Investigations of Transmitted Power in Intersatellite Optical Wireless Communication

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***Abstract*—The intersatellite optical wireless communication link is designed and simulated for performance characterization. In IsOWC link two parameters mainly bit rates and transmitted optical power is adjusted. The paper investigates the effect of transmitted power on link range and minimize transmitter power for bit rates of 0.008, 0.08, 0.8 and 8 Gbps. Maximum link range IsOWC is examined for transmitted powers of 5, 10, 15 and 20 dBm. This paper examined 8 channel IsOWC link and we calculate the minimum transmitted power for 8 channels in IsOWC link. It is observed that for lower data of 8 Mbps data rates we need less power for successful communication and for higher data rates of 8 Gbps we need large transmitted power at transmitter of IsOWC. Reduction in laser power could improve overall system performances and cost.**

Keywords-component; Inter-satellite optical wireless communication (IsOWC), Q-factor, bit error rate (BER), Wavelength Division Multiplexing (WDM), Minimum Transmitted Power.

I. INTRODUCTION

Optical communications systems have evolved from lengthy fibers to powerful wireless systems which lead to use of optical wireless communication system in space communications. Free space intersatellite optical communications systems provide a high bandwidth, small size, light weight, low power and low cost alternative to present microwave satellite systems [1,2]. Optical communication was one of the best ways in term of high bandwidth and high data rates communication. Optical wireless communication is a concept of transmitting information through air with light as a carrier wave. In intersatellite optical wireless communication information signal is modulated on a light source generally laser and it is transmitted through free space to another satellite where light is detected by a photo detector and converted to electrical signal. As the number of satellites orbiting Earth increase year by year, a network between the satellites provides a method for them to communicate with each other IsOWC can be used to connect one satellite to another, whether the satellite is in the same orbit or in different orbits. With light travelling at 3 x 10^8 m/s, data can be sent without much delay and with minimum attenuation since the space is considered to be vacuum. The advantages of using optical link over radio frequency (RF) links is the ability to send high speed data to a distance of thousands of kilometers using small size payload. Small beam divergence and the ultra-long distance of the link require high precision system, for example, the point error in the transmitter's line of sight can have a significant effect on the performance of the link. The distortion of the optical devices can cause wave front aberrations which can change the far-field intensity distribution and bring on transmitting errors [8]. In 2001, the world-first IsOWC link was established (between the SPOT-4 and Advanced Relay and Technology Mission Satellite (ARTEMIS) satellites), proving that optical communication technologies can be reliably mastered in space[4]. The first intersatellite optical communications systems will be deployed in space by the US military in the near future. The NASA Goddard Space Flight Center is developing optoelectronics hardware and performing system analysis for the first US civilian experiments [7].

In this paper, we demonstrate an 8×100 Mbps high capacity optical wireless intersatellite communication by integrating wavelength-division-multiplexing (WDM) technology. Using simulation software Optisystem, an 8 channel WDM optical wireless transmission system simulation model was designed in this paper. The 8 channels range from 193.0 - 193.7 THz with a fixed channel spacing of 100 GHz and the bit-rate of each channel is 100Mbps

II. SYSTEM MODEL

IsOWC block diagram presented in figure2, the system is modeled with basic communication components. The first design consists of basic OWC communication system and is shown in Figure2. In the design model shown, the model is for simplex system. The model consists of 8 channel intersatellite optical communication system employing wavelength division multiplexing (WDM) between two LEO satellites. The eight channels range from 193.1 - 193.8 THz with a fixed channel spacing of 100 GHz is taken. An optical communication system consists of transmitter, communication channel and receiver.

A. Transmitter

The transmitter consists of four components. The first component is the pseudo-random bit sequence generator. This is to represent the information or data that wants to be transmitted and the data usually come from the satellite's TT&C system. The signal then passed to NRZ pulse generator. The NRZ pulse generator generates a non return to zero coded signals. The rise and fall time of NRZ pulse generator is 0.05 bit.. The role of the optical transmitter is to convert the electrical signal into optical form [5]. An optical modulator varies the intensity or amplitude of the input light signal from LASER according to the electrical signal. Continuous wave laser whose power is set at 12 dbm and whose line width is 10 MHz is used here for modulating the incoming signal. A Mach Zehnder modulator modulate electrical signal coming from NRZ pulse generator and light signal from CW laser. The Mach Zehnder modulator has an extinction ratio of 30 db. Eight transmitter blocks are used, and 8×1MUX is used to send the light signal through wireless channel.

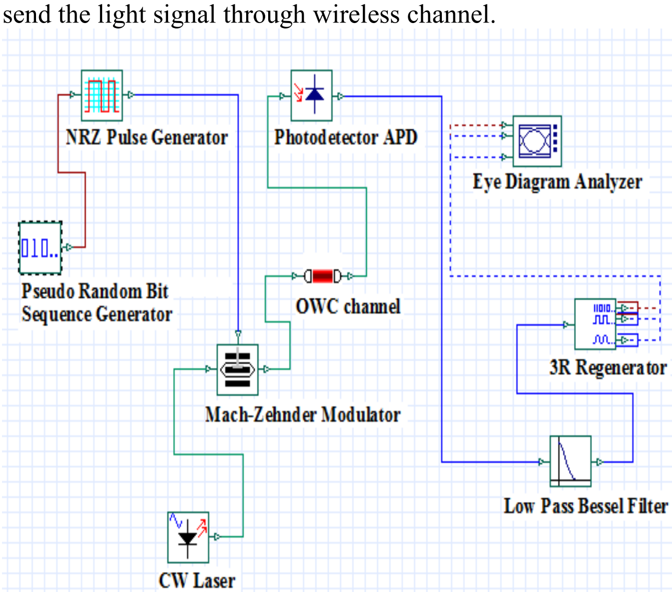

Fig 2. IsOWC simplex design model

B. Optical Wireless Channel

In the OptiSystem software, the OWC channel is between an optical transmitter and optical receiver with 15cm optical antenna at each end. The transmitter and receiver gains are 0 dB. The transmitter and receiver antennae are also assumed to be ideal where the optical efficiency is equal to 1 and there are no pointing errors

The optical wireless channel is modeled by mathematical equation. The optical power P_R received by the receiver satellite is [3]:

$$P_R = P_T \eta_T \eta_R \left(\frac{\lambda}{4\pi \cdot Z} \right) G_T G_R L_T L_R$$

Where P_R is transmitter optical power; η_R is the optics efficiency of the receiver; η_T is the optical efficiency of the transmitter; λ is the wavelength; Z is the distance between the transmitter and the receiver; G_T is the transmitter telescope gain; G_R is the receiver telescope gain; and L_T, L_R are the transmitter and the receiver pointing loss factor, respectively where the pointing loss factor L is given by:

$$L = \exp(-G_T \cdot \theta^2)$$

Where **θ** is the radial pointing error angle. This factor defines

the attenuation of the received signal due to inaccurate pointing.

C. Receiver

The receiving end of the inter satellite optical wireless communication link signal consists of a photodiode, a low pass filter, regenerator and a visualizer. A photodiode detects the received light signal and converts it into electrical signal. Photo detector used here has a gain of 3, responsivity of 1 A/W and dark current of 10 nA. Avalanche photodiode (APD) is used in long distance free space optical data transmission due to its characteristics of producing high amplification for low or weak light signals. Then signal is passed through low pass Bessel filter whose cutoff frequency of 0.75*bit rate to limit the bandwidth. The 3R regenerator is the subsystem use to regenerate electrical signal of the original bit sequence, and the modulated electrical signal as in the transmitter to be used for BER analysis. The output of the 3R regenerator is connected to the eye diagram analyzer and to satellite's TT&C system for further signal processing. The eye diagram analyzer gives the value of maximum Q factor, minimum BER, eye height and threshold.

D. Simulation of 8 Channel IsOWC model

System model for 8 channels are shown below in fig.3 at each sub systems consist of a transmitter block which consists of a CW laser, a pseudo random sequence generator, a NRZ pulse generator, a Mach-Zehnder modulator at transmitter side as shown in fig.3(a). The 8 sub systems at transmitter side consist of components as shown in fig.4. On the other hand 8 such sub systems are shown at receiver side. Each subsystem consist of a photo detector, a low pass Bessel filter, a regenerator and a eye diagram analyzer as shown in fig.3(b). The purpose of creating subsystems is only for clarity.

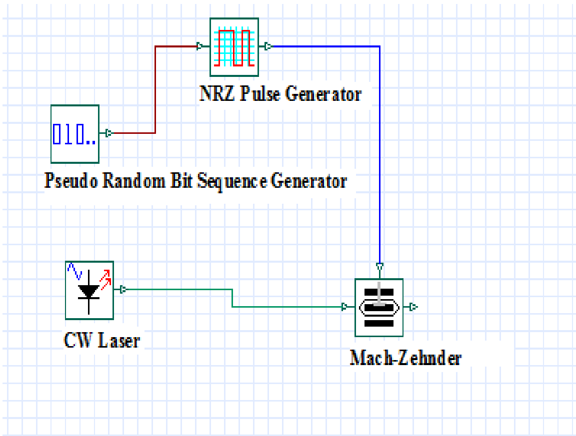

Fig .3(a). The structure of a sub system at transmitter side

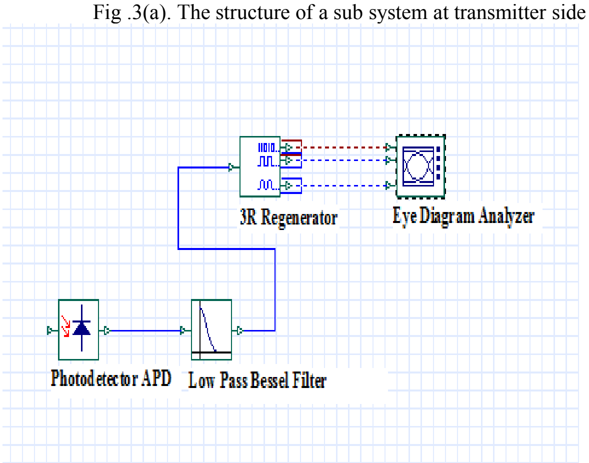

Fig .3(b). The structure of a sub system at receiver side

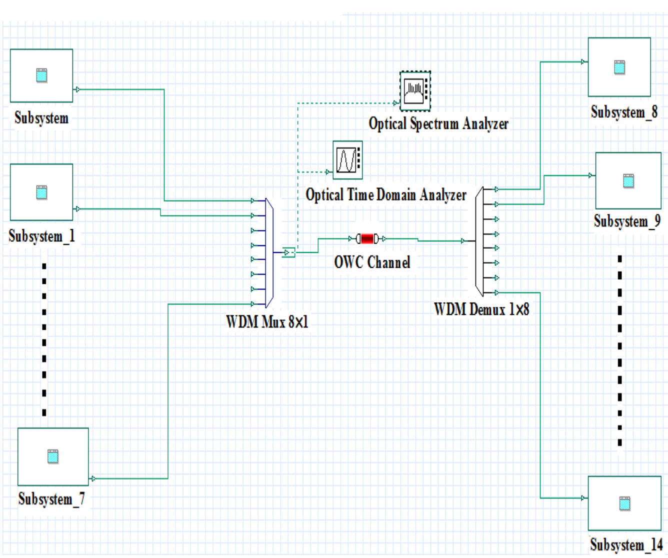

Fig.4. Simulation Model of 8-Channel WDM System for intersatellite optical link.

III. RESULTS AND DISCUSSION

Here the effect of transmitted power on IsOWC link is examined. Transmitted power has major role in determining the link distance. As transmitted power of IsOWC link is increased the link distance also increases. So transmitter power is adjusted to a minimum value to get error free communication

A. Effect of Transmitted Power on link distance .

It is often necessary to determine if a wireless optical communication can achieve a certain transmission distance. Transmission distance is dependent on transmitted power for a IsOWC link as we increase the transmitted power, the link distance increases. The system performance is be evaluated by analyzing the BER and Q-factor. Q-factor is a measurement of the signal quality. It is proportional to the system's signal to noise ratio. From simulations it is investigated that with large transmitted power, greater transmission distances is achieved. The impact of variable transmission power on link range of IsOWC is examined by considering a single channel. Here we set the values of transmitted powers from 5 - 20 dBm and link distance varies from 1000 - 5000 km. Their impact on link distance is investigated. By varying transmitted power in IsOWC, the value of Q factor is obtained and a graph is plotted between Q factor and link distance as shown in fig.5. To achieve error-free communication (BER < 10^{-9}) in our system, the maximum possible link distance between two satellites for different transmitted powers are examined. It is observed that as we increase the transmitted power, link range also starts increasing. By performing simulation it is calculated that for a transmitted power of 5 dBm, a link range of 950 km is achieved. Bit rate of IsOWC link is set at a constant value of 800 Mbps. For transmitted power of 10 dBm link range is1700 km, for value of 15 dbm link range comes out to be 3000 km and for 20 dBm transmitted power link distance of 5300 km is achieved. It is observed that for long distance communication we need higher input power.

TABLE.1 TECHNICAL DATA OF MAXIMUM LINK RANGE OF ISOWC FOR DIFFERENT TRANSMITTED POWERS

Transmitted power (dBm)	Max. Distance (km)	Max. Q factor	Min. BER
5	950	5.72	5.04×10^{-9}
10	1700	5.65	7.6×10^{-9}
15	3000	5.75	4.6×10^{-9}
20	5300	5.81	2.96×10^{-9}

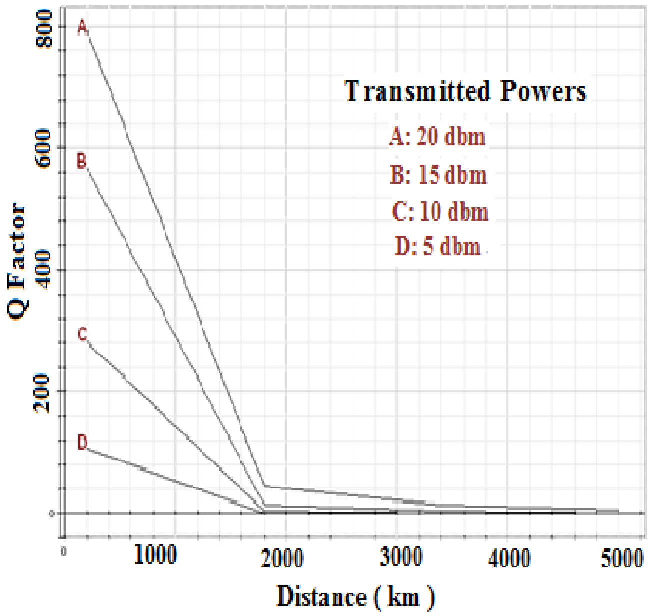

Fig.5. Q Factor vs link distance for different transmitted powers.

B. Minimization of transmitted power for different bit rates.

The interstellite optical wireless communication link is made between LEO – LEO satellites which are approximately 5000 km apart. Two parameters mainly bit rates and transmitted optical power of IsOWC link is adjusted. The transmitted LASER power plays important role in determining system performance because as the transmitted power is increased the link distance increases. The transmitted power is adjusted to a minimum value to achieve error free communication of IsOWC link of 5000 km, this helps in reduction in transmitted power and hence improve system performance and reduces cost. The transmitted powers of of each eight channels are adjusted to a minimum value for different bit rates. Effect of transmitted power on q factor for different bit rates is examined. Optimization of transmitted power to a minimum value is performed by using optimization tool box in optisystem software. Minimum transmitted power for every 8 channels for different bit rates is calculated for which error free communication (BER < 10^{-9}) can be achieved for 4 different bit rates. Bit rates values are set at 0.008, 0.08, 0.8 and 8 Gbps. It is observed that minimum value of transmitted power is a function of bit rates. For lower bit rates of 8 Mbps less transmitted power is required and for higher bit rates such as 8 Gbps, more transmitted power is required to achieve successful communication up to a link distance of 5000 km. From eye diagrams the value of Q Factor and Min.BER is observed and values are taken up to BER = 10^{-9}, as this is the limit up to which successful communication can take place, beyond this value of BER our communication link breaks. A graph is plotted between Q Factor and Transmitted optical powers for different bit rates. Transmitted power values are taken from 5 – 30 dBm. It is investigated that for a bit rate of 8 Mbps and 30 dBm, we get large value of Q factor of 1273.6 and very small value of BER. Similarly for 8 Gbps and transmitted power of 20 dBm, we get small value of Q factor of 4.40. Graph 1 shows the variation of transmitted powers vs Q Factor for different values of bit rates for channel 0. We can made graphs for all eight channels but that all looks very similar so it is of no use. Firstly we consider the IsOWC is working at 8 Mbps bit rate and we calculate the minimum power required by every single channel. It is observed that for every single channel different value of minimum power is required to achieve an error free communication (BER < 10^{-9}). These values are listed in table shown in Table 2. Now these minimum values of transmitted power of 8 channels are multiplexed by 8×1 MUX and the total transmitted power of signal measured by Optical Power Meter which is listed in table 3.

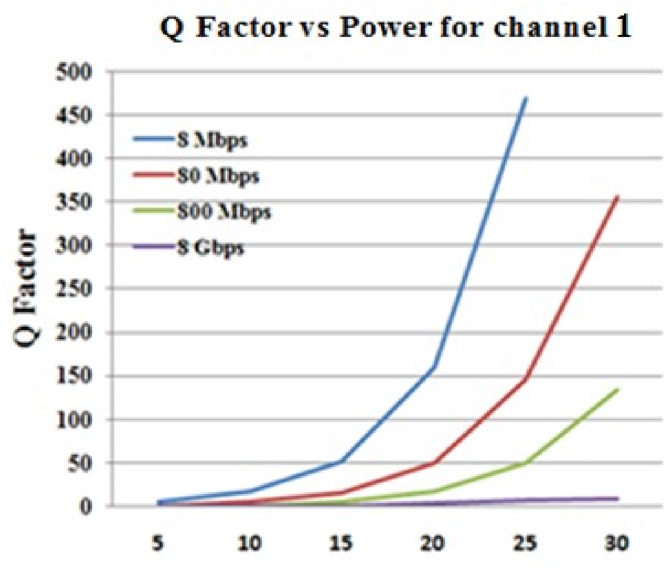

Fig 6. Q factor vs Transmitted Powers for different bit rates.

Finally we investigate that for optical wireless intersatellite communication link of bit rate 8 Mbps we have to transmit a minimum power of 10.440 dBm to achieve a error free communication. Similarly for IsOWC communication link working at 80 Mbps, the minimum transmitted value for each channels are calculated which are listed in table 3. Now at bit rate of 80 Mbps minimum transmitted power of 15.651 dBm is required and for bit rates of 800 Mbps minimum value of power needed is 20.847 dBm. At last investigation for a bit rate of 8 Gbps is done and minimum total output signal power is calculated is 20.83 dBm. The minimum values of transmitted power for each channel for different four different bit rates are listed in table.3.

TABLE 2. TECHNICAL DATA OF MINIMUM POWER REQUIRED FOR DIFFERENT BIT RATES.

Bit Rates (Gbps)	Minimum required value of Transmitted Power. (dBm)
0.008	10.440
0.08	15.651
0.8	20.847
8	28.83

TABLE 3. TECHNICAL DATA OF MINIMUM TRANSMITTED POWERS FOR 8 CHANNELS IsOWC LINK FOR DIFFERENT BIT RATES.

Bit Rates (Gbps)	Minimized Transmitted Power (dBm)							
	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
0.008	4.87	4.6	5.2	4.8	5.6	5.1	5	5
0.08	9.95	9.75	10.20	9.80	10.56	10.22	10.87	10.42
0.8	15.58	15.21	15.37	15.75	15.2	15.34	15.51	15.46
8	23.75	22.3	23.3	23.6	23.23	24.00	24.16	22.73

IV. CONCLUSION

The results of the simulation for 8 channel ISOWC system model are presented and discussed. The effect of transmitted power on IsOWC link range is discussed. Transmitted powers are set at four values 5, 10, 15 and 20 dbm . In this model we investigates that to achieve error-free communication (BER < 10^{-9}) in our system, for a transmitted power of 20 dbm we have link range of intersatellite of 5300 km and for 5 dbm distance remains 950 km only. Next we minimizes the transmitted power for different bit rates, for a bit rate of 8 Mbps minimum power required is10.440 dBm, for 80 Mbps it is 15.651 dBm, for 800 Mbps it is 20.847 dBm and for 8 Gbps it is 28.83 dBm. We also investigate the minimum value of power needed for each channel for different bit rates. Reduction in laser power could improve overall system performances and cost**.**

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