Available online at: http://www.ijmtst.com/vol4issue3.html
International Journal for Modern Trends in Science and Technology
ISSN: 2455-3778 :: Volume: 04, Issue No: 03, March 2018

Inter-Satellite Optical Wireless Communication System (IsOWC)

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To Cite this Article
Pardeep kaur, Monika Aggarwal and Naveen Goyal, "Inter-Satellite Optical Wireless Communication System (IsOWC)", *International Journal for Modern Trends in Science and Technology*, Vol. 04, Issue 03, March 2018, pp.-103-108.

DOI: https://doi.org/10.46501/IJMTST040316

ABSTRACT

Free-space optical communication is an essential method which is used for the satellites orbiting around the earth in order to communicate with each other. One of the important application of the WSO/FSO technology is in inter-satellite optical wireless communication systems in space. The idea of connecting two satellites raised from the evolution of the optical communication systems from using long fibers to the robust wireless system with the help of optical wireless link. The quick developments in the field of the satellite communication provide the possibility to build the satellite networks for communicating with each other. At the higher speed, the optical wireless communication helps in exchanging the information between the satellites. In this method, the satellite act as the intermediator between the satellite and the ground base station or between the two satellites. For the optical link, a light signal which has the high frequency is used as a carrier between the lasers and satellites as a source of light. The main reason for selecting the optical wireless communication system is high data rate having acceptable bit error rate as compared to the RF link. This research analyzed the long distance communication upto 12500 Km with 64 channels and 20 Gbps data rate. The results are comparatively high and show an efficient and high capacity of the proposed network.

Index Terms: *Inter-Satellite Communication Systems (IsOWC),Free Space Optical (FSO), Line of sight (LOS) system, Q-factor, bit rate, and eye-opening.*

I. INTRODUCTION

From past 40 years, governments, individuals, companies, and universities from the different countries had made tremendous technical progress in optical space communication. The inter-satellite optical wireless communication system is one of them. This system can use the microwave technology for space to ground communication. In future, the satellite to satellite communication should be managed wirelessly using infrared wavelength to transmit optical signals[4].Is-OWC technology is used to connect satellite either from same or different orbits to send data at the speed of light. It transfers the data from one satellite to another with lesser chances of data loss using a highly accurate tracking system. This system is designed and simulated at the bit rate of 400 Gbps (Gigabyte per second)[1].This is a non-diffused link which uses a coherent qudrature phase shift keying (QPSK) modulation technique.IsOWC is a maximum bit rate system that can communicate interstate link at different orbit like Low Earth orbit, Medium Earth orbit and Geosynchronous Earth orbit. This system is designed and analyzed over the link distance of 6000km.

There are two types of optical wireless communication system. One is non-line-of-sight or diffused- link and other is a line of sight (LOS) system. The diffused link system solves the problem of severe shadowing and mobility but involves huge loss because of multipath propagation. LOS provide excellent transformation capability but face the problem of mobility and shadowing. [2]

1.1 Working principle of Optical Wireless Communication Systems

To establish the optical communication link between two satellites, the line-of-sight of their optics must be aligned during the time of transmission of signals. A line-of-sight wireless optical communication link is implemented by using the telescope type transreceiver[15][16]. The wireless optical communication provides the line-of-sight links with high bandwidth. These systems are now being preferred over radio frequency communication systems because of the high usable bandwidth of optical signals, which increase the transmission capacity that is directly proportional to the carrier frequency and larger difference in wavelength[16].

The IsOWC can be used to connect the one satellite to another satellite, whether the satellite is in the same orbit or the different orbit. The light travels at a speed of $3*10^8$ m/s. So the signals from one satellite to another satellite can be sent without much delay and with minimum distortion and attenuation because spaceis considered as vacuum [15]. The Inter-Satellite Optical Wireless Communication is shown in figure 1 below:

Fig 1:Inter-Satellite Optical Wireless Communication

1.2 Components of IsOWC

The Transmitter, Receiver and propagation channel are the main parts of the system design. The transmitteris positioned in first satellite and Receiver is on the second satellite. Transmitter receives data from telemetry, tracking, and communication (TT&C). Data that are transmitted by a satellite is altitude tracking, image capturing, and satellite position for satellite and voice data for the telephone network.Optical communication uses two types of lights:

- LED (Light Emitting Diode)
- Injected Laser Diode (ILD)

. Basic diagram of Inter-Satellite Wireless Optical Communication (IsOWC) is shown in figure 2 below:

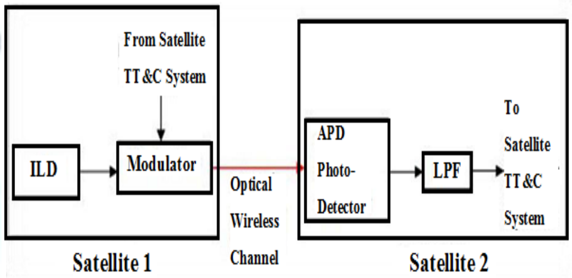

*Fig 2: **IsOWC block diagram for simplex communication***

The free space between two satellites is used as the communication medium to transmit the .light signal. The transmitting satellite has a light generating source that is Laser, satellite telemetry, tracking, and communication system and an optical modulator. [4]

1.3 Parameters affecting the IsOWC system

As IsOWC is a high speed optical wireless transmission system,there are some parameters that affect the system .Optical wireless communication channels use wavelength to transfer data from sender to receiver. There are several types of wireless systems which use different wavelength with different speed like 1R-A category has used wavelength ranging from 700-1400nm, 1R-B used 1400-3000nm and 1R-C uses 3000nm-1mm. This range can affect the speed in medium and creates variation in the scattering of solar rays. Modulations technique is also a parameter that affects the OWC system. The selection of filter for choosing appropriate and inappropriate data has an impact on the system. By increasing the power level, the performance of satellite can be increased. Components of system impose a limit on the power, so we cannot increase the power infinity. The varying data rate of 1550nm wavelength changes the distance from 200-1200km.

1.4 Inter-satellite OWC Performance analysis

Modulation techniques play a vital rule in the electric and optical system. Therefore, the selection of modulation technique is an important part of system design. The commonly used modulation scheme is Intensity Modulation or Direct detection

(IM/DD). This technique is very resistant to non-predictive channel because it produces random fluctuation noise[5].OWC has conquered the entire world in satellite due to its features like low cost, low power consumption and long-distance transmission which is not possible in the fiber optic cable. It can utilize two satellites transmission through unguided media.Despite the advantage, this system faces some problems like power constraints, extent quantity of transmission and noises in communication systems, etc.

A 32 channel DWDM covers 5000km distance using inter-satellite OWC. It uses two different modulation formats: NRZ (non-return to zero) and RZ (return to zero). [6]

2. RELATED WORK

K. Sharma et al. (2017) reviewed the inter-satellite optical wireless communication system and its various applications.Inter-satellite Optical wireless communication is better and suitable for the point to point communication. In this research, the author also described the free space optics as IsOWC link. Microwave and RF frequencies used to transfer the information, but they transfer the information at less data rate because of losses. This is the main reason that wireless optical technology is used in place of microwave and RF links [1].

H. Kaur and H. Kaur (2017) reviewed the inter-satellite optical wireless communication system. This research presented the description of the system of inter-satellite optical wireless communication using different parameters. These parameters affect the performance of the system. The results indicated that the performance of the inter-satellite optical wireless communication couldbe improved with the help of several methods like diversity techniques and advanced modulation formats [2].

S. Pradhan et al. (2015) proposed the inter-satellite optical wireless communication system with the help of diversity techniques. In this research, the proposed system is analyzed, simulated and designed for a 6,000km of a link distance with accomplishing the 7.63 Gbps of bit-rate for the 25dBm of input power.The results indicated that the proposed system showed the improvement of the data rate of 1.35 times as compared to the previous research. [3]

N. Kaur and G. Soni (2015) performed the performance analysis of the inter-satellite optical wireless communication system (IsOWC) with the help of RZ and NRZ modulation. The BER is 10-25 for RZ and 0-41 for NRZ. These two modulations were used for the comparison. In this research, the optical inter-satellite link was modeled with the help of Optisystem. This system was implemented between two satellites that are separated by a 1700 km distance and 3 Gbps of the data rate having varying modulation formats. [4].

V. Kiran et al. (2017) performed the performance analysis of the inter-satellite optical wireless communication.In order to analyze the performance of the inter-satellite link, BER or the quality factor is used as a key metric The results indicated that the proposed system could support the 10Gbps of data rate and can employ the 4 x 4 transceiver system over the distance of 6000km. In this research, 40 Gbps of higher data rate is accomplished in an inter-satellite optical wireless communication system with the help of QPSK modulation [5].

P. Kaur, A. Gupta, M Chaudhary (2015) demonstrated the performance of inter-satellite optical wireless communication system link with the help of DWDM multiplexing technique. The inter-satellite link is modeled at 10 Gbps of the data rate for the 5000 kilometers of communication range. In this research, the modeled system uses 32 channel inter-satellite optical wireless communication systems which are operated at 10 Gbps with the help of various modulation formats.. [6].

3. METHODOLOGY

In this research, the DWDM model is studied using different optical amplifiers such as Raman amplifier, EDFA, etc. There are total 64 channels in this system, and we have analyzed the results at the bit rate of 1 Gbps and 20 Gbps.

Model in OptiSystem

The design of the model in the OptiSystem is as shown below:

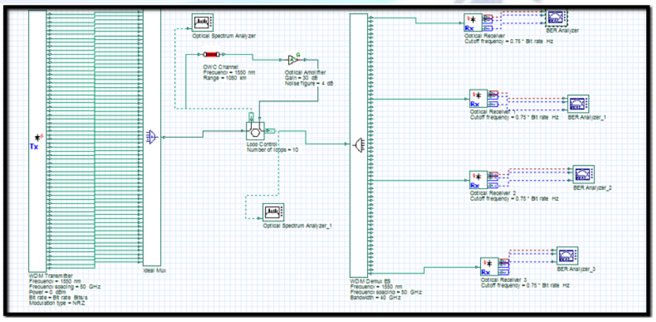

*Fig 3:**Model in Optisystem***

The high capacity DWDM is designed using Er-doped fiber at a bit rate of 1gbps and 20 Gbps with 64 number of channels. The optical wireless cable length is varied from 250km to 1250 km with loop control value of 10. Transmitter wavelength is taken as 1550nm, and the transmitter antenna aperture and receiver antenna aperture for the OWC channel is made as 25 cm each.

Block Diagram of the Overall design

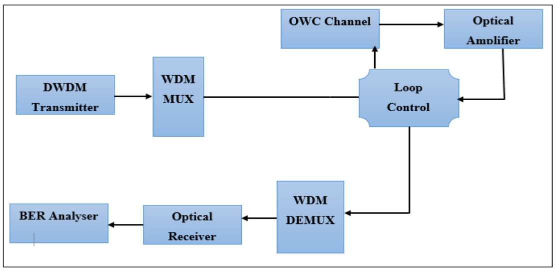

*Fig 4:**Block Diagram of the Overall design***

The above model is divided into three parts. These parts include the Transmitter part, Channel part, and the Receiver Section. The transmitter section embraces the WDM transmitter, WDM MUX; the channel part embracesLoop Control, OWC channel, and the Optical amplifier; and the receiver part includes the WDM DEMUX, Optical receiver, and BER Analyser. The different optical amplifiers are used in this work.

The details regarding the various components in the OptiSystem are as following:

OWC Channel: OWC stands for Optical Wireless Channel. The OWC is the transmission of the optical data in the wireless medium. This communication is possible through the unguided media only. We are transmitting the data between two satellites and in the presence of the OWC Channel, it is called as IS-OWC channel (Inter-Satellite Optical Wireless Channel). The OWC channel has the wavelength of about1550 nm.

Optical Amplifier: The optical amplifiers are the devices which are used for the boosting up the optical signal and boosting up of the signal is without converting the light signal into an electrical signal. Optical amplifiers are used when the user has to transmit the signal to some long distance, which can be more than 100 kilometers.[13]

Types of optical amplifiers:

- EDFA Amplifier (Erbium Doped Fiber Amplifier)
- SOA (Semiconductor Optical amplifier)
- RAMAN Amplifier

Loop Control: We have used loop control in our circuit as it is used to controla number of loops in the circuit. It is used when we are using the amplifiers in the circuit.

Optical Receiver: It is used in the model just to simplify the overall layout. It is provided with the input from the WDM DEMUX, and its output is then given to the BER Analyser.

BER Analyser: It is considered as the primary visualizer for the model. BER stands for Bit Error Rate. BER Analyzer provides us with the Eye-Diagram, BER plot and various values like BER value, Q-factor value and eye height

4. RESULTS

The network was simulated in Optisystem. The results for the designed model at 1Gbps and 20 Gbps with varying optical length is given as below:

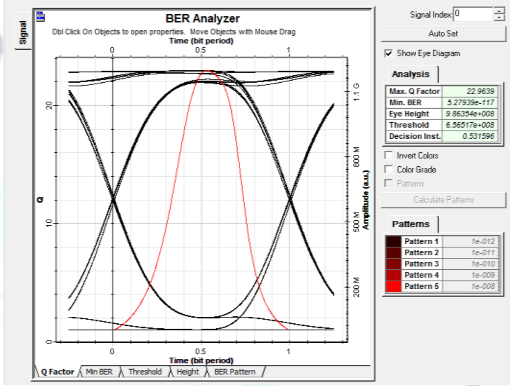

*Fig 5:**Eye diagram for 250km at 1 Gbps***

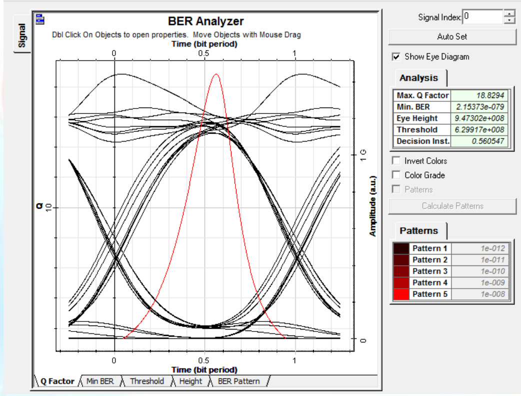

*Fig 6:**Eye diagram for 250km at 20 Gbps***

Output Table

The below table shows the output values which includes the resultant values of Q-factor, BER values, and SNR at different OWC Channel length. The output values are analyzed at two values of bit rate; they are 20 Gbps and 1 Gbps.

*Table 1:**Output values for bit rate 1 Gbps***

Length	Q-factor (1 Gbps)	BER (1 Gbps)	SNR (1 Gbps)
2500	22.8573	6.13E-116	35.9457
3500	22.8786	3.76E-116	32.8183
4500	22.8085	1.87E-115	30.3462
5500	22.6201	1.36E-113	28.2124
6500	22.2713	3.48E-110	26.2407
7500	21.6921	1.21E-104	24.2995
8500	20.7596	5.01E-96	22.2529
9500	19.2538	6.56E-83	19.9205
10000	18.1834	3.49E-74	18.5739
10500	16.842	5.97E-64	17.0658
12500	8.88248	3.14E-19	9.19778

Table 2: ***Output values for bit rate20 Gbps***

Length	Q-factor (20 Gbps)	BER (20 Gbps)	SNR (20 Gbps)
2500	18.8324	2.04E-79	34.9797
3500	18.7445	1.07E-78	31.8522
4500	18.3573	1.44E-75	29.3802
5500	17.6496	5.12E-70	27.2463
6500	16.6181	2.58E-62	25.2746
7500	15.264	6.63E-53	23.3335
8500	13.5688	3.02E-42	21.2868
9500	11.4751	8.49E-31	18.9544
10000	10.2541	5.38E-25	17.6079
10500	8.91251	2.32E-19	16.0997
12500	3.24711	0.000523594	8.2317

Output Plots

A. Q-Factor Vs. Length

The below figure shown is the plot of the Q-factor versus length at abit rate of 20 Gbps and 1 Gbps. The values of the curves are decreasing for both the bit rates which means that the value of the Q-factor decrease with increase in the length.

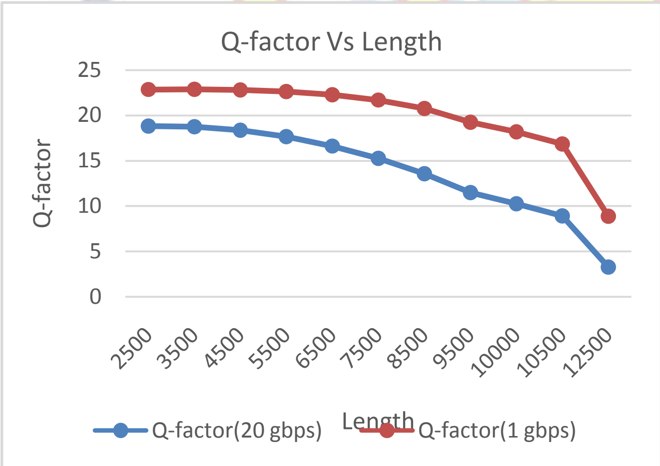

Figure 7: ***Q-Factor vs. Length***

B. BER vs. length

The below figure is the BER vs. Length plot. As there is little difference in the BER achieved from both the bit rates, it can be said that both data rates are suitable for communication in terms of achieving less Bit error rate.

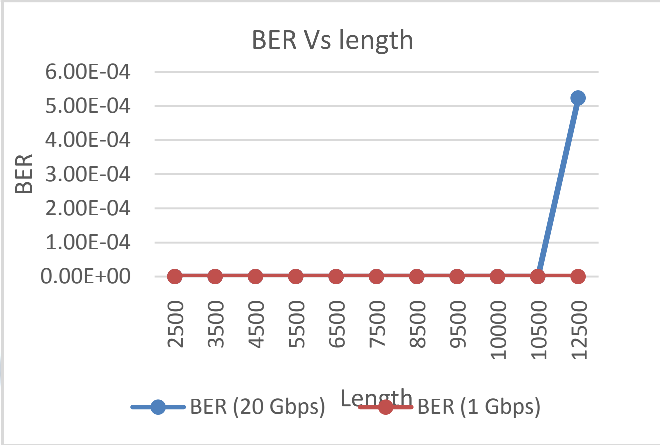

Fig 8: ***BER vs. length***

C. SNR vs. Length Plot

The SNR vs. Length Plot is represented in the figure below. The SNR values represent the signal-to-noise ratios for the channel. These are important to know the power of a signalwith respect tothe power of noise on the channel. It can be observed from the SNR vs. Length graph, that SNR value is very high for 1 Gbps bit rate and it decreases as the increase in the length of thechannel. The SNR values of 20 Gbps bit rate are comparatively minimum as compared to the SNR of 1 Gbps data rate.

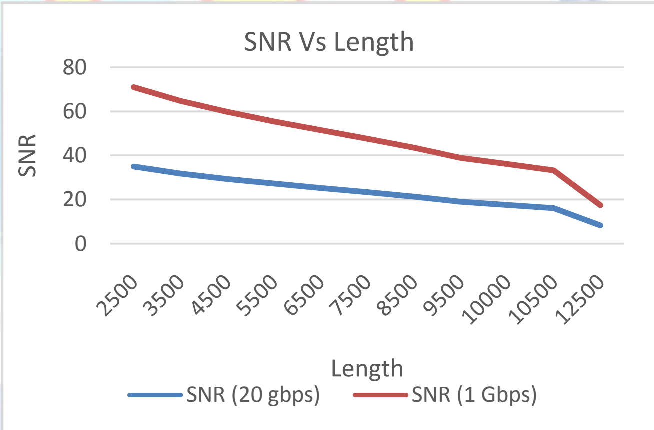

Figure 9: ***SNR vs. Length Plot***

This research analyzed the long distance communication upto 12500 Km with 64 channels and 20 Gbps data rate. The results are comparatively high and show an efficient and high capacity of the proposed network. In this research, for 20 Gbps data rate, the quality factor achieved at 12500 Km was 3.24711 with $5.235\,X10^{-4}$BER and 8.2317 SNR value.For 1 Gbps data rate at 12500 Km distance, the BER achieved for quality factor 8.88248 is 3.14E-19.

In the previous work of the same field [11], the authors have taken the total number of channels as 45 channels. The Kaur P. et al. in 2016 achieved the results on 10 Gbps bit rate with 10,000 Km distance. The 32 channels considered on the network. The minimum BER achieved corresponding to the Q-factor 37.74 was $2.65\,X10^{-312}$ [12]. In our proposed model, we considered 64 channels for the IS-OWC network along with high bitrate of 20 Gbps. The comparison of thenew network is made with the data rate of 1 Gbps. The research is thus better in terms of high data rate achievements and long-distance communication.

5. CONCLUSION

In optical wireless communication, the integration of DWDM has undeniably transformed the satellite communication systems which were used in the forthcoming time. The reason of OWC for beingpopular is because of their uniqueness and outstanding performance. DWDM model is studied using different optical amplifiers such as Raman amplifier, EDFA, etc. There are total 64 channels in this system, and we have analyzed the results at the bit rate of 1 Gbps and 20 Gbps.The system performance parameters are bit error rate, eye-opening, Q-factor, etc. In this research, for 20 Gbps data rate, the quality factor achieved at 12500 Km was 3.24711 with $5.235\,X10^{-4}$BER and 8.2317 SNR value.For 1 Gbps data rate at 12500 Km distance, the BER achieved for quality factor 8.88248 is 3.14E-19.The setup of the purpose system is very practical for the forthcoming and the present generation which has low earth orbit inter-satellite communication applications. This research also analyzed further in order to improve the data rate and link distance.

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