



Review on Inter-satellite Optical Wireless Communication system

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Abstract: Inter-satellite optical wireless communication has attained recognition in small time due to its innumerable advantages as compared to its RF counterpart. This study includes system description of Is-OWC system with study of different parameters which effects system performance along with applications and advantages of utilizing this technology.

Keywords: OWC, wavelength, modulation format, filter selection.

I. Introduction

With increase in the number of users, we have witnessed a tremendous increase in demand of bandwidth too. Now-a-days user wants broadband wireless services for example video calls, high speed for internet, high definition TV etc all requiring a huge amount of bandwidth. Some of the solutions are microwave communication; RF based cellular communication, FTTH, etc. All these suffer from various shortcomings like limited bandwidth, congested spectrum, very expensive licensing, and higher installation costs. OWC is a promising solution to this problem. In satellite communication also this problem of bandwidth limitation occurs. As per a report published in 2009, there were approximately 6124 satellites in space and this number has increased and thus the demand for RF spectrum increased [1]. With improvement lasers are now able to transmit data up to several thousands of kilometers. This opened up the idea of Inter-satellite Optical Wireless Communication (Is-OWC). In Is-OWC the ground station and satellite link remains in microwave regime, but link joining two satellites in space is replaced by optical signal [2]. There benefits of doing this are like; relaying GEO satellites with LEO satellites, lesser delay, light weight payload and higher bandwidth. This technology is most viable technology for the current scenario.

Optical Wireless Communication predominantly has two categories, outdoor and indoor OWC. Indoor OWC consist of LOS, non LOS, diffused and tracked links. Outdoor OWC has two sub-categories; terrestrial and space communication. These include satellite-to-ground and vice-versa, satellite-to-satellite communication etc. The first theoretical study was done by Fried (1967), and after that various theoretical studies were suggested. Some of the earlier ground-to-satellite communication experiments include uplink based RME (1990) and GOPEX (1992), two way communication link GOLD (1995). The first Inter Satellite Link (ISL) was established between SPOT-4 and ARTEMIS by European Space Agency. Later a link between a KIRARI and ARTEMIS was successfully built in 2005. In 2008, Terra SAR-X and NFIRE were linked using

optical communication. Several other experiments have been performed till now in the area of Inter-satellite Optical Wireless Communication (Is-OWC) systems and research is still going on to improve system performances.[3]

II. Related Work

By assuming all LEO transponders synchronized and have LOS, the effect of changing bit rate and link distance between satellites on system performance was studied as these are the most dominating factors. Distance was varied from 0 to 5000 km and bit rate was set from 1 Mbps to 10 Gbps. It was concluded that by increasing distance and bit rate system needs improvement for proper functioning as Q was below 5 and BER more than 10^{-5} also, received signal. [4]

The received power was calculated for a system engaging space diversity. For single Transmitter-Receiver, the received power was evaluated to be -37dBm and when diversity with four Transmitter-Receiver pairs was engaged, the received power was -25dBm and BER obtained was 10^{-16} [5].

The outcome of engaging modulation format QPSK on inter-satellite system performance was studied. A changing coverage distance of 4767, 7542 and 9532 km for bit-rate 400,160,100 Gbps respectively was achieved using 30 dBm power which proved that advanced modulation format QPSK give better performance when compared to BPSK in such systems [6].

A system was modeled with aperture diameter of 15cm, laser linewidth 5 MHz, link distance 1000 km and wavelength 850 and 1550 nm. Results demonstrated that SNR reduction, from 54 dB to the value 2 dB at wavelength 850 nm and 48 dB to 2 dB at 1550 nm, Received power was [-39,-80,-87.5 dBm] and [-48,-85,-88 dBm] at distance of 40 km, 500 km and 1000 km at a wavelength of 850 and 1550 nm respectively [7].

A link model between satellites was suggested in free space over LEO to recognize maximum bit-rate also; the effects of changing wavelength were studied on ISL performance recognizing high bit-rates. NRZ modulation was used being a superlative scheme at that time for obtaining maximum coverage distance of the link. This research was concentrated on bit rates transferred between LEO links. For wavelength 1550nm Q, BER and received power was 4.5,10⁻⁶ and -30.09 respectively for link length 1000 kilometers and -39.62 for 3000 km. For 860 nm, received power

obtained was -24.96 for 1000 kilometers and -34.50 for 3000 kilometers. [8]

With the motive to find optimal modulation format for Low power Is-OWC work was done using NRZ, RZ, DRZ, CSRZ employing SOA. FEC threshold was set to BER 10^{-12} and Q was 6.8. It was noticed that CSRZ can increase link distance up to 1300 km above FEC threshold while others were not able to attain threshold.[9].

Space and polarization diversity was employed using NRZ as modulation format, data rate was varied from 1 to 15Gbps, power from 15 to 25 dbm, also taking pointing errors and additional losses under consideration. A distance of 6000 km was achieved with received signal power of 51dbm below transmitted signal. Also for 7.63 Gbps, Q obtained was 6.8 and BER was 5.08×10^{-12} . It was also claimed that combination of space and polarization diversity can improve the system as link distance using these was 6000 km while without diversity it was 2083km [10] DWDM based system was modeled for low power Is-OWC. Role of EDFA was analyzed and it was presented that RZ was better than NRZ for long distance communication. Their system model included a 20 channel DWDM system for a distance of 1000 km with NRZ modulation is implemented at 1541-1560 nm. It was proved that EDFA reduces BER and increases Q. With 0 dBm power BER is approximately 10^{-291} , Q= 36.44 at 1559 nm [11].

III. System Description

The whole system is split up into three parts; Transmitter or Satellite 1, transmission channel and Receiving transponder or satellite 2. Transmitter incorporates a digital data source, a light source both are connected to a modulator which modulates the optical laser signal externally in accordance with system requirements. The digital data source is a PRBS Generator followed by a pulse generator.

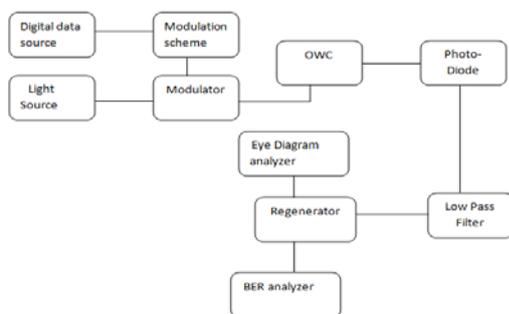


Fig 1: Inter-satellite Optical Wireless Communication (Is-OWC) System

The light sources used are basically laser diodes as they produce highly directional beams thus able to cover large distances. The laser used here is Continuous Wave Laser due to its coherent, monochromatic, highly directional beam characteristics. Modulation is

performed either directly or externally. These are further categorized like Intensity modulation, Frequency modulation and Phase modulation. External modulation is performed by utilizing continuous bias of optical device and a circuit where modulation takes place. This is a costly process but it has numerous advantages.

The free space between receiver and transmitter is Optical Wireless Channel. It is considered to be ideal but practically there is presence of pointing errors [12]. Different from FSO, OWC includes unguided Visible, Infrared or Ultraviolet light. For Is-OWC system, Line-of-Sight is required between transmitter and receiver. [13]

Receiver includes Photodiodes, Filter, and Regenerator. Photodiode working as transducer; converts optical signal to electrical signal. The received power of the system is given by

$$P_r = P_t \eta_t \eta_r G_t G_r L_t L_r (\lambda / 4\pi Z)^2 \dots(1)$$

Where G_t, G_r are transmitting gain and receiving gain and are given by equation (3) and (4) L_t, L_r are transmitter pointing loss factor and receiver pointing loss factor and are given by (5) and (6) and Z is the link distance.

$$G_t = (\pi D_t / \lambda)^2 \dots\dots\dots(2)$$

$$G_r = (\pi D_r / \lambda)^2 \dots\dots\dots(3)$$

$$L_t = \exp(-G_t / \theta_t^2) \dots\dots\dots(4)$$

$$L_r = \exp(-G_r / \theta_r^2) \dots\dots\dots(5)$$

IV. Different Parameters effecting Is-OWC system

- a. **Wavelength:** Space- based optical applications chose wavelength on the basis of a trade between receiver sensitivity and pointing bias due to thermal variations, longer wavelength also helps to reduce solar scattering [3]. The international Commission on Illumination specified three types of Optical radiation [16] as:

Table 1: Classification of optical radiation

Category	Wavelength
IR-A	700-1400nm
IR-B	1400-3000nm
IR-C	3000nm-1mm

They are further sub-classified as: Near Infrared ranging from 750-1450 nm for fiber optics, Short Infrared whose range is 1400 – 3000 nm out of which 1530-1560 nm is to cover longer distance, Mid Infrared from 3000-8000 nm is for Military applications. But 1550 nm is most exploited wavelength as longer the wavelength lesser will be the bad impacts of Rayleigh and Mie scattering also it is compatible with existing equipments [5].

- c. **Modulation Formats:** several different modulation formats can be exploited in these systems. Previously,

NRZ was a dominating format under study for the strong technical background of it. Now a days focus is on exploiting advanced formats like Carrier-suppressed Return-to-Zero, Differential Phase shift keying, Differential Quadrature phase shift keying etc to make a robust system.

- b. Power Levels:** By increasing power level, system performance can be improved. Also in inter-satellite communication eye safety regulations are not to be considered. However practically, there are restrictions related to system components which impose a limit on input power levels of the system and thus one cannot increase the power infinitely. **Data Rate:** The effect of varying data rate at wavelength 1550 nm and changing distance from 200 to 1200 kilometers in [17]. It was observed that for high data rates and increasing distances values of quality factor, SNR reduces. The results of study shows that Q was 275 at 1 Gbps and 82 at 5 Gbps and similarly SNR varies from 48 to 23 as data rate changes from 1 to 5 Gbps with corresponding change in distance. With advancements in technology data rates have been increased.
- c. Filter selection:** The purpose of utilizing an electronic filter in Is-OWC system is to accept required signal and reject all other noises. Low Pass Bessel filter with cut-off frequency $0.75 \times \text{Bit rate}$ is the most commonly used filter in Is-OWC. The effect of using different filters on system performance in terms of Q-factor and BER, Results from different studies like [18] show that Bessel, Cosine Roll off and Gaussian filters are best for Is-OWC.
- e. Aperture diameter:** The aperture diameter of transmitting and receiving antenna plays an important role in such systems where the mode of transmission is wireless. The major advantage of using light as carrier for information transfer is that antennas with small aperture diameters are required which leads to light weight and easily manageable systems.

IV. Advantages

- a. High data rates and speed:** It provides very high rates of data transmission and high speed of communication. Several Gbps of transmission rates are reported in this area.
- b. Unregulated spectrum:** the spectrum available for optical system is unrestricted and is 10,000 times more than RF rays. RF rays have been exploited in number of ways and now there is a strong need to find its suitable replacement in possible areas. Also RF spectrum is highly expensive. [19]
- c. Reduced Delay:** As GEO satellites which are present at a height of 35768KM above Earth produces greater delay when connected to ground stations. In order to lower this delay, they are relayed with LEO satellites present at a height of approximately 1000KM via optical links in order to reduce delay.
- d. Lesser weight:** Is-OWC reduces the area of payload and weight of satellites because components required

are compact and light in weight as compared to RF based satellite communication.

- e. Narrow Beam Width:** RF wavelengths are longer than optical wavelength thus the beam produced by optical wavelength is narrower but also a highly accurate tracking system is required for proper alignment of satellites.
- f. Reduced Cost:** Once established, it has low maintenance cost as system components have longer life times as compared to RF communication.
- g. Easy Configuration:** It is easy to reconfigure the Is-OWC network if required in case of any kind of network failure or Outage. It has easier deploy and redeployment available.

V. Applications

- a. In space activities:** An OWC link could be a better option for information interchange, experimental data sharing, high rate internet accessibility in space planes.[20]
- b. In earth monitoring missions:** they need more precise and high resolution systems onboard. In present scenario data rates of several gigabits are acquired by satellites and one single satellite does not work for one specific area but covers entire earth, so Gbps class systems are obvious requirements [21].
- c. In meta-galactic space activities:** where the weight, power and volume of onboard equipments are very much limited. One of the obvious solutions is to use a considerably huge aperture optical platform or a relay system which is a small user terminal. This would deliver an effective backbone communication station, unaffected by visibility conditions of the earth stations [22]
- d. Communication within satellites:** Many satellites are working around earth and their work is divided among various satellites, so a robust network is needed to convey data with each other. This needs proper control and synchronization and Is-OWC is best alternative to achieve this.

V. Conclusion

There are various advantages of using OWC instead of RF in space communications such as lightweight circuitry, easy reconfiguration etc along with numerous applications. Is-OWC system can be improved by using different ways such as advanced modulation formats, diversity techniques. More improvement in terms of capacity, interference reduction etc should be studied here.

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