Design of Radio over Fiber Optical System using WDM with Polarization Division Multiplexing (PDM)

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Abstract: In the quest to achieve more bandwidth and data rate to meet the growing demand of users in today's internet driven cellular communication, multiplexing techniques have proved to be extremely useful. Multiplexing of signals allow several signals to be simultaneously transmitted. In this work, a multi-channel radio over fiber (RoF) system is proposed which uses multiple multiplexing techniques i.e. wavelength division multiplexing (WDM) and polarization division multiplexing (PDM) to transmit a radio frequency signal through an optical fiber cable. The performance of the system is measured in terms of performance parameters such as received optical power, optical signal to noise ratio (OSNR), bit error rate (BER) and eye diagram at the receiver. The system is designed and analysed using Opti System software, with results obtained accordingly.

Keywords: Bit Error Rate (BER), Eye Diagram, Polarization Division Multiplexing (PDM), Radio over Fiber (RoF) systems, Signal to Noise Ratio (SNR), Wavelength Division Multiplexing (WDM).

1. Introduction

Communication systems designed using optical fiber cables has revolutionized the transmission of signal over long distances by providing higher bandwidth and much lower losses than available options like co-axial cables. The advantages of fiber optic communications can also be exploited in transmission of radio signal by transmitting a radio signal over an optical fiber cable [1][2]. This transmission is called as radio over fiber or RoF system. The benefits of optical system can further be utilized in a radio over fiber system by employing multiple multiplexing techniques in transmission of signal through optical fiber cable.

Multiplexing involves sending many signals through the same transmission channel simultaneously. Wavelength division multiplexing (WDM) is one of the most widely used multiplexing technique in optical fiber communication system where multiple signals are transmitted simultaneously with each signal being transmitted at different frequency [3]. WDM can be divided into two categories which are coarse WDM(CWDM) and dense WDM(DWDM). In coarse WDM channel spacing between adjacent wavelengths is large and thus fewer channels exist. In dense WDM channel spacing is narrow between adjacent wavelengths resulting in large number of channels [3][4]. In DWDM, signal rate can be increased significantly without the need to change the network infrastructure [3][5].

Another multiplexing technique that can be used for transmission of optical signal and increasing the transmission bandwidth is polarization division multiplexing (PDM). In PDM, two signal with orthogonal state of polarization are transmitted [5][6][7]. WDM and PDM techniques can be combined to achieve increased data transmission rate for an optical system [6].

2. System description

A four-channel radio over fiber (RoF) channel is designed using polarization division multiplexing and wavelength division multiplexing. The communication system is made up of transmitter section, channel and receiver section.

The transmitter section is shown in Figure 1. It consists of ng four channels. Each channel consists of a 10Gbps Pseudo Random bit generator to generate the input bit sequence. The output of pseudo random bit generator is fed to the NRZ pulse generator which encodes the input bit sequence in non-return to zero format. After this with the help of an MZ modulator a CW laser is used to modulate the NRZ signal obtained. The various light sources are operating from 1550 nm to 1551.5 nm with a spacing of 0.5 nm. The output of first two channels is fed two a 2x1 WDM multiplexer and output of remaining two channels is fed to another 2x1 WDM multiplexer. The output of the two 2x1 WDM multiplexers is fed to polarization controller to change the azimuth parameter of the polarization controller to obtain two orthogonal signals. The output of the two polarization controllers is finally fed to another 2x1 WDM multiplexer before transmission.

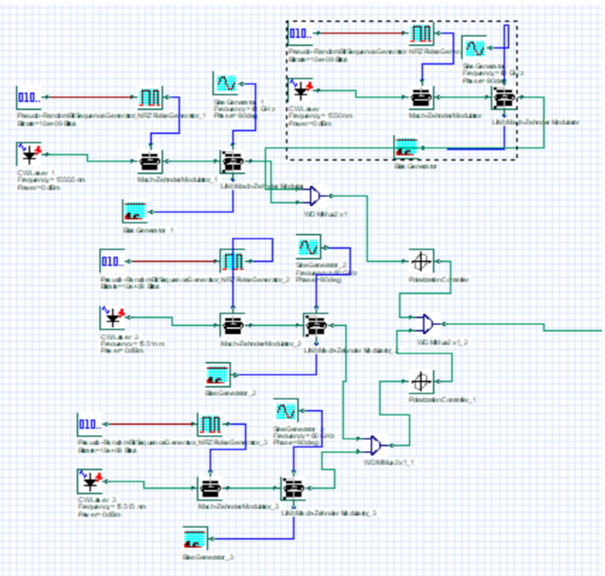

Figure 1: Transmitter section.

The output of 2x1 WDM multiplexer is transmitted through a optical fiber cable as channel which is shown in Figure 2. The channel also consists of a pre and post amplifiers of 20dB and 2 dB gain noise figure each.

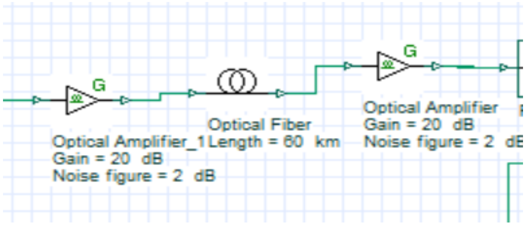

Figure 2: Channel

At the receiver, shown in Figure 3, a polarization splitter separates the received signal according to its state of polarization. After this two 1x2 WDM demux are used to demultiplex the multiplexed received optical signal After this a PIN photodiode is used to detect the optical signal and convert the optical signal into an electrical signal. Finally, the output signal is recovered after passing it through a gaussian optical filter. Further, a BER analyser is used to analyse the received signal.

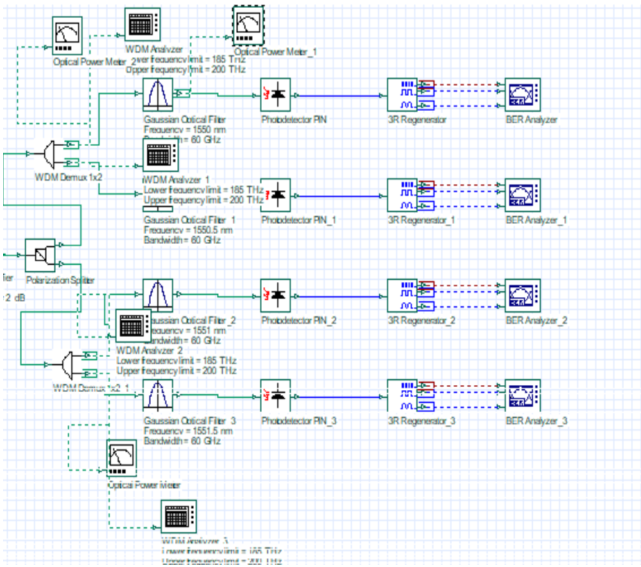

Figure 3: Receiver Section

3. Results and discussions

Table 1 summarizes the received signal power, signal to noise ratio (SNR) and bit error rate(BER) of different channels with varying distance. It is clearly visible that as distance increases both the signal power and SNR reduces symbolizing the deterioration in signal. Furthermore, the bit error rate (BER) also increases drastically as fiber length is increased from 30 Km to 80 Km.

Fiber Length	Channel	Received power (dBm)	Signal to Noise ratio(SNR) (in dBm)	Bit error rate (BER)
30Km	1550.0 nm	14.85	40.29	5.70 x 10^{-29}
	1550.5 nm	16.00	41.46	2.56 x 10^{-27}
	1551.0 nm	14.95	40.44	3.33 x 10^{-32}
	1551.5 nm	16.02	41.55	1.14 x 10^{-28}
45Km	1550.0 nm	11.85	40.13	1.48 x 10^{-23}
	1550.5 nm	13.00	41.30	2.72 x 10^{-20}
	1551.0 nm	11.95	40.27	3.64 x 10^{-24}
	1551.5 nm	13.02	41.39	2.57 x 10^{-22}
60Km	1550.0 nm	8.85	39.82	1.84 x 10^{-14}
	1550.5 nm	10.00	40.99	5.44 x 10^{-13}
	1551.0 nm	8.95	39.97	1.23 x 10^{-15}
	1551.5 nm	10.02	41.08	1.73 x 10^{-14}
80Km	1550.0 nm	4.85	39.01	1.90 x 10^{-06}
	1550.5 nm	6.00	40.18	3.44 x 10^{-06}
	1551.0 nm	4.95	39.15	1.55 x 10^{-06}
	1551.5 nm	6.02	40.26	3.41 x 10^{-06}

Table 1 Comparison of SNR, BER and received power v/s distance for all four channels.

Further, the eye diagram of the optical system for 30 Km and 80 Km optical fiber length is shown in Figure 4 and Figure 5 respectively. It is undeniably visible that as the distance between transmitter and receiver is increased the eye diagram worsens signifying difficulty in signal identification.

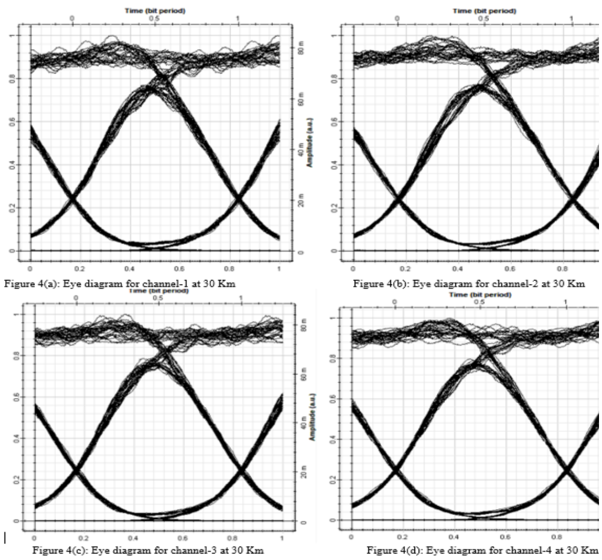

Figure 4: Eye diagram at optical fiber length of 30 Km.

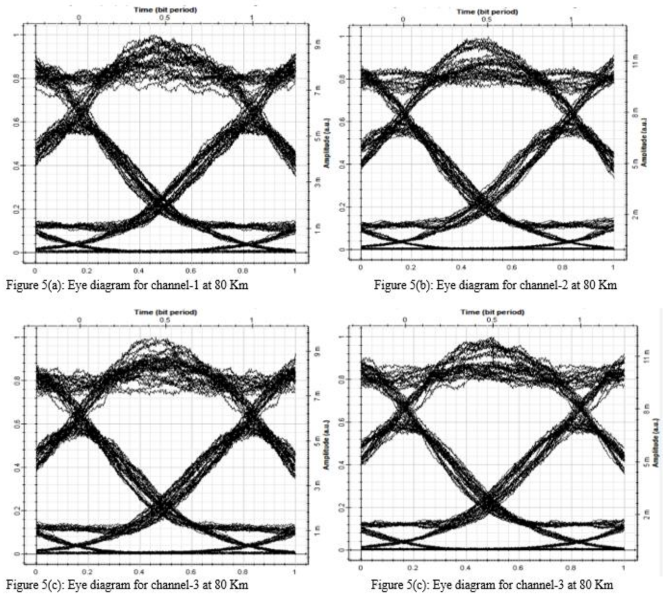

Figure 5: Eye diagram at optical fiber length of 80 Km

4. Conclusions

In this study, a 40 Gbps Radio over fiber optical system is realized and transmission of optical signal is achieved by utilizing wavelength division multiplexing and incorporating polarization division multiplexing as well in the transmitter. The signal strength deteriorates, and bit rate worsens as the optical signal travel through optical fiber owing to factors such as attenuation and dispersion in the fiber. The signal recovered at the transmitter for 30 Km optical fiber length has performance parameters as 14.85 dBm as received power strength and bit error rate of 5.70 x 10^{-29} for channel 1, 16.00 dBm as received power strength and bit error rate of 2.56 x 10^{-27} for channel 2, 14.95 dBm as received power strength and bit error rate of 3.33 x 10^{-32} for channel 3, 16.02 dBm as received power strength and bit error rate of 1.14 x 10^{-28} for channel 4. As the transmission distance is increased the performance parameters values deteriorates well beyond the acceptable limit due to constraints such as attenuation and dispersion. Attenuation can be overcome by using more amplifiers in the transmission path. The detrimental effects of dispersion can be reduced by introducing a dispersion compensation fiber or fiber bragg grating in the optical system designed.

5. References

1) Sharma, A., Chaudhary, S., Thakur, D. & Dhasratan, V. (2020). A Cost-Effective High-Speed Radio over Fibre System for Millimeter Wave Applications . Journal of Optical Communications, 41(2), 177-180. https://doi.org/10.1515/joc-2017-0166.

2) H. M. gheni et al., "Radio Over Fiber (RoF) Implementation using MZM For Long Distance Communication," 2019 International Conference on Information Science and Communication Technology (ICISCT), Karachi, Pakistan, 2019, pp. 1-6, doi: 10.1109/CISCT.2019.8777428.

3) N. Muchhal, A. Bhatt, "High speed and spectrally efficient optical communication system - review of the recent advances and emerging trends", International Journal of Latest Trends in Engineering and Technology, Volume 7 Issue 1 - May 2016, 523-530, http://dx.doi.org/10.21172/1.71.075

4)R. Mishra, N. K. Shukla, M. Atif and C. K. Dwivedi, "Performance Analysis of 8 Channel DWDM Systems via Dispersion Compensation Fiber Using NRZ, RZ, CSRZ Modulation Schemes," 2018 International Conference on Computer Communication and Informatics (ICCCI), Coimbatore, India, 2018, pp. 1-6, doi: 10.1109/ICCCI.2018.8441500.

5) C. Supraja, T. Kavitha and C. K. Pappa, "Design of 32 Channel Wavelength Division Multiplexing Optical Communication System," 2022 International Conference on Knowledge Engineering and Communication Systems (ICKES), Chickballapur, India, 2022, pp. 1-5, doi: 10.1109/ICKECS56523.2022.10059979.

6) Upadhyay, K., Srivastava, S., Shukla, N. & Chaudhary, S. (2019). High-Speed 120 Gbps AMI-WDM-PDM Free Space Optical Transmission System . Journal of Optical Communications, 40(4), 429-433. https://doi.org/10.1515/joc-2017-0086

7) I. S. Desher, "Optimization of Radio over Fiber Transmission over Polarized Conversion Light Using SOA," 2020 2nd Annual International Conference on Information and Sciences (AiCIS), Fallujah, Iraq, 2020, pp. 81-85, doi: 10.1109/AiCIS51645.2020.00022.