Investigations on Aperture Diameter of Telescope in Intersatellite Optical Wireless communication system

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ABSTRACT

Optical communications link have evolved from lengthy fibers to wireless system such as intersatellite transmission system, for which transmission capacity and distance of optical signal are always an important consideration factor to improve the performance of the optical wireless transmission system. This paper investigates the effect of bit rates on link distance. We have taken bit rates from 8 Mbps to 8 Gbps for an 8 channel optical wireless communication (IsOWC) system. The effect of transmitter and receiver apertures diameters on interstellite distance are also analyzed in this paper. The value of aperture diameters varies from 15 cm to 50 cm and further results are observed fot bit rate of 800 Mbps. The simulation results recommended that for lower bit rates and for large aperture diameters we can achieve a high value of Q factor.

Keywords - **Inter-satellite optical wireless communication (IsOWC), Q-factor, bit error rate (BER), Wavelength Division Multiplexing (WDM).**

1. INTRODUCTION

Optical wireless communication is a concept of transmitting information through air with light as a carrier wave. . The traditional satellite communication links are built by microwave. In recent years intersatellite communication are becoming very important as it has several advantages over traditional microwave links. Transmission at such frequencies provide following advantages: high data transmit rate, high bandwidth, small optical antenna size and weight, narrow field of view, narrow laser emit beam, power efficiency, high precision, less power consumption, high security and resistance to interference[1][2]. 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. For intersatellite communications, signal need to travel thousands of kilometers from one satellite to another. If RF system is to be employed, the size of the transmitting and receiving antenna that is needed would be very big (about meters wide) and also heavy, compared to using optical link that would only need an optical antenna of several centimeters higher in size. Reducing size and weight of the satellite's payload can reduce the cost of the satellite. In order to establish optical communication between twosatellites the line of sight of their optics must be aligned during the entire time of communication. In order to meet this requirement the satellites use the Ephemerides data (the position of the satellite according to the orbit equation) for rough pointing, and a tracking system for fine pointing to the other satellite. The basic and popular method of tracking between satellites includes use of a beacon signal on one satellite and a quadrant detector and tracking system at the other satellite [3]. In 2001, the world-first optical intersatellite communication 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]. In 2006, the Japanese Space Agency (JAXA) demonstrated a bidirectional optical link between its Optical Inter-Orbit Communications Engineering Test Satellite and ARTEMIS, and in 2008, the German Space Agency (DLR) established an inter satellite link between the near-field infrared experiment and TerraSAR-X satellites already based on the second generation of laser communication technology. In this paper, we investigate high capacity optical wireless inter satellite communication link by integrating wavelength-division-multiplexing (WDM) technology. Investigation of 8- channel WDM optical wireless transmission system is done in which the wavelengths of 8 channels ranges from 193.1 THz - 193.8 THz with a fixed channel spacing of 100GHz and the bit-rate of each channel is 100 Mbps .

2. SYSTEM MODEL

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 THz - 193.8 THz with a fixed channel spacing of 100 GHz is taken. An optical communication system consists of transmitter, communication channel and receiver.

2.1 TRANSMITTER

The role of the optical transmitter is to convert the electrical signal into optical form [5]. The transmitter takes information from satellite's telementary, tracking and communication (TT&C) 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 ILD 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 NRZ pulse generator a non return to zero coded signals. The rise and fall time of NRZ pulse generator is 0.05 bit. The Mach Zehnder modulator has an extinction ratio of 30 db. Here 8 such transmitter blocks are used, and 8×1MUX is used to send the light signal through wireless channel. Optical antennae or optical lenses can be used at the transmitter and the receiver.

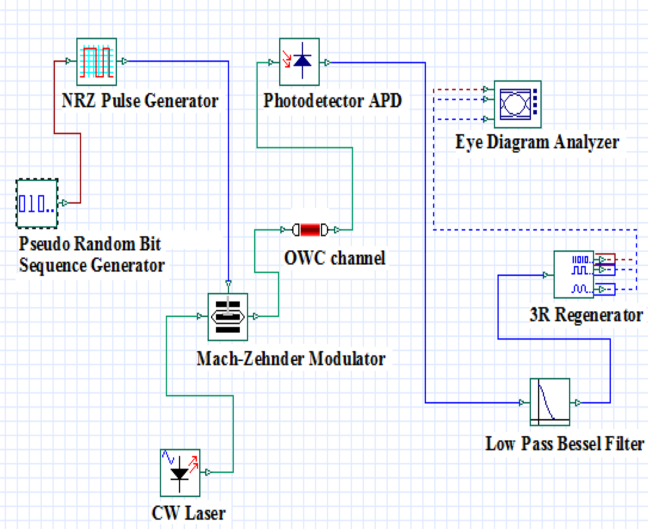

Fig.1. IsOWC simplex design model

2.2 OPTICAL WIRELESS CHANNEL.

The optical wireless channel can also be 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 gain by:

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

where **θ** is the radial pointing error angle. This factor defines the attenuation of the received signal due to inaccurate pointing. The free space between two connecting satellites is considered as OWC channel which is the propagating medium for the transmitted light. In the OptiSystem software, the OWC channel is between an optical transmitter and optical receiver with 15 cm optical antenna at each end. Additional losses from scintillation and mispointing are assumed to be zero. The transmitter and receiver optics efficiency is taken as 1. Due to the altitude of the satellites that is above the Earth's atmospheric layers, there is no attenuation due to atmospheric effects.

2.3 RECIEVER

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 have 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. Filter is used to to remove all the unwanted frequencies. 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 Visualize (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.

2.4 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. The 8 sub systems at transmitter side consist of components as shown in fig.3. 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 visualizer (eye diagram analyzer). The purpose of creating subsystems is only for clarity.

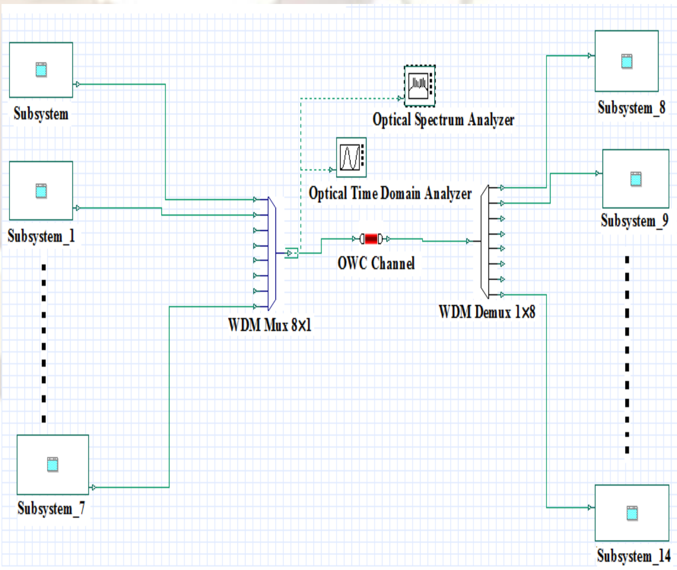

Fig.2. Simulation Model of 8-Channel WDM System for intersatellite optical link.

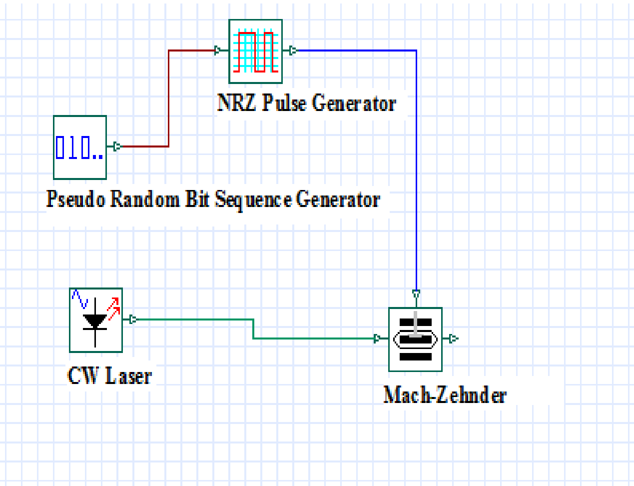

Fig.3. The structure of sub system at transmitter side.

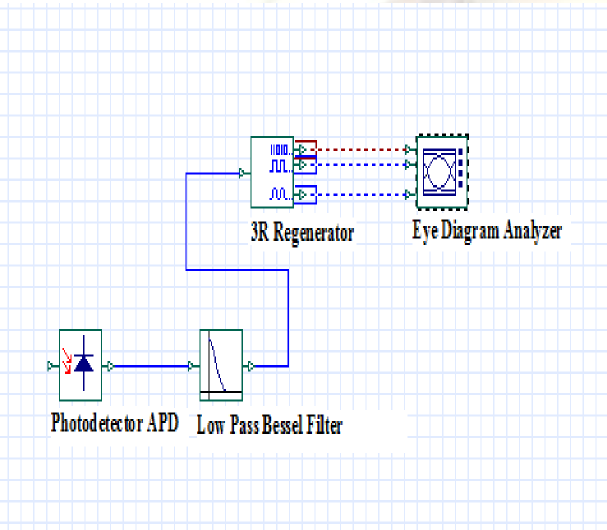

Fig.4. The structure of a subsystem at receiver side.

3. RESULTS AND DISCUSSION

3.1. RELATIONSHIP BETWEEN Q FACTOR AND BIT RATE WITH DISTANCE OF INTERSATELLITE COMMUNICATION.

By varying distance between intersatellite communication network for different bit rates, the value of Q factor is obtained and a graph is plotted the link distance varies from 1000 km to 5000 km as shown in fig.5. The input power is maintained at 12 dbm. In this model 8 channels are taken with inter channel spacing of 100 GHz and bandwidth of 800 GHz. With references to previous research [6], capacity of the inter satellite model and bit rates are increased in this model their effect on link distance is investigated. As we increase the distance between satellites, the value of Q factor is decreased at fixed bit rate. Graph is plotted for different bit rates between q factor and link distance. To achieve error-free communication (BER < 10^{-9}) in our system, we also investigated the maximum possible link distance between two satellites. For bit rate of 8 Mbps maximum communication distance is 11,500 km. When we increase the distance beyond this value our BER also increases. It is further investigated that for bit rate of 80 Mbps the distance comes out to be 6500 km and for 800 Mbps bit rate distance comes out to be 3550 km. For very high data rate such as for bit rate 8 Gps the link distance becomes only 2100 km. It was analyzed that as we increase the bit rates the link distance decreases. The bit rate is inversely proportional to link distance. From the simulations it is investigated that for link distance of 11,500 km, IsOWC can only be received at bit rate of 8 Mbps only and for higher bit rate of 8 Gbps link distance reduces to 2100 km [6]. Therefore, in order to send signals at higher data rate over a longer distance, higher input power is needed or amplification can be done either at the transmitter or at the receiver.

Table1. Technical data of maximum distance achievable for difference bit rates.

Bit rates (Mbps)	Max.Distance (km)	Q factor	Min. BER
8 Mbps	11,500 km	5.69907	5.99×10^{-9}
80 Mbps	6500 km	5.63288	8.82×10^{-9}
800 Mbps	3550 km	5.93674	1.44×10^{-9}
8 Gbps	2100 km	5.67415	6.94×10^{-9}

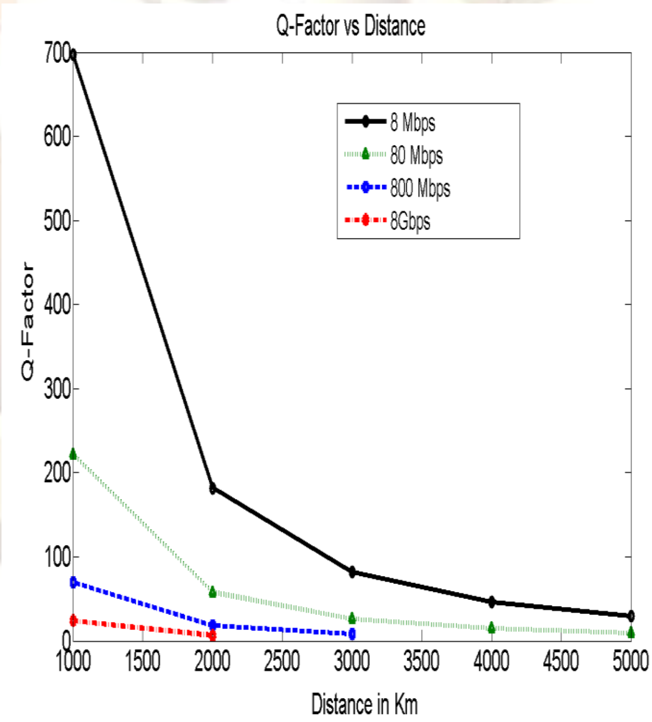

Fig.5. Relationship between Q factor and link distance for different bit rate.

3.2 RELATIONSHIP BETWEEN Q FACTOR AND APERTURE DIAMETERS OF TELESCOPE WITH DISTANCE OF INTERSATELLITE.

Here we have taken transmitter and receiver aperture diameters of same values. The effect of both is studied by plotting two graphs, one for transmitter aperture and second for receiver's aperture. Fig.6. graph is plotted between Q factor and intersatellite distance with transmitter aperture diameter as a variable. Transmitter aperture diameters were set at four values which are 15 cm, 26 cm, 38 cm, 50 cm and the link distance was set from 1000 km to 5000 km. We analyzed from graph that as we increase the aperture diameter, Q factor also increases for a fixed value of distance. But when we increase the distance our Q factor starts decreasing. Graph below shows the relationship between Q factor and link distance for multiple aperture diameters. It can be observed that aperture diameters are directly proportional to Q factor. Further investigation reports that for a fixed date rate and input power of 12 dbm, when we adjust our transmitter and receiver aperture diameters at 15 cm value for data rate of 800 Mbps we can obtain error free communication (BER < 10^{-9}) up to a distance of 2000 km only. Then we set the value of aperture diameters at 26 cm [6] and now distance comes out to be 6000 km, for 38 cm it comes 13000 km and for 50 cm the distance becomes 22,500 km. It is observed that as we increase the aperture diameters, Q factor increases and so our link distance. It is further investigated that for a fixed data rate, if we want to increase link distance we have to either increase the aperture diameters or transmitted power [6]. For LEO to LEO intersatellite links we can achieve successful communication for aperture diameters having value of 26 cm for bit rate of 800 Mbps. For higher data rates we have to either increase aperture diameters or transmitted power.

Table2.Technical data of maximum achievable distance for different transmitter and receiver aperture diameters.

Aperture diameters (cm)	Maximum distance (km)
15	2000
26	6000
38	13,000
50	22,500

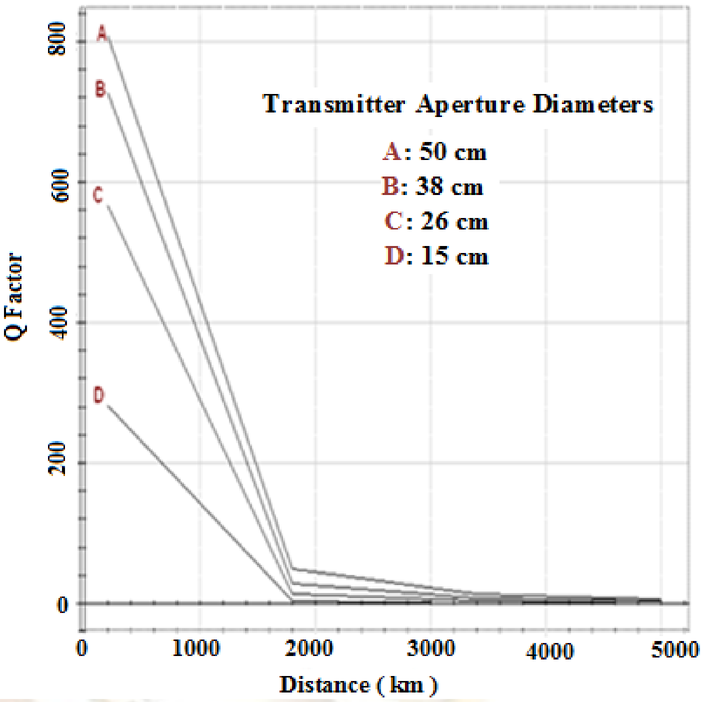

Fig.6. Q factor plots for four transmitter aperture diameters with variable link distance.

Second graph is plotted for receiver's aperture. In same way we set receiver aperture diameters at same four values which are 15 cm, 26 cm, 38 cm, 50 cm and link distance was set from 1000 km to 5000 km. We get the graph as shown below.

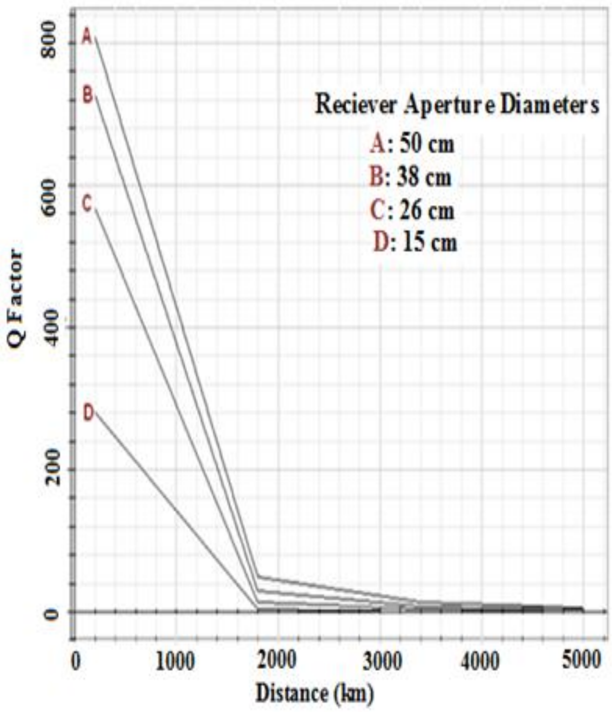

Fig.6. Q factor plots for four receiver aperture diameters with variable link distance.

4. CONCLUSION

The results of the simulation for 8 channel IsOWC system model are presented and discussed. The system performance was analyzed when several parameters of the system characteristics are varied. The effect of bit rates on system performance is discussed. Bit rates are set at four values 8 Mbps, 80 Mbps, 800 Mbps and 8 Gbps and it is observed that to attain a long distance transmission we have to use low bit rates. In this mode we investigates that to we achieve error-free communication (BER < 10^{-9}) in our system for a bit rate of 8 Mbps we have link distance of intersatellite of 11,500 km and for 8 Gbps distance remains 2100 km only. From the IsOWC model and simulation results, it can be concluded that signals with smaller bit rate travel further than the one with higher bit rate. Next we analyzed the impact of transmitter and receiver apertures on link distance and on Q factor of our system. It is further investigated that for a bit rate of 800 Mbps as we increase the aperture diameters from 15 cm to 50 cm, the link distance varies from 2000 km to 22,500 km. For aperture diameter of 50 cm we can achieve error-free communication up to 22,500 km. As we increase our aperture diameters Q factor increases, but for a particular aperture diameter Q factor starts decreasing as we increase the link distance and bit rates.

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