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SIMULATION ANALYSIS OF INTENSITY MODULATION FOR HIGH SPEED N×40Gb/S TRANSMISSION OVER STANDARD SINGLE MODE FIBRE USING WAVELENGTH DIVISION MULTIPLEXING

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Abstract

In this paper, a design approach for high capacity wide-area optical network is demonstrated and a proposed program of research is presented to address key performance of intensity modulation techniques and some other device issues. The network architecture is developed using the 'Optisystem' platform for 40 GBit/s embedded in single channel long haul WDM (Wavelength Division Multiplexing) links and is scalable in terms of the number of channel users, and the aggregate network capacity. Of paramount importance to the achievement of scalability, a set of 4 and 16 channel WDM having different length of single mode fibre is selected and the corresponding BER (Bit Error Rate) is measured both for the best and worst case scenario. Under idealized assumptions with an increase in BER from 10-12 to 10-5 for a certain length of 90 km and 270 km respectively, a N-Channel WDM with "NRZ-OOK" exhibited a more persistent and robust performance compared to a N-Channel WDM with "RZ-OOK" modulation format.

Keywords: Next Generation High Data Rate 40GB/S, Non Return to Zero (NRZ), Return to Zero (RZ), Single Mode Fibre (SMF), Wavelength Division Multiplexing (WDM).

1. Introduction

Recent improvements in low-loss optical transmission in a single-mode fiber and significant advancements in dense wavelength division multiplexed optical networks has changed the fiber optic communication systems drastically to form the high-capacity transport infrastructure. The system improvises global broadband data services and advanced internet applications with enhanced capacity [1, 2]. The need for higher transport capacities and lower costs per end-to-end transmitted information bit has led optically routed networks demanding for higher spectral efficiencies. The increased data rate also requires a larger receiver electrical bandwidth, which degrades the receiver SNR [2-4]. This widens the interest for research works based on performance analysis of different modulation formats in optical network links.

To enhance optical network capacity, system architecture and optimization have to take into consideration all the major contributing issues; for example: data rate of channel, chromatic dispersion, transmission distance, spectral efficiency, optical power level, amplifier noise, spacing of channel, optical amplifier, fiber nonlinearities, dispersion management strategy, receiver bandwidth and so on [1-4]. With the increase in the bit rate from 40 Gb/s or above, chromatic dispersion and distortion compensation become a matter of great concern to all kinds of fiber [2-5]. Return-to-zero (RZ) signals and Non-return-to-zero (NRZ) are considered to be the most common modulation technique widely used in communication system. Moreover, most of fiber nonlinearities function along with dispersion management techniques, polarization division multiplexing, and optimization of the modulation format play a key part in evaluating the transmitter performance (e.g., [1-5]). Past few decades, both theoretically and experimentally between NRZ and RZ performance comparison on tolerance to optical noise fiber nonlinearities, and dispersion [1-5].

For long-haul transmission, it is recognized that RZ has better transmission performance than NRZ. For the past few decades, Wavelength Division Multiplexing (WDM) has been widely used to transmit high bandwidth data [5-8]. The new generation light wave system has facilitated higher data rate per channel (40 Gb/s and above) [2]. Although both RZ and NRZ have been widely used previously as traditional modulation techniques, for a next generation high data rate, they are yet to be implemented for long haul transmission in WDM. Not only this research gives the performance analysis of the traditional intensity modulation format (IM), Return to Zero and Non Return to Zero in long haul multiple spanned optical fibre transmission for current generation high data rate of 40GB/s, but also the research shows a comparison in receiver output with and without WDM for both the modulation techniques.

2. Literature Review

2.1. Intensity modulation

IM or Intensity Modulation is a special form of 'Amplitude Shift Keying' (ASK) in which there is no carrier wavelength to be present when transmitting a '0'. It can simply be applied by switching the optical source off and on, which is direct modulation. However, it has few drawbacks such as causing chirp as well as causing variation in source's amplitude and frequency. This leads us to use an external modulator, which is known to be as Mach-Zehnder Modulator [7-9]).

Where A is the amplitude which is ‘0’ when the optical source is off and ‘A’ when the device is on. In terms of duty cycle, there are two kinds of intensity modulation, which are Non Return to Zero (NRZ) OOK and Return to Zero (RZ) OOK (Fig. 1). In the RZ format, the pulse representing bit 1 returns to zero before finishing the bit slots. Actually, the bit duration in RZ is smaller than the bit slots. On the other hand, in NRZ format, the pulse amplitude does not drop to zero between two or more successive 1 bit. The pulse remains on throughout the bit slot [9, 10]. An advantage of the NRZ format is that the bandwidth associated with the bit stream is smaller than that of the RZ format.

When the source is turned on for the full period of its 'On Time' meaning 100% duty cycle, it refers to RZ and on the contrary. When it is on for the fraction of the period for example 1/2 or 1/3 of its period causing duty cycle to be 50% or 30% respectively, it is referred to RZ [11-13].

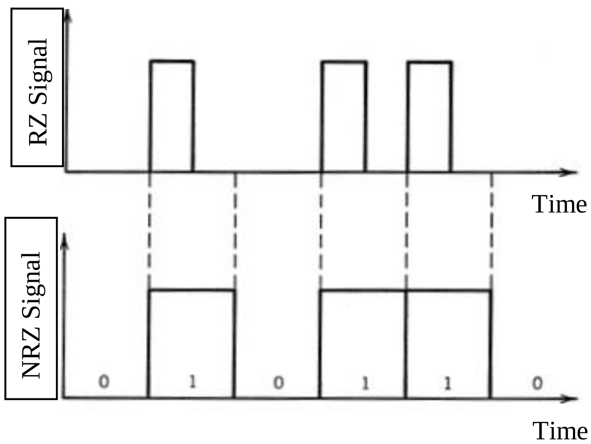


Fig. 1. NRZ-OOK and RZ-OOK modulation technique.

2.2. Wavelength Division Multiplexing (WDM)

FDM is often referred to as WDM because range of frequencies is called the wavelength. In the case of WDM, the channels are spaced apart in the frequency domain as a range of frequency. Each channel has a carrier wave of its own. To avoid the overlapping, the carrier frequencies are spaced, as seen Fig. 2. It is suitable for both analogue and digital signals. For broadcasting of radio and television channels, it is also used.

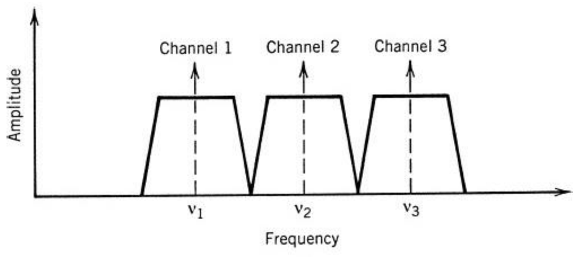


Fig. 2. Wavelength division multiplexing [9].

2.3. Bit Error Rate (BER)

Accuracy is the first priority in digital system, which is usually characterized in terms of the bit-error rate (BER). Bit error rate is defined as the probability of error for each bit. When the areas covered by the tails of the PDF it is not matched of the tails then it may lead to orders-of-magnitude difference, which determines the BER [9-11]. Besides, it can be measured by comparing the total number of bits transmitted to the received bits and finding the number of errors.

$$\text{Bit error rate} = \frac{Number\ of\ bits\ error}{Total\ number\ of\ bits} \qquad (1)$$

3. Methodology

Information in a form of random bit of streams was generated by Bit generator, which then went through Pulse Generator to form a square pulse. Next, it was passed through RZ and NRZ modulation schemes with the carrier laser wave. Thereafter it was sent to the fibre optics through WDM and after pre and post amplifying process, the optical signal would be received by the receiver consisting of a Demultiplxer, photodiode and filter. Simulation was done in order to test the optical system in Optsim. After implementing the design parameter, the performance parameter (Eye diagram and Bit Error Rate, BER) were evaluated to get the impairment parameter and the data was compared. The entire process is explained in the following data process flow figure (Fig. 3).

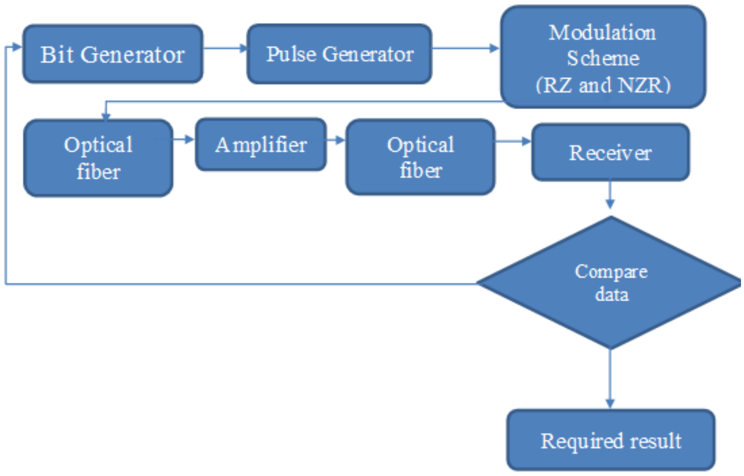


Fig. 3. Process flow of the methodology implemented.

4. Simulation Operation

Table 1 shows the parameter specification for the simulation model. The design and modelling were constructed in the University of Nottingham Malaysia Campus using the industrial level simulation software, “OptSim”, version 5. 'CW Lorentzian Laser' was used as the optical source and its “Centre Emission Wavelength” was fixed at ~1550 nm. The power was fixed at ~0 dB. Three types of optical links were used. These are Single Mode Fibre (SMF), Dispersion Compensated Fibre (DCF) and EDFA (Erbium Doped Fibre Amplifier). Standard SMF was chosen and the span was varied with an interval of 90 km from 90 km to 270 km.

Table 1. Parameter description for Optsim simulation.

Optical Link (Standard Single Mode Fibre)	Standard Single Mode Fibre
Optical Source	Laser of 1550 nm & 1310 nm
Bit Rate	40 B/S
Modulation Format	RZ, NRZ
Performance Parameter 1	BER
Performance Parameter 2	Eye Diagram

Table 2 displays the Non-Linearity, dispersion and gain setting in the simulation software. For the configuration, few past cases were taken in consideration where these parameters were fixed in these values to get maximum optimization [9-13]. The length of the DCF was calculated in order to null the total dispersion in the transmission link.

Table 2. Non-linearity, dispersion and gain configuration [7-13].

Dispersion in SMF	17 ps/nm/km
Non-linear coefficient	~1.36811 1/w/k
Dispersion was introduced to DCF (*D_{SMF}*)	'-100ps/nm/km'
EDFA	30 dB (Flat Gain)
Noise Figure	5 dB

Figures 4 and 5 are the simulation and transmission line set-up whereas Figs. 6 and 7 indicate the NRZ and RZ modulation format respectively built in Optsim.

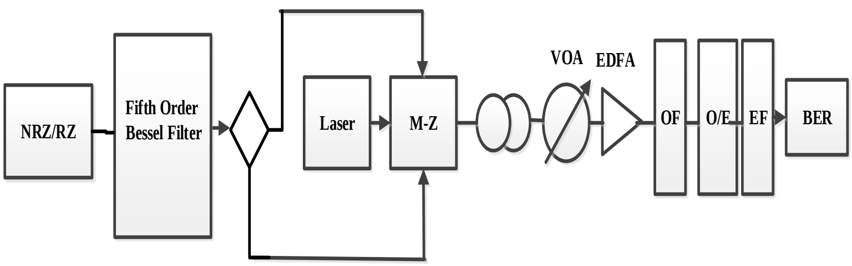


Fig. 4. NRZ-OOK and RZ-OOK simulation set-up.

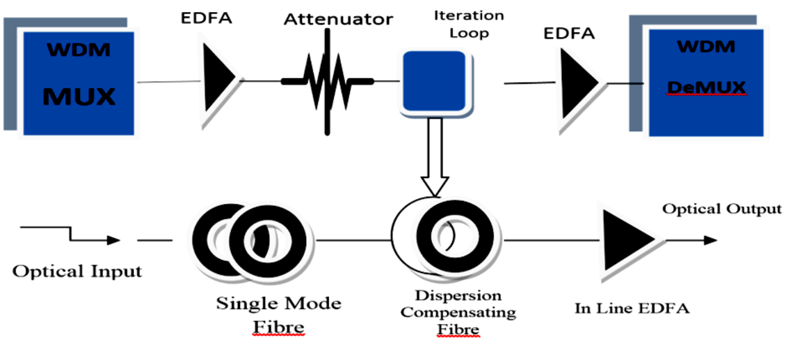


Fig. 5. Transmission link set-up.

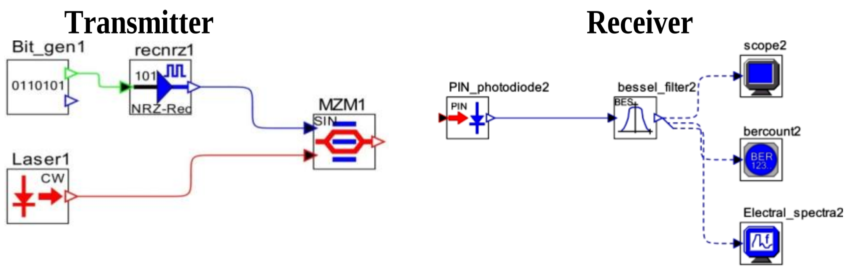


Fig. 6. NRZ Modulation format.

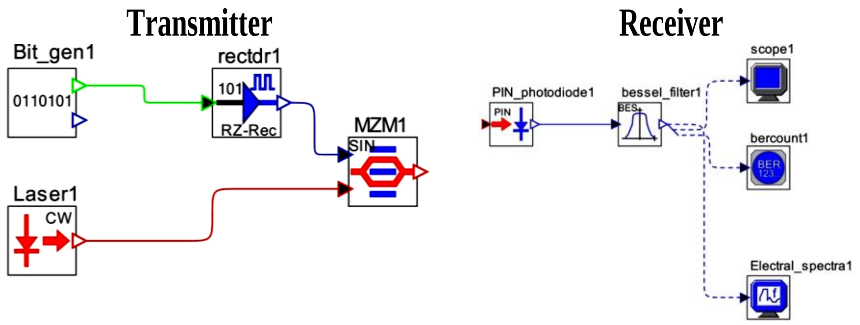


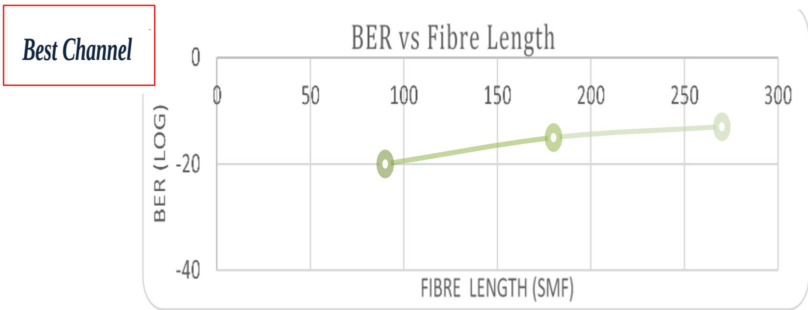
Fig. 7. RZ Modulation format.

5. Result Analysis

As said in the section 4, SMF spans were varied from 90 km followed by 180 km and 270 km in order to measure the Bit Error Rate of the system output. Inline EDFA was used for the last two distances, which were 180 km and 270 km. Since the first span consist of SMF having a distance less than 90 km, no inline amplifier was needed. Simulation was carried for 4 and 16 channels in WDM. For NRZ modulation, referring to Figs. 8 and 9, it was clearly noticeable for ‘16 Channel WDM’ that BER increased significantly for the distance of 180 km and 270 km. Due to the increase of the span and as well as number of channel, worst channel performance kept getting poorer. But it was logical since cross talk and non- linearity affect in the centred channel of WDM extensively. Overall NRZ showed standard performance for short distance transmission and became moderate with the increase of number of channel as well as fibre length.

As far as RZ concerns, BER fell down drastically with the increase of fibre length (Figs. 10 and 11). With the increase of number of channel, BER became even worse. To analyse the reason behind it, it was figured out that due to the wide optical spectra of RZ, while transmitting through WDM, the signal got affected severely by the other channels and cross talk and non-linearity took place. Considering ‘4 Channel WDM’ RZ showed poor performance for best channel in terms of fibre length for all the 3 spans than NRZ as the BER increased from 10^{-9} to 10^{-8}.

Lastly, while investigating ‘16 Channel WDM’, BER increased for both the modulation formats. “NRZ-OOK” showed moderate performance for 90 km fibre span but BER increased as the fibre span increased and for a span of 270 km, it came up with a high BER of 10-5. “RZ-OOK” showed the worst as the BER increased from 10-6 to 10-4. Figures 9 and 11 show the eye diagram from the simulation result the value of which is provided in tabularised form.



Fibre Length (km)	Worst channel (BER)	Best Channel (BER)
90	10^{-11}	10^{-20}
180	10^{-10}	10^{-15}
270	10^{-8}	10^{-13}

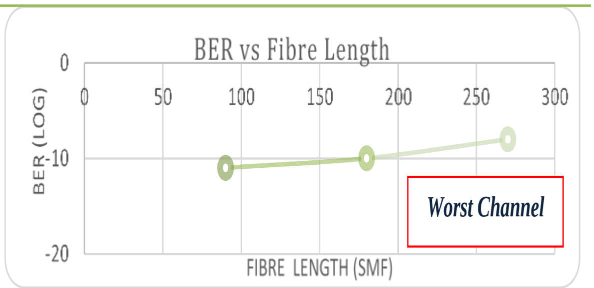
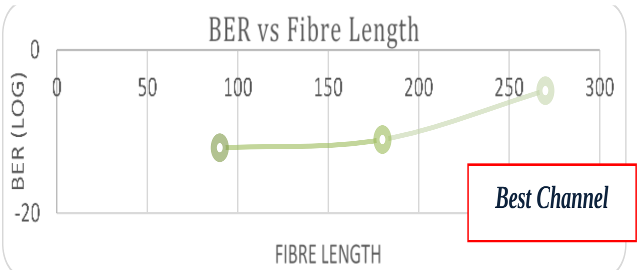


Fig. 8. BER values for 4 Channel WDM NRZ-OOK (Bit Rate~ 40 Gb/s).



Fibre Length (km)	Worst channel (BER)	Best Channel (BER)
90	10^{-4}	10^{-12}
180	10^{-3}	10^{-11}
270	10^{-2}	10^{-5}

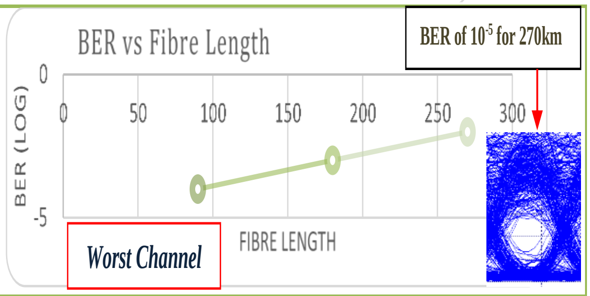
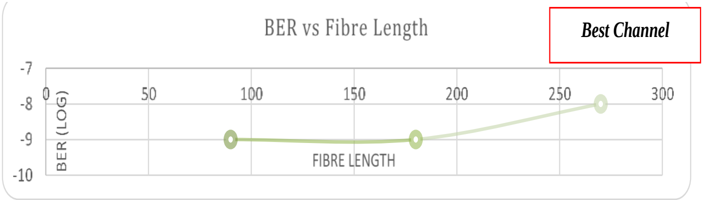


Fig. 9. BER values for 16 Channel WDM NRZ-OOK (Bit Rate: 40 Gb/s).



Fibre Length (km)	Worst channel (BER)	Best Channel (BER)
90	10^{-4}	10^{-9}
180	10^{-4}	10^{-9}
270	10^{-4}	10^{-8}

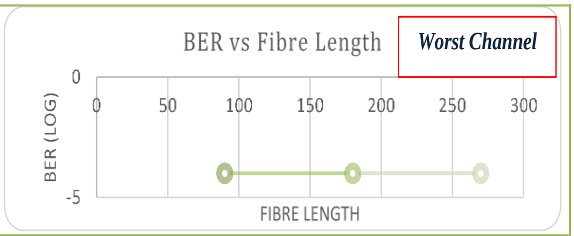
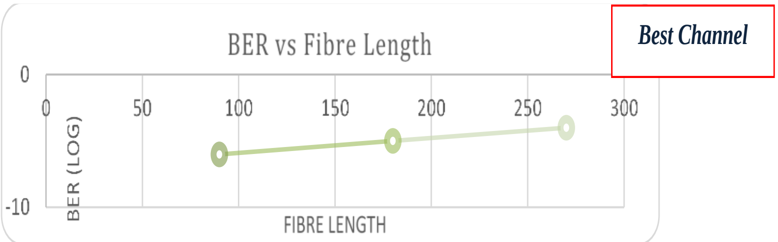


Fig. 10. BER values for 4 Channel WDM RZ-OOK (Bit Rate~ 40 Gb/s).



Fibre Length (km)	Worst channel (BER)	Best Channel (BER)
90	10^{-3}	10^{-6}
180	10^{-3}	10^{-5}
270	10^{-2}	10^{-4}

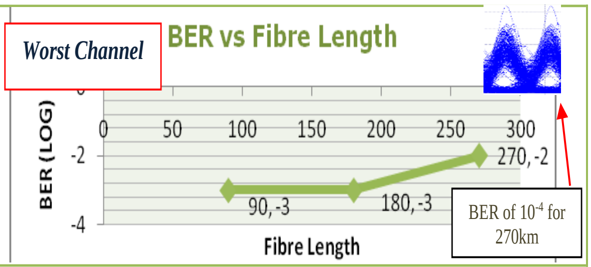


Fig. 11. BER values for 16 Channel WDM RZ-OOK (Bit Rate~ 40 Gb/s).

6. Conclusions

To recapitulate, it should be mentioned that the objectives of this research were successfully accomplished. NRZ-OOK modulation showed standard performance overall but went down at the end while performing for 16 Channel WDM. On the contrary RZ-OOK performed the worst in terms of all categories making it unworthy for long haul transmission. To sum it up, this research has a significant importance in terms of optical fibre communication. The two most commonly used modulation were compared in WDM system for high-speed data transmission in long haul SMF. A wide range of future work scope including addition of Duobinary, DQPSK and more advanced modulation can be included for further research.

Nomenclatures

D_{SMF}	Dispersion in Single Mode Fibre

Abbreviations

BER	Bit Error Rate
CD	Chromatic Dispersion
DBPSK	Differential Binary Phase Shift Keying
DCF	Dispersion Compensating Fibre
DPSK	Differential Phase Shift Keying
DQPSK	Differential Quadrature Phase Shift Keying
DWDM	Densed WDM
EDFA	Erbium-doped fiber amplifiers
IM	Intensity Modulation
NRZ	Non Return to Zero
OOK	On-OFF Keying
RZ	Return to Zero
SMF	Single Mode Fibre
WDM	Wavelength Division Multiplexing

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