Designing of Intersatellite Communication System Using Mach-Zehnder Modulator

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Abstract: ***The Objective of this paper is to make 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)

1. 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 communications 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 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 as in Figure 1.

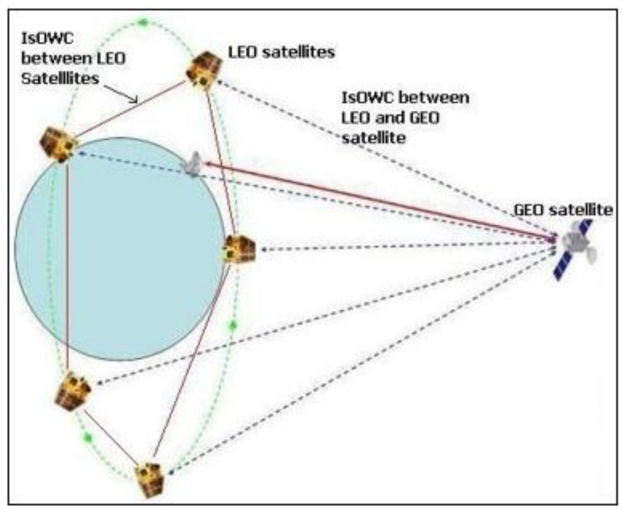

Figure 1: Overview of IsOWC

FSO is a line-of-sight technology that uses lasers to pro- vide 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 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:

1) No licensing requirement
2) Non- appearance of radio frequency and removal of the problem of radiation hazards

3) Wide bandwidth which gives high data rates [3].

a) 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 based on a Mach-Zehnder interferometer. The intensity modulation is obtained by creating phase differences between the two arms of the interferometer. The basic principle behind the Mach Zehnder Interferometer. Hence, the PSK output signal of the phase modulator can be converted into an amplitude shift keyed (ASK) optical signal using this device. The figure 2 below shows a schematic of the Mach Zehnder Interferometer:(diagram intended only for understanding and so not practical).

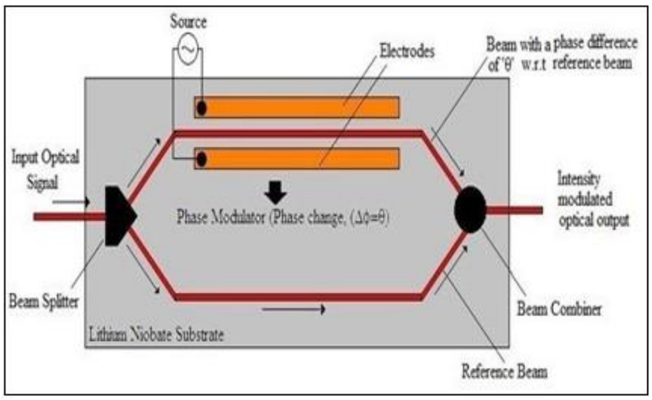

Figure 2: Mach-Zehnder Interferometer

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. The 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. Depending on the value of ϑ these beams interfere either constructively or destructively and the output signalis obtained accordingly. For a value $\vartheta = \Pi$, 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 below in figure 3:

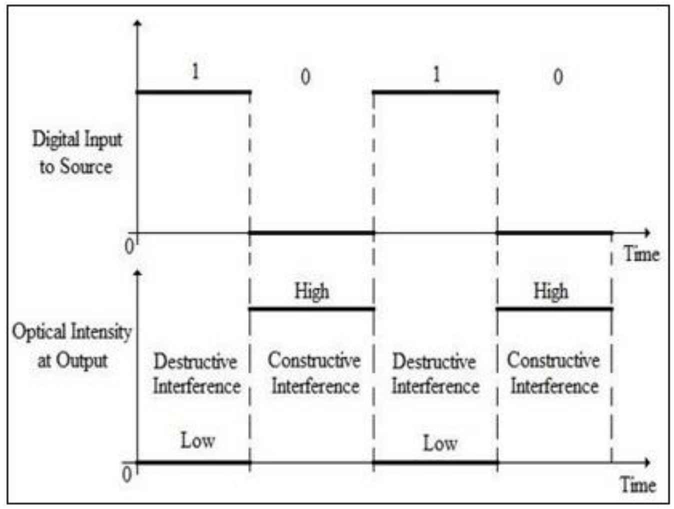

Figure 3: Output of Mach Zehnder Interferometer to digital input at the source

b) System Architecture

The basic architecture used to model ISL system is shown in Figure 4. This gives an overview of 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 is 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

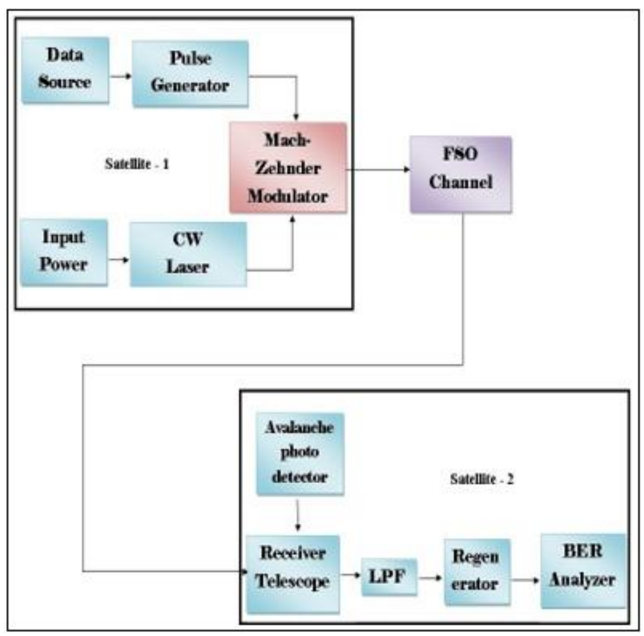

Figure 4: Design of Inter Satellite Optical Wireless Communication System

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 receiver antennae are also assumed to be ideal. The OWC channel is considered to be 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 sends 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 [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 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 optical wireless channel various in our 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].

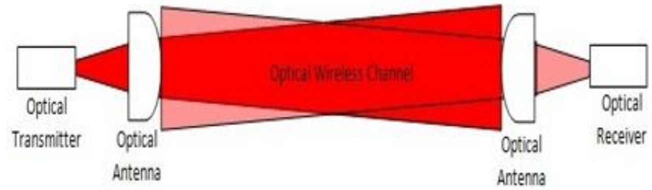

Figure 5: Optical Antenna

2. Discussion

1) Performance analysis of the optimized link at wave-length 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 freespace medium at operating wavelength of 980 nm and 1550 nm [7]. Table I shows numerical results for the performance analysis of link at varying wavelength of 980 nm and 1550 nm between two satellites at the distance of 1300 km at data rate 3 Gbps.

Table I: Performance analysis of the link at wavelength of 980 nm and 1550 nm

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

2) Performance analysis of the optimized link at wave-length of 980nm by 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 II 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.

Table II: Performance analysis of the optimized link at wavelength of 980 nm by using modulation formats

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

3) Comparison between DPSK and QPSK

Free-space optical communication systems employing QPSK modulation for data rate 2.5 Gbps and 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 shows (Table III) that in general, we can operate better by using QPSK modulation in high power than DPSK in Free space.

Table III: Comparison between QPSK and DPSK

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

IsOWC system designed was modeled and simulated for 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.

a) Relationship between Q-factor and Bit rates with Distance of Intersatellite Link

By varying the bit rate and the distance between the satellites in the IsOWC system, the system performance in terms of Q-factor was obtained [9]. The distance was set from 0km up to 5000km and the input power is set at a constant value of 10dBm and signal wavelength of 1550nm is used. The bit rate was set at 5 levels which are 1Mbps, 10Mbps, 100Mbps, 1Gbps and 10Gbps.

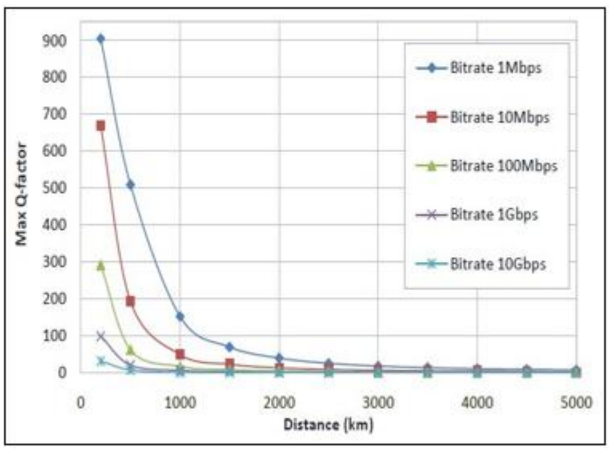

Figure 6: Maximum achievable Q-factor for variable distance at 1550nm IsOWC link for bitrate up to 10Gbps

From the graph of Figure 6, it can be observed that at longer distance the maximum Q-factor of the system decrease [11]. This shows that the error in the received signal increases as the distance increase. The graph also shows that with higher bit rate, maximum Q-factor is reduced [14]. At the distance of 5000km, only the 1Mbps can be used as the Q-factor received does not equals to zero. It was also observed that data transmission at high bit rate of 10Gbps can only be used for shorter distance of less than 500km. This however, can be increased by using higher optical input power or by improving the modulation technique.

b) Relationship between Q-factor and Signal Wave-length

At long-haul transmission, the common wavelength used is 1550nm but shorter wavelengths can also be used.

Table IV: Maximum Q-factor recorded for respective signal wavelengths

Signal Wavelength (nm)	Maximum Q- Factor
850	82.12
950	70.25
1550	32.72

From the table IV, it can be observed that at higher wavelength, more error is produced due to lower value of Q-factor [13]. However, by using longer wavelength, the effect of scattering can be reduced. Attenuation due to Rayleigh and Mie scattering is inversely proportional to the wavelength. Therefore, it assumes that there are no particles obstructing the light signal, but small and large particles by the means of space dusts and meteorites can happen to be within the light signals way. Therefore, the longest possible wavelength is to be used which is 1550nm. Another reason of using 1550nm is because the compatibility with current technology and devices.

c) Relationship between Diameter of Optical Antennae with Received Power and Distance

From the figure 7 we have observed that the power received is increasing with the increment of optical antennae diameter. However, increasing the distance between the satellites reduce the level of received power. Optical received power can be associated with the receivers sensitivity where in- creasing the received power would result in increasing the sensitivity. Therefore, it can be concluded that by increasing the diameter optical antennae, the receiver's sensitivity is also increased. It can also be conferred that lower sensitivity is obtained for longer intersatellite distance. Higher sensitivity will allow more throughputs and reducing the error received by the system.

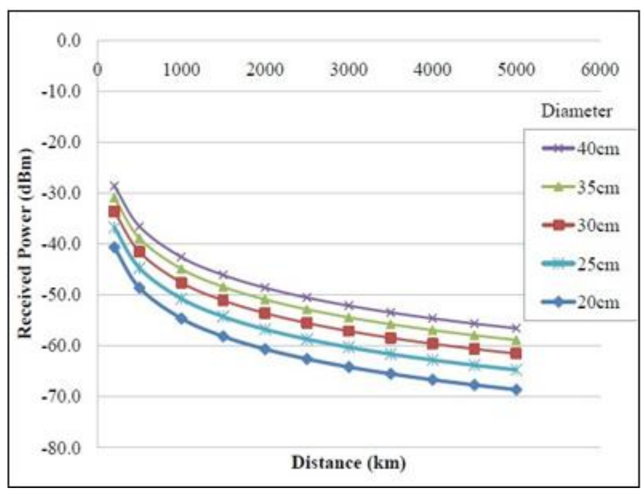

Figure 7: Received power for respective optical antennae diameter at distance up to 5000km and input power of 10dBm

3. Conclusion

Satellite used in space to perform many application for human being. Wireless Communications (IsOWC) can pro- vide intersatellite communication at high speed and achieve farther distance compared to RF links. The advancement in satellite communication technology provide cellular services for people at many places. In this paper, inter-satellite links and application of optical wireless communication were fully studied. The conclusions of this paper are as the followings:

1) The performance of intersatellite communication for lower bit rate is better for particular optimam distance range.
2) There are many effects of scattering and compatibility at longer signal wavelength but we can reduce such type of effects at 1550nm wavelength
3) The sensitivity of the receiver can be increase by using the different optimam data rates
4) The requirement of power for multiple channel are lower so that we can reduce the effect of laser power

4. Future Work

Intersatellite communication is used primarily for "networking" a constellation of satellites at data rate up to many 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 combination of Hybrid FSO/RF links. There 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 proto-col
- System Quality of Service (QoS) performance analysis by comparing to RF links

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