OPTIMIZATION OF MACH-ZEHNDER MODULATOR FOR INTERSATELLITE COMMUNICATION : A REVIEW

By

POOJA SHARMA * SHARAD MOHAN SHRIVASTAVA ** ANUJA MISHRA ***
PRACHI AGRAWAL **** RAHUL PARGANIHA *****

*,***,****,***** PG Scholar, Department of Communication Engineering, Chhattisgarh Swami Vivekanand Technical University, Bhilai, CG, India.
** Assistant Professor, Department of Electronics & Telecommunication, Shri Shankarachrya Technical Campus, Bhilai, CG, India.

ABSTRACT

The Objective of this review paper is to make the readers understand the key terms related to Intersatellite Optical Wireless Communication System to help them carry out their future project work.The concept of wireless communication system has paved its way in optical communication system replacing long lengthy fibers which were previously opted. This has enabled optical wireless systems to be used in free space communications as well. A network is required enabling communication between the satellites prevailing in space because of increasing number of satellites in free space. Higher data rates of Gbps can be achieved using laser communication along with greater distance offered. The communication being carried out between the satellites in space via optical wireless systems is basically termed as Intersatellite Optical Wireless Communication (IsOWC). In this review paper, Intersatellite Optical Wireless Communication (IsOWC) system modelling and simulation for performance characterization and estimation are specifically understood and discussed. The system parameters namely bit rates, receiver sensitivity and distance of LEO and GEO intersatellite links were found.The intersatellite link was designed and simulated using a known optical system simulator named OptiSystem by Optiwave.

Keywords: (IsOWC) Intersatellite Optical Wireless Communication, Intersatellite Links (ISL), Free Space Optics (FSO), Q-factor, Bit Error Rate(BER).

INTRODUCTION

For the research and communication purpose for the benefits of the mankind, the manmade satellites have been developed. A satellite is an object that orbits around another object in space. An intersatellite link is a communication link that connects two separate satellites directly. One satellite could have several links to numerous other satellites. Inter-satellite links are very important for communication of two satellites in the same orbit or two different orbits. The present satellite communications system uses microwave technology for space-to-ground and geosynchronous satellite to low earth orbiting vehicles [15]. In the future system, the satellite to ground links would remain in the microwave regime but satellite-to-satellite communication will be governed by optical wireless links. The technology uses laser light of infrared wavelengths to transmit optical signals between two points via free space [16]. Laser communication is now able to send information at data rates up to several Gbps and at distance of thousands of kilometers apart [1]. This has open up the idea to adapt optical wireless communication technology into space technology, hence Intersatellite Optical Wireless Communication is developed. An overview of inter-satellite link is shown in Figure 1.

FSO is a line-of-sight technology that uses lasers to provide optical bandwidth connections or FSO is an optical communication technique that propagate the light in free space means air, outer space, vacuum, or something similar to wirelessly transmit data for telecommunication and computer networking. The use of lasers is a simple concept similar to optical transmissions using fiber- optic cables, the only difference is the transmission media. Light travels through air faster than it does through glass, so it is fair to classify FSO as optical communications at the speed of

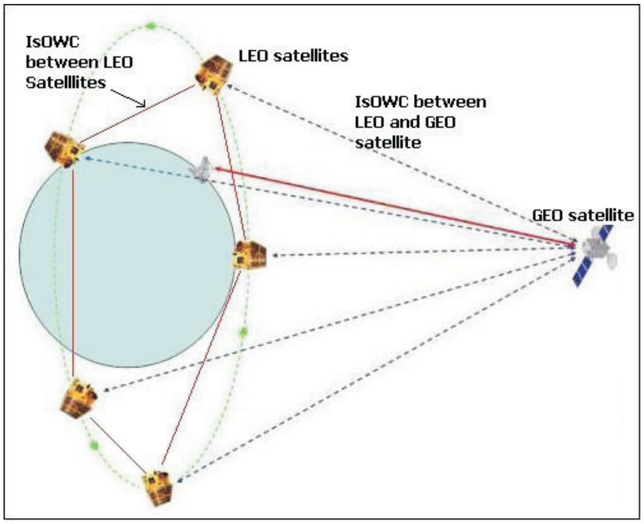

Figure 1. Overview of IsOWC

the light. FSO communication is considered as an alternative to radio relay link Line-of Sight (LoS) communication systems. The advantages of free space optics are as follows,

- No licensing requirement.
- Non appearance of radio frequency and removal of the problem of radiation hazards.
- Wide bandwidth which gives high data rates [3].

1. Mach-Zehnder Modulator

The application of electro-optic material to change the phase of an incoming optical signal is essentially the simplest and the most basic version of an integrated optical device. However, this phase modulation of an optical phase modulator can be further used for amplitude (intensity) modulation of light by implementing it in the principle of interference. An intensity modulator is based on a Mach-Zehnder interferometer. The intensity modulation is obtained by creating phase differences between the two arms of the interferometer. Hence, the PSK output signal of the phase modulator can be converted into an Amplitude Shift Keyed (ASK) optical signal using this device. Figure 2 shows a schematic of the Mach Zehnder Interferometer.

The input optical signal beam is split into two parts at the two-way power divider and these beams travel equal distances through distinct paths until they recombine by interference at the other end in the beam combiner. However, the phase change in the two beams is different as they travel along the channel waveguides. One beam is allowed to travel undisturbed along the reference path and is known as the reference beam. The relative phase of the reference beam is assumed to be 0. Other beam travels through a phase modulator which changes the phase of the beam by some pre-determined amount, say θ and so the relative phase difference between the two beams when they arrive at the beam combiner is θ.

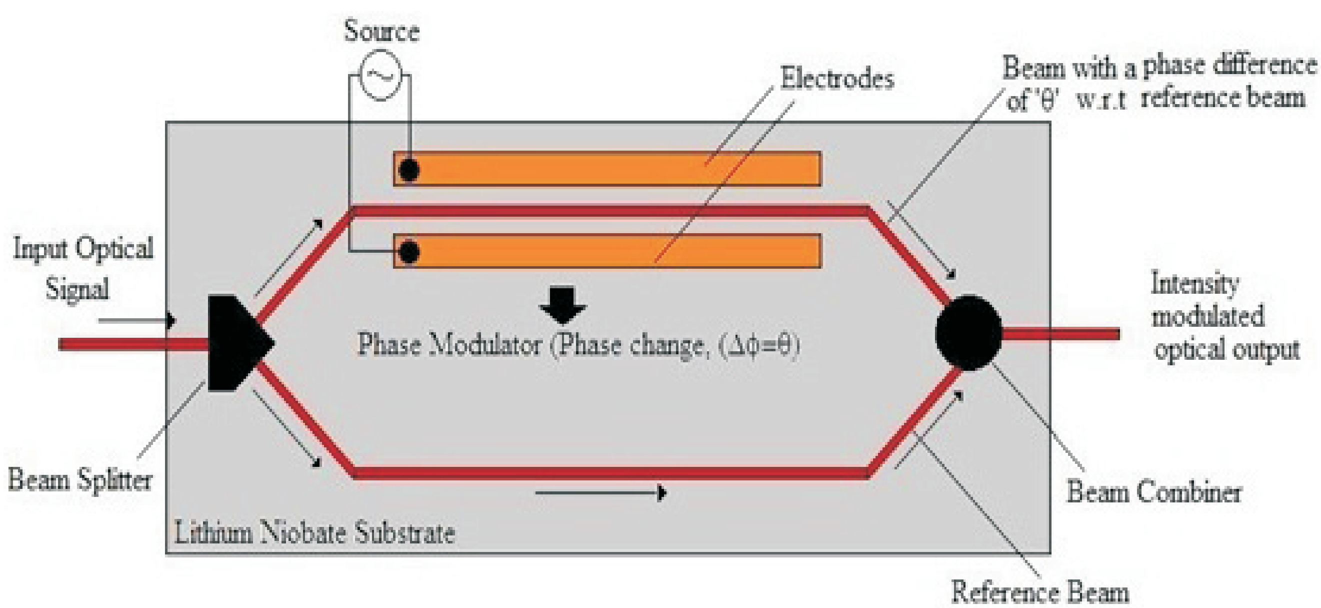

Figure 2. Mach-Zehnder Interferometer

Depending on the value of these beams, interfere either constructively or destructively and the output signal is obtained accordingly. For a value, $\theta = \prod$, the two beams interfere destructively and the Mach Zehnder Interferometer acts as an inverter in case of a digital input at the source of the modulator. The input and output waveforms corresponding to this case are shown in Figure 3.

2. System Architecture

The basic architecture used to model ISL system is shown in Figure 4. This gives an overview of the proposed optical ISL system. The IsOWC system consists of transmitter, propagation medium and receiver which is shown in Figure 4, where the transmitter is in the first satellite and the receiver is in the second satellite. The free space between the satellites in the propagation medium is the OWC channel that is used to transmit the light signal. Optical wireless communications uses light at near-infrared frequency to communicate. The IsOWC system is not much different from free space optics and fiber optic communication, where the difference relies in the propagation medium. In the Optisystem software, the transmitter and the receiver antennae are also assumed to be ideal. The OWC channel is considered to be an outer space, which is free from additional losses and attenuation factors but there will be some transmitter and receiver pointing errors [2]. The IsOWC transmitter receives data from the satellites Telemetry, Tracking and Communication (TT&C) system. The Telemetry System collects data from sensors on board, the satellite and send these data via telemetry link to the satellite control center which monitors the health of the satellite. Tracking and ranging system located in the earth station provides the information related to the range and location of the satellite in its orbit. The command system is used for switching on/off of different subsystems in the satellite based on the telemetry and tracking data. Light source is the most important component in optical signal since communication is done by transmitting light. Light emitting diode and laser diode are two types of optical light source commonly used in optical communication. The output light emitted by the laser diode is monochromatic, coherent and has high radiance which makes it suitable for long distance free space transmission [4,5]. The light generated by the laser can travel much further than the light emitted by LED. Hence, a CW laser diode is used for IsOWC system. The electrical signal from TT&C system and optical signal from the laser will be modulated by an optical modulator before it is transmitted out to space. An optical modulator varies the intensity or amplitude of the input light signal from CW laser according to the electrical signal. This is done by changing optical parameters such as, refractive index, reflection factor

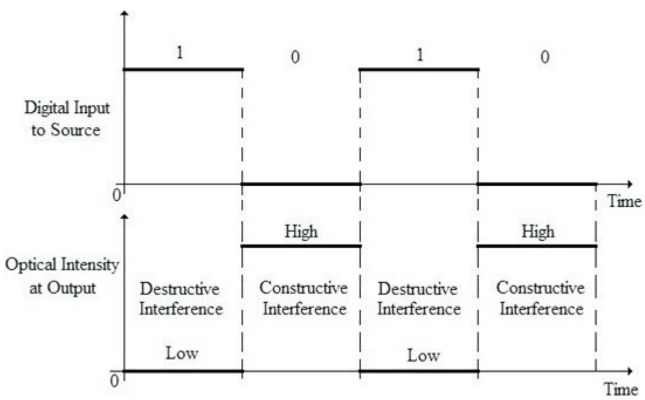

Figure 3. Output of Mach Zehnder Interferometer to Digital Input at the Source

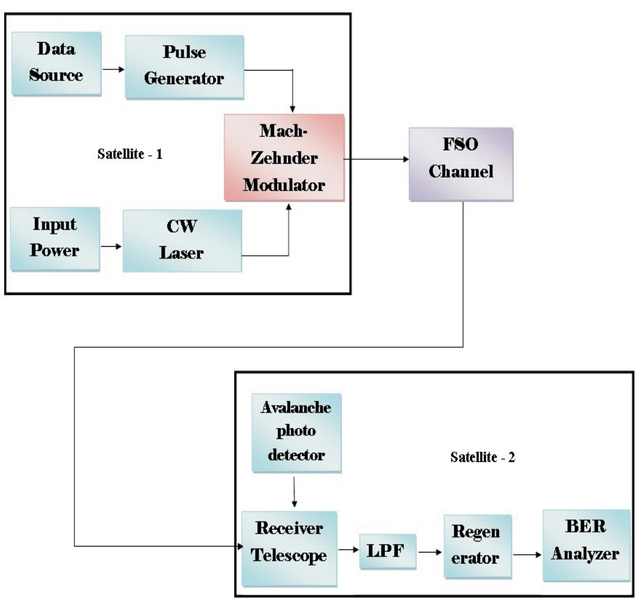

Figure 4. Design of Inter Satellite Optical Wireless Communication System

Figure 5. Optical Antenna

and transmission factor of the optical modulator that is made from fiber waveguides. Different from free space optics that is subjected to many losses due to weather and atmospheric attenuation, the optical wireless communications channel is considered as vacuum and free from atmospheric losses. At an ideal case, the only cause of signal attenuation is the distance of the transmission. Optical antenna or optical lenses can be used at the transmitter and the receiver. Therefore, the free space loss is taken as 0 dB/km of the optical wireless channel various in this proposed model. The optical antenna allows wider light beam divergence and detection [6]. An optical antenna is actually a lens or a telescope that is placed before and after the transmission medium to increase the signal divergence as shown in Figure 5. The receiving end of the IsOWC system consists of an Avalanche photodiode and a low pass filter. Amplification in APD photo detector or Avalanche phenomenon occurs when charged electrons are introduced in such high electric field area and collide with neutral semiconductor atoms, thus generating other carriers. This process is then repeated to effectively amplify the limited number of carriers [7].

3. Discussions

3.1 Performance Analysis of the Optimized Link at Wavelength of 980nm and 1550nm

An inter-satellite optical wireless system is designed with the help of OPTI-SYSTEM simulator consisting of two satellites with a space difference of 1300 km exchanging externally modulated optical data at 3 Gbps through free space medium at operating wavelength of 980 nm and 1550 nm [7]. Table 1 shows the numerical results for the performance analysis of link at varying wavelength of 980 nm and 1550 nm between two satellites at a distance of 1300 km at data rate 3 Gbps.

S. No.	Range (km)	Wavelength (nm)	Q Factor	BER
1.	1300	980	7.30323	1.25545 $^{e\text{-}013}$
2.	1300	1550	14.4179	1.58648 $^{e\text{-}047}$

Table 1. Performance Analysis of the Link at Wavelength of 980 nm and 1550 nm

S. No.	Range (km)	Modulation Formats	Q Factor	BER
1.	1700	NRZ	13.4289	1.6803 e^{-041}
2.	1700	RZ	10.095	2.8934 e^{-025}

Table 2. Performance Analysis of the Optimized Link at Wavelength of 980 nm by using Modulation Formats

3.2. Performance Analysis of the Optimized Link at Wavelength of 980nm using Modulation Formats

An inter-satellite optical wireless system is designed with the help of OPTI-SYSTEM simulator consisting of two satellites with a space difference of 1700 km exchanging externally modulated optical data at 3 Gbps through free-space medium at operating wavelength of 980 nm by using two modulation formats i.e. NRZ and RZ [12]. Table 2 shows the performance analysis of link by using two modulation formats at wavelength of 980nm between two satellites at the distance of 1700 km at data rate 3 Gbps.

3.3 Comparison between DPSK and QPSK

Free-space optical communication systems employing QPSK modulation for data rate 2.5 Gbps and that gives significant comparison with DPSK modulation and every component requirement is presented [8]. QPSK is simulated using the Optisystem software and its various parameters such as, Q factor, BER, Eye Diagram, etc, were compared for different categories of coding such as QPSK and DPSK studies shown in Table 3 that in general, it can be operated better by using QPSK modulation in higher power than DPSK in free space.

Parameter	QPSK	DPSK	Condition
Max Sactor	9.25	7.94	Data Rate = 2.5 Gbps Power = 10mW
Min BER	$1.05*10^{-20}$	$9.45*10^{-16}$	
Eye Height	$4.97788*10^{-005}$	$2.92781*10^{-005}$	

Table 3. Comparision Between QPSK and DPSK

IsOWC system designed was modeled and simulated for

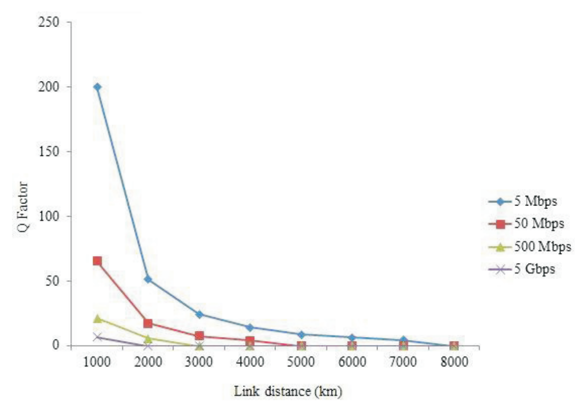

Figure 6. Maximum Achievable Q-factor for Variable Distance at 1550 nm IsOWC Link for Bitrate up to 10 Gbps

performance characterization. Several parameters of the system were varied to obtain optimum system performance. From the simulation, two observation was done, which is the relationship of the Q-factor and the bit rate at varying distance and also the relationship between Q-factor and the signal wavelength.

3.4 Relationship between Q-factor and Bit Rates with Distance of Intersatellite Link

Figure 6 shows the graphical representation of Q factor as a function of link distances for varying bit rates. By keeping the fixed power at 15 dBm, the Q factor observed for various distances from 0 to 8000 km. The bit rates used are 0.005, 0.05, 0.5, 5 Gbps. From Figure 3, it is clear that, as the distance increases, the quality of the system decreases [9]. The maximum achievable distance decreases as the bit rate increases [11]. So lower bit rates are used for long distance communication. However, long distance can be achieved by increasing the transmitted power [13].

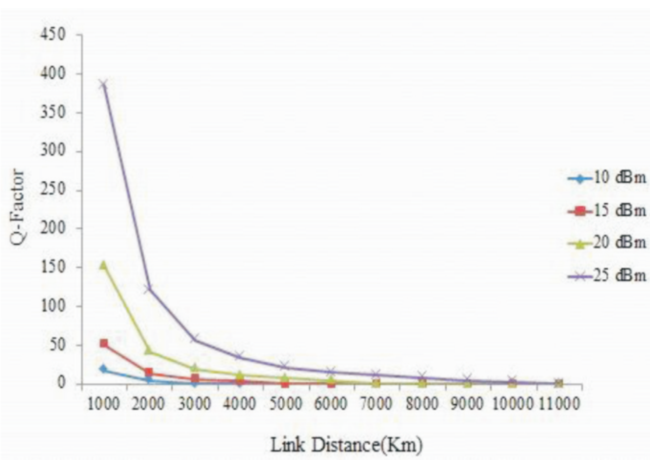

Figure 7. Q factor Vs Link Distance by Varying Transmitted Power

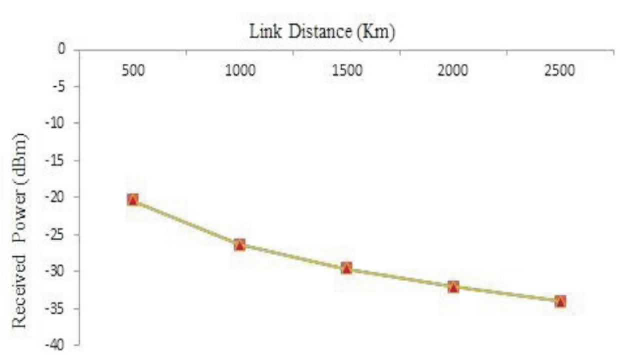

Figure 8. Received Power for Respective Optical Antennae Diameter at Distance up to 5000 km and Input Power of 10 dBm

3.5 Relationship between Q Factor and Link Distance by Varying Transmitted Power

It is often necessary to determine whether a wireless optical communication can achieve a certain transmission distance. Transmission distance depends on the transmitted power. For an IsOWC link, as the transmitted power increases, the link distance increases. The system performance is evaluated by analyzing the BER and Q-factor.

From the results it is clear that, larger transmission distance is achieved by increasing the transmitted power [13-14]. The Impact of variable transmission power on link range of IsOWC is examined by considering a single channel. Here, the transmitted power and the link distances are varied from 10-25 dBm and 1000-11000 km respectively. Figure 7 shows the graphical representation of Q factor as a function of link distance for varying transmitted power.

3.6 Relationship between Diameter of Optical Antennae with Received Power and Distance

From Figure 8, the received power of the intersatellite system is observed by varying the link distances from 0 to 2500 km keeping the transmitter power at 12 dBm, input bit rate 80 Mbps and transmitter antenna diameter 25 cm [10]. Figure 8 shows the graphical representation of the received power as a function of link distance. From the graph, it is observed that the received power decreases as the intersatellite link distance increases..

Conclusion

In this review paper, the authors have studied the performance parameters (such as BER, Q-factor, receiver sensitivity, link distance, etc.) that can affect the performance of an Intersatellite optical wireless communication system. Free space optics technology can achieve farther distance and provide better result as compared to the RF links. The advancement in satellite communication technology is to send data at any part of the world with a very high speed and provide a better mobile services for mankind. The conclusion of this review paper are as follows:

- The IsOWC system can perform better at lower bit rates.
- 1550nm wavelength are widely used, because it can

reduce the effect of scattering.

- The IsOWC system can perform better at small distance and small wavelength because of the high quality factor.

Future Work

Intersatellite communication is used primarily for "networking", a constellation of satellites at data rate up to several Gbps. It is expected that the parameters like size, weight, power and cost can be optimized in future satellite communication. FSO can be replaced by the combination of Hybrid FSO/RF links. There are more topics and areas that can be improved for this project. Due to that, the following topics are recommended for the IsOWC and intersatellite communication system improvements:

- Path prediction model for intersatellite optical communication link,
- Development of intersatellite optical data network protocol, and
- System Quality of Service (QoS) performance analysis by comparing to RF links.

References

[1]. **Isha Aggarwal, Paras Chawla, Rohan Gupta, (2013).** "Performance evaluation of inter-satellite free space optical communication system with varied parameters and transreceiver diversity". ISSN 2231-1297,Vol. 3, No. 7, pp.847-852.

[2]. **Gaurav Soni and Sanamdeep Singh, (2013).** "Pointing error evaluation in FSO link". *Communication and Computing (ARTCom 2013), Fifth International Conference on Advances in Recent Technologies*, pp.365-370.

[3]. **Shlomi Arnon, (2003).** "Optimization of Urban Optical Wireless Communication systems". *IEEE Transactions on Wireless Communications*, Vol. 2, No. 4, pp.629-629.

[4]. **Jaz M., Ghassemlooy Z, Ansari, S. and Adebanjo, O., (2010).** "Experimental investigation of the performance of different modulation techniques under controlled FSO turbulence channel". *5th International Symposium Telecommunications (IST),* pp.59-64.

[5]. **Vishal Sharma and Amandeep Kaur, (2013).** "Challenging issues in Inter-satellite Optical Wireless Communication systems (IsOWC) and its mitigation techniques", *Proc. of Int. Conf. on Advances in Communication, Network and Computing*.

[6]. **A. Jamalipour, (1999).** *Low Earth Orbital Satellites for Personal Communication Networks*. Artech House Publisher, UK.

[7]. **Navjot Kaur and Gaurav Soni, (2014).** "Performance analysis of inter-satellite optical wireless communication (IsOWC) system at 980 nm and 1550 nm wavelength". *Contemporary Computing and Informatics (Ic31), 2014 International Conference,* pp.1245-1250.

[8]. **A Penchala Bindushree, Nataraju A. B., Vijesh T V, Laxmiprasad AS, (2014).** "Design And Simulation of QPSK Modulator for Optic Inter Satellite Communication". *International Journal of Scientific and Technology Research*, Vol. 3, No. 8, pp. 402-408.

[9]. **Aida Hasfiza Hashim, Farah Diana Mahad, Sevia M. Idrus and Abu Sahmah M. Supa'at, (2010).** "Modeling and Performance Study of Inter Satellite Optical Wireless Communication System". *Photonics, 2010 International Conference*, pp. 1-4.

[10]. **Resmi R. S. and Rafeekha M. J., (2013).** "Investigations of Bit rates in Optical Intersatellite Wireless Links". *International Journal of Science and Research*, Vol.4, No. 1, pp. 2527-2529.

[11]. **Ravi Gupta, Sandhya Sharma, Manoj Kumar Sharma, (2014).** "Modification in Parameter of Intersatellite Communication using Multiple Transmitter and Receiver". *International Journal of Engineering Trends and Technology*, Vol.12, No. 10, pp.495-498.

[12]. **Navjot Kaur and Gaurav Soni,(2015).** "Performance analysis of Inter-satellite Optical Wireless Communication (IsOWC) system by using NRZ and RZ modulation". *International Journal of Scientific and Research Publications*, Vol. 5, No. 1, pp. 1-5.

[13]. **Resmi R. S. and Rafeekha M. J.(2015).** "Performance Evaluation of Optical Intersatellite Links with Varied Parameters". *International Journal of Engineering Research & Technology*, Vol. 4, No. 1.

[14]. **B. Patnaik P.K. and Sahu, (2012).**"Inter-satellite Optical

Wireless Communication System Design and Simulation". *Communications, IET*, Vol. 6, No. 16, pp. 2561 – 2567.

[15]. **Naresh Kumar, (2014).** "Enhanced performance analysis of Intersatelite Optical-Wireless Communication (ISOWC) system". *Science Direct Journal, Optik*, Vol.125, No.8, pp.1945-1949.

[16]. **Vishal Sharma and Amandeep Kaur,(2014).** "Modeling and simulation of long reach high speed Inter-Satellite Link (ISL)". *Science Direct Journal, Optik*, Vol.125, No.2, pp.883-886.

ABOUT THE AUTHORS

Pooja Sharma is currently pursuing her M.E. Degree in the Department of Communication Engineering from Chhattisgarh Swami Vivekanand Technical University, Bhilai, CG, India. She received her B.E. Degree in Electronics & Telecommunication Engineering from Chhattisgarh Swami Vivekanand Technical University, Bhilai, CG, India. Her research interest includes Photonics, Non Linear Fiber Optics and Optical Communication.

Sharad Mohan Shrivastava is currently working as an Assistant Professor in the Department of Electronics & Telecommunication at Faculty of Engineering & Technology, Shri Shankarachrya Technical Campus Bhilai, CG, India. He received his B.E. Degree in Electronics & Communication Engineering from Rajiv Gandhi Proudyogiki Vishwavidyala, Bhopal, MP, India and M.E. Degree in Electrical Communication Engineering from the Indian Institute of Science Bangalore, Karnataka, India. His research interests include Photonics, Non Linear Fiber Optics and Optical Communication.

Anuja Mishra is currently pursuing her M.E. Degree in the Department of Communication Engineering from Chhattisgarh Swami Vivekanand Technical University, Bhilai, CG, India. She received her B.E. Degree in Electronics & Telecommunication Engineering from Chhattisgarh Swami Vivekanand Technical University, Bhilai, CG, India. Her research interest includes Photonics, Non Linear Fiber Optics and Optical Communication.

Prachi Agrawal is currently pursuing her M.E. Degree in the Department of Communication Engineering from Chhattisgarh Swami Vivekanand Technical University, Bhilai, CG, India. She received her B.E. Degree in Electronics & Telecommunication Engineering from Chhattisgarh Swami Vivekanand Technical University, Bhilai, CG, India. Her research interest includes Photonics, Non Linear Fiber Optics and Optical Communication.

Rahul Parganiha is currently pursuing his M.E. Degree in the Department of Communication Engineering at Chhattisgarh Swami Vivekanand Technical University, Bhilai, CG, India. He received his B.E. Degree in Electronics & Telecommunication Engineering from the Chhattisgarh Swami Vivekanand Technical University, Bhilai, CG, India. His research interest includes Photonics, Non Linear Fiber Optics and Optical Communication.