A Brief Study of Advantages and Limitations of Inter-satellite Optical Wireless Systems

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Abstract : Inter-Satellite communication link is effective techniques to established a link between various satellites in different earth orbits such as lower , medium and geosynchronous. IsOWC is an attractive and innovative technique in which high frequency laser beams are used to transmit high data rate signals to longer link distances. In this paper, a review of IsOWC links is discussed keeping into considerations of various advantages and disadvantages of inter-satellite communication systems. Performance of IsOWC links depends upon three main factors such as operating wavelength, antenna size and distance between satellites orbits. This work is also emphasized on the various suggested techniques to eliminate degrading factors of IsOWC systems.

IndexTerms **- Optical wireless communication, wavelength division multiplexing, data rate, LEO, MEO, GEO, attenuation, range, pointing errors.**

DEVELOPMENT OF ISOWC SYSTEMS

Inter-satellite Optical wireless communication (IsOWC) is a point to point communication .It is attractive and effective technique to achieve a very high data rate. Due to development in wired and wireless devices with high data rate and high speed it is obvious to some changes in our environment system [1]. Based on wired and wireless data transmission microwave and RF frequency generally used to transmit signals at high data rate and high speed but normally they suffer from insufficient radiations reach at receiver end and due to this reason they achieved a less data rate at destination end [2]. Due to this reason these technologies are replaced by optical wireless technology. IsOWC technology has numerous benefits over RF and microwave communication. In IsOWC links signals are transmitted at high data rate, large bandwidth, less power, high efficiency, lesser antenna sizes, low cost and without any license spectrum. These advantages made the IsOWC technology different from others technologies [3]. Tracking and misalignment problem between transmitter and receiver apertures are major drawbacks occurred in IsOWC. Transmitter and receiver apertures changes due to atmospheric conditions. Laser relative noise intensity creates various tracking problems. Johnson noise, dark current noise, Vibration noises are widely degrades the performance of IsOWC communication system. Although, communication system faces a major problem of laser lifetime, but our main focus is to reduce the power dissipation and BER. This result in high transmitter power and lesser receiver noise to obtain desired signal [4]. IsOWC has provided effective solution to achieve a better connectivity between transmitter and receiver at long distance, by fiber optic communications, and inter-space laser connections. Indoor optical remote communication is referred as remote infrared communication whereas outdoor optical remote communication is referred as wireless optical communication. Main significant applications of wireless optics is that of inter-satellite optical wireless communication (IsOWC) system transmitted between satellite and space interchanges at short range. But applications of wireless infrared communication do not required a directed links and alignment between transmitter-receiver line-of-sight (LOS) and diffuse links are mainly used in wireless infrared communication. LOS links require a dedicated path for hassle-free communication whereas diffuse links require multiple optical paths from surface reflections. IsOWC provides a connection between transmitter and receiver by using directed LOS and point-to-point laser links. It also provides potentials of broadband communication capacity with unlicensed optical wavelengths. Due to different temperature and atmospheric pressure refractive index varied in transmission path, these refractive index variations creates spatial and temporal variations in the optical intensity at destination end which result a fading problem. This problem degrades the system problems by increasing bit error rate (BER) and transmission delays.

In IsOWC, signals are transmitted at longer distance with high information rate and less constriction using light wave transmission of 3×10^8 m/s and optical connection over radio frequency (RF) technology. To reduce attenuation loss in entire communication process OWC systems prefers over RF wavelength compared to lasers in terms of beam-width. IsOWC systems provide high security due to which deployment of these systems is increasing. Therefore it is compatible with any advanced sensor communication system.

A BRIEF ABOUT SATELLITES

A satellite is a movable object which revolves another object in circular way in space. This space segment is the combination of three separate units such as fuel system, satellite and telemetry controls, and the transponder. The transponder includes the receiving antenna for getting earth station signals, broad band receiver, an input multiplexer, and frequency converter which is used for downlink transmission using high powered amplifier. Telecom satellites are used to receive a signals from a ground station and again retransmit to another ground station which is located at some distance away from the first ground station. Another main purpose of satellite to broadcasts a television signals from uplink ground station's to down link ground station over

large coverage area. So, many customers received required information through satellite communication. The Moon is revolves around the Earth and the Earth is a revolves the Sun. The Moon is satellite of the Earth and the Earth is satellite of the sun. Satellites is classified into two types: (a) Natural satellites (b) Manmade satellites. A natural satellite is defined as natural object which revolves around orbits of a particular planet. Moon is only one natural satellite of our earth. Some other planets have more than one natural satellite. Satellites which are sent by humans in the space referred as manmade satellites. Satellites further classified into two types: active satellite and passive satellite. In the passive satellite system uses a beams power at the reflector, the receiving ground system receives a fraction of the power that has been intercepted by the reflector and reradiated. In active satellites, the satellites receive a fraction of the energy beamed toward it by the ground transmitting system and the received power is amplified by active electronics means, usually in conjunction with frequency shifting.

OPTICAL ORBITS FOR SATELLITE COMMUNICATION

The route or the path that object follows around a star or planet is referred to as the orbit of communication. The size and shape of the orbit is ellipse and placement of the satellite is in the two focus of ellipse. Figure 1 shows the satellite orbits revolving around the Earth. According to its distance or height, orbits are divided into three categories like;

- Low Earth Orbit (LEO)
- Medium Earth Orbit (MEO)
- Geosynchronous Earth Orbit (GEO)
- Now the separation of the satellite orbits is based on its distance from the ground. Upto the distance of 1000 km, a orbit is called as the lower obit of earth. Earth orbit that is at lower distance is tries to be in circular shape. As the distance or height increasing from earth or ground, typical at the height of 5000 km to 25000 km, is called as the Medium Earth Orbit (MEO). Medium earth communication plays an important role in large distance satellite surveillance. Geosynchronous satellites are place in GEO orbit and typically at the height more than 36000 km. The placing time of satellite in this orbit is 24 hours. Three satellites in GEO placed 120^0 apart from equator cover most of the world for communications purposes [18].

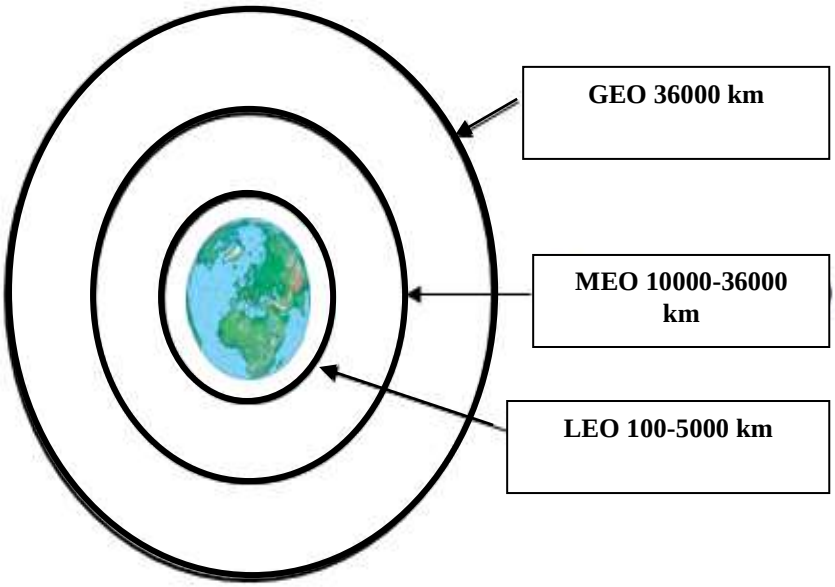

Figure 1 Earth Satellite Communication Orbits

HISTORY OF SATELLITES

In 1977, European space agency (ESA) had demonstrated a modulator to provide high data rate laser links in space. This is the first investigation and involvement of ESA in space optical communications. ESA R&D investigated a more hardware developments in optical communication .In mid 1980 ESA studied more optical device and its development in space like semiconductor laser inter-satellite link experiment (SILEX) program, to demonstrate a preoperational optical communication link in space. In 2001, investigated a first optical link between Advanced Relay and Technology Mission Satellite (ARTEMIS) and SPOT-4, from that period of time optical communication technologies mastered in space. In 2006, the Japanese Space Aatgency (JAXA) provided a more information of optical data signal in space and demonstrated bidirectional optical link between its Optical Inter-Orbit Communications Engineering Test Satellite and ARTEMIS. In year 2008, the German Space Agency (DLR) by using second generation of laser communication technology established an inter satellite link between the near-field infrared experiment and TerraSAR-X satellites. In March 2003, SILEX continually worked at optical communication inter-satellite links. ESA providing a lot of work on optical communication links and getting a leading position in world optical agencies .In 1993, the Japanese Space Agency National Space Development Agency (NASDA) and ESA perform optical inter satellite communication

experiments. They investigated second generation equipments which are used in orbit, since 2008. ESA is a backbone of new European Data Relay Satellite (EDRS) system which used from 2013.

REPORTED WORKS

Based on the present work on optical links, various advanced technological application are investigated by government authorities, corporate, and higher academics. The usage of precision pointing and tracking control subsystems in optical inter-satellite communication was researched in 1990 [5]. Due to more development in communication links some noise factors occurred in these links. Various new techniques were proposed to reduce these unwanted factors. To order to reduce a FWM-induced crosstalk, a technique was developed for channel frequency allocation [6]. According to researched work on optical links, large bandwidth data signals face a unequal channel separations without any imposition of four-wave mixing product on the channels. To probe a effectiveness to noise minimization techniques simulation work was performed at 10-channel with 10 Gbps per channel. New techniques were proposed to provide high speed optical satellite networks for integrated space terrestrial network [7]. Optical satellite study introduced new optical wireless inter-satellite links for global networking by using local area networks and wide area networks across the globe. Inter-satellite links connects a more number of communication equipments such as remote sensing satellites, submarines, ships, and Quantum cryptography systems [8]. Another study used laser as a beacon and a transmitter in a pointing control system for inter-satellite laser communication and ranging link [9]. Optical inter-satellite network can also be implementing by wavelength division multiplexing (WDM) technology consisting of a fixed node, high altitude platform (HAP) of 30 Km from the earth's surface, and a mobile node on a LEO orbit communicating between HAP and eight LEO micro satellites [10]. Further study on inter-satellite links described the error performance of heterodyne differential phase-shift keying (DPSK) OWC system under intensity-fluctuated conditions such as turbulence-induced fading and path loss [11]. Laser satellite communication used for inter-satellite and satellite-to-ground communications [12].At longer wavelengths optical inter-satellite communication links provides better performance compared shorter wavelengths [13]. Further study on inter satellite communication described a design of an ultra-high bit-rate (400 Gbps) inter-satellite optical wireless communication (IsOWC) system by using non-diffused link for quadrature phase-shift keying (QPSK) modulation [14] [15]. Another research work investigated inter-satellite link (ISL) which can be implemented between satellites at1000 Km by using 2.5 Gbps data rate with or without square root module (SM) [16].To achieve a better BER at improved SNR ratio SM modules were used at 1550 nm wavelength with less transmitting power at 2.5 Gbps data rate up to1000 Km [17]. At 2.5 Gbps data rate inter-satellite OWC system for establishing ISL of 1000 Km length between satellites [19].

VARIOUS ADVANTAGES OF ISOWC SYSTEMS

1. **License free spectrum:** Inter satellite system are different from radio and microwave syetem because they do not require any licensing spectrum and frequency coronation with other clients. Therefore they do not, suffer any interference from or to other systems. In IsOWC provides high security by using point-to-point laser signal which is extremely difficult to intercept.

2. Compact antenna size: IsOWC links used very less transmitting power by reducing the antenna size with large carrier frequency which reduces the weight of the satellite.

3. Wide Bandwidth: In IsOWC 2000 THz signals are sent over large distance. By using high information capacity these systems are different from radio frequency based communication systems. At high electromagnetic spectrum range they include infrared, visible and ultra violet frequencies, which is greater than the radio frequency[21].

4. **High Directionality** – IsOWC works on extremely narrow beam, which has a diffraction limited divergence of between 0.01 – 0.1μrad. This is only reason for transmitted power concentrated within a very small area.

5. Ultra High Bit Rates – By using high frequency light signals IsOWC provides very high speed communication at high data rate signals.

APPLICATIONS OF ISOWC

IsOWC system is explained based on its several applications.

Data Relay for Inter Orbit Satellites

In IsOWC links three types of satellite orbits are used, we already studied working. But based on its caparison with GEO satellite, orbit always stationary with respect to earth. But on the other hand LEO and MEO satellites orbit are not stationary with respect to earth .They do not exit constantly in earth station's view.

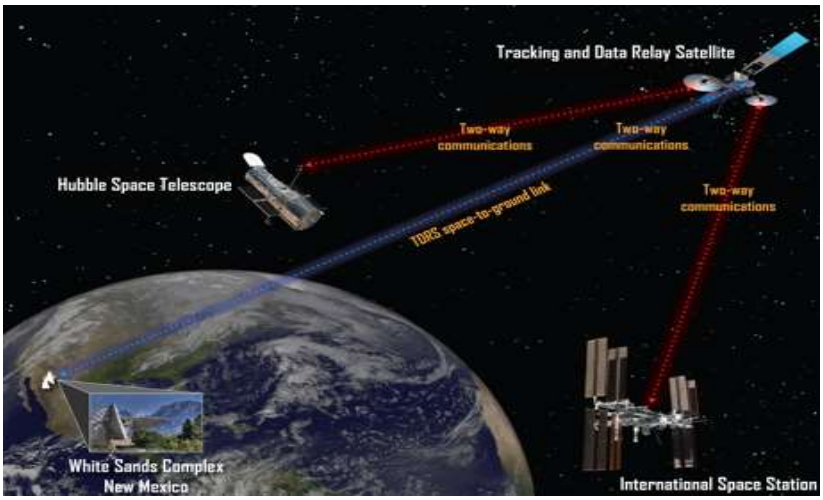

Figure 2 Tracking and Data Relay Satellite communications between the ground and space

By using inter-satellite link, information signal provided to LEO and MEO satellite at any time by using a GEO satellite as relay. Data can also be relayed from one LEO satellite to another if they have line of sight. This configuration explained in Fig 2. Side by side conventional way of relaying data is shown in figure 3 (a) relayed data by using inter-satellite links are shown in figure 3 (b). To transmit a data from earth to satellite, high time Delay degrades the performance of the system which reduces by using IsOWC links.

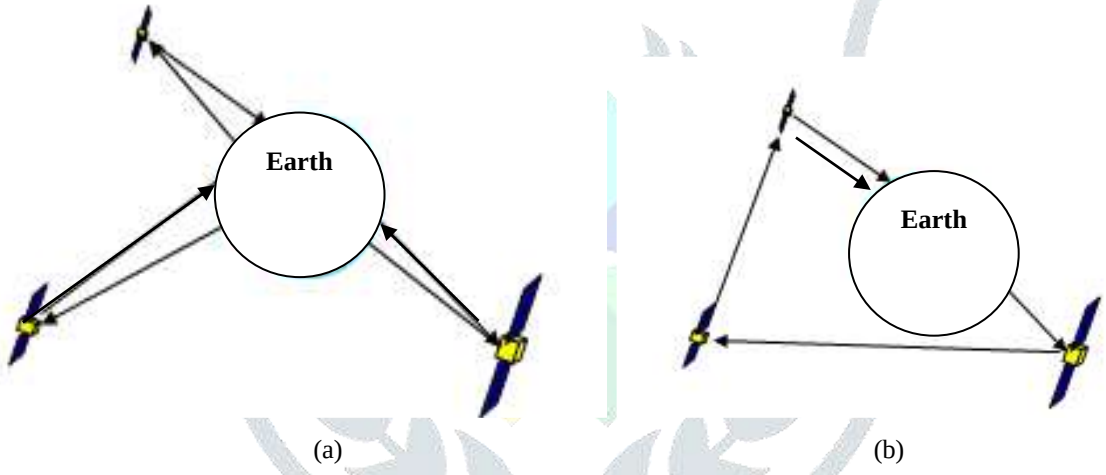

Figure 3 Data relay methods (a) conventional (b) using inter-satellite data relay

To perform a high satellite links with other communication equipments, some missions and applications require more than one satellite such as the global tracking system (GPS) satellites and Iridium satellites. Figure 4 shows constellation of satellites orbiting Earth.

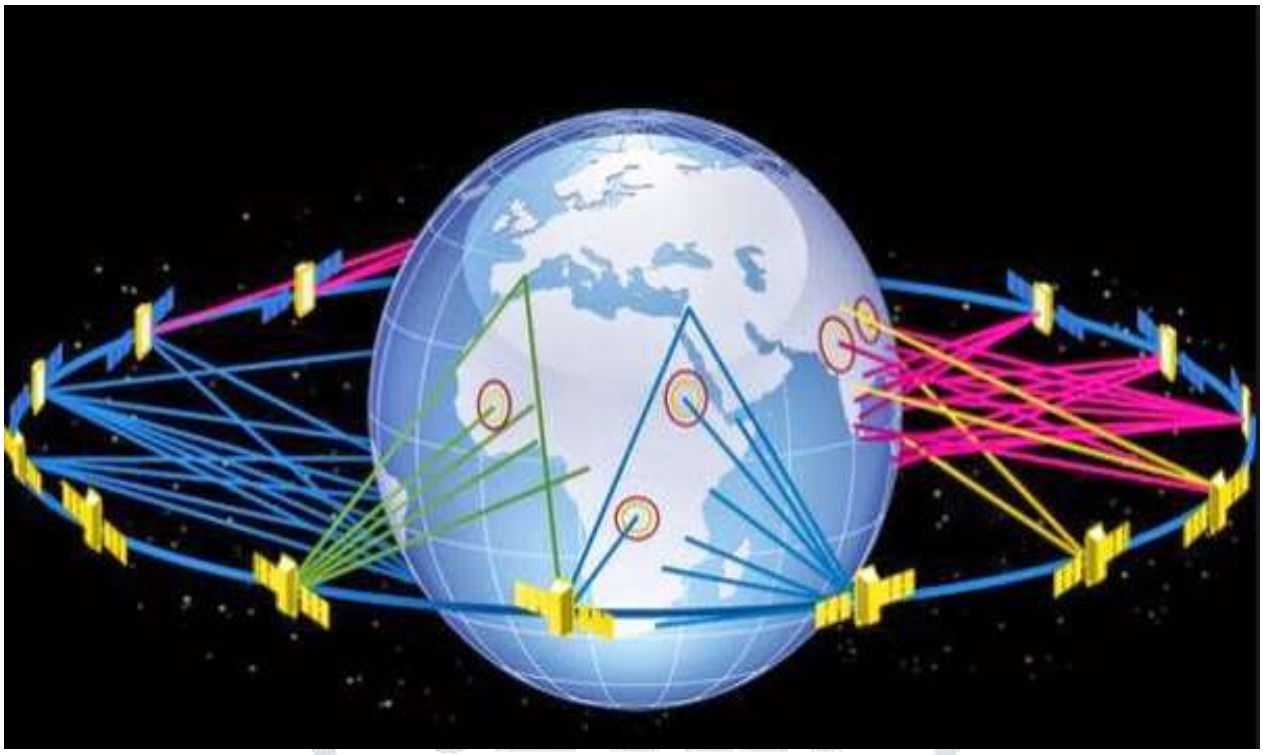

Figure 4 Satellites constellations orbiting around Earth

ADVANTAGES AND DISADVANTAGES

Figure 5 classified optical communication based on wired and wireless systems such as fiber communication and optical wireless communication. Fiber communication uses fiber as communication channel to transmit a high frequency signals. On the other hand wireless communication forward a data signals without fiber. OWC further classified into two main parts such as: Is-OWC and free space optics (FSO). Is-OWC is used for satellite communication and FSO used for ground or terrestrial communication. Based on the reported works on Is-OWC we examined a some disadvantages of IsOWC such as beam divergence, and receiving and transmitting pointing errors which degrade the performance of the system with limiting link length and information rate. Misalignment between transmitter and receiver creates another power reduction problem at receiver end. These further results in pointing losses as shown by the equation below:

$$L_{pointing}=4.3229(\phi/\Omega_0)2$$

In the above equation, ϕe refers to the boundary angle of diffraction which is the limited beam of the transmitter. Beam divergence defined as spreading of beam during its propagation from transmitter to receiver. These drawbacks must be considered by researchers during the design of inter-satellite communication system.

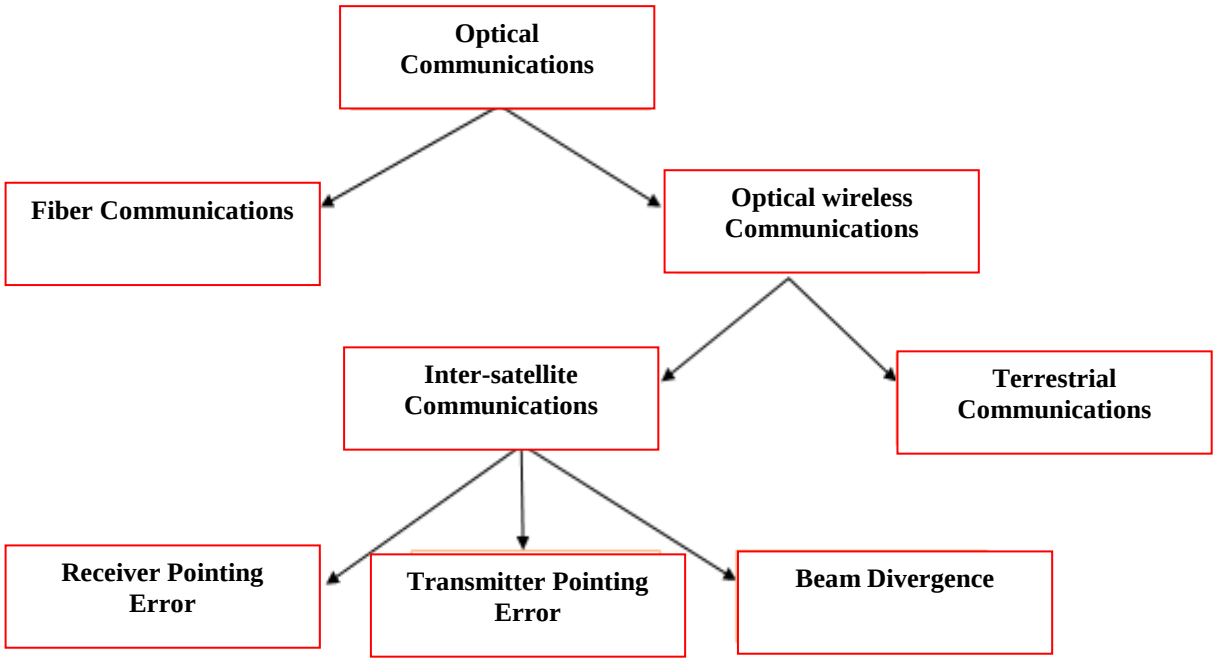

Figure 5 Optical Communications and its different fields

CONCLUSION

Is-OWC is the attractive and effective technique for establishing a communication link between satellites using high frequency carrier signals. Is-OWC communication has numerous benefits but side by side it has some drawbacks such as Turbulences, transmitting pointing errors, receiving pointing errors, beam divergences etc. which degrade the performance of communication links .These attenuation factors must be taken under consideration while designing Is-OWC transmission system.

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