV, Table V and Table VI, Fig. 22, Fig. 23, Fig. 24 and Fig. 25 have been drawn. The results shown in Fig. 22, Fig. 23, Fig. 24 and Fig. 25 depict the performance of the effect of varying fiber length on maximum Q-factor, minimum BER, eye height and threshold for RZ, NRZ and Gaussian line coding.

VII. CONCLUSION

In this paper, we have proposed a RoF system for HAN and simulated the transmission of 1 to 3 Gbps, 10 GHz and 15 GHz RF signals over 20 km to 60 km standard SM fiber at wavelength of 1550 nm. The results shown in Fig. 18 – Fig. 21 and Fig. 22 – Fig. 25 depict the performance of RoF system using different line coding schemes for different data rates and fiber lengths. Figure 9 and Figure 10 showed small amount of deviation in the received optical spectrum at BS 1 and BS 2 due to non-linear effect. Since the central frequency is still around 193.1 THz so it will not cause severe deviation at received signal. After been transmitted for 20 km, received signal accumulated some noise as shown in Fig. 12 and Fig. 13. Fig. 14 and Fig. 15 showed eye diagram at BS 1 and BS 2 where vertical and horizontal eye opening corresponds to minimal signal distortion. Simulation results showed that with the increase of bit rate and fiber length Q-factor, eye height and threshold decrease and minimum BER increases in most instances. Comparison between RZ, NRZ and Gaussian line coding have been made based on the performance metrics, such as, Q-factor, minimum BER, eye height and threshold. System with Gaussian pulse displayed superior performance for maximum data rate of 2.5 Gbps and maximum fiber length of 60 km. Good eye diagram and low BER were achieved which implies the better performance of the system. Our proposed system is suitable for 1 Gbps to 2.5 Gbps bit rate and fiber length of 20 – 60 km with Gaussian pulse.

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