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Enhanced performance analysis of inter-satellite optical-wireless communication (IsOWC) system

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ABSTRACT

In this paper, we have reported the improved performance by usage of a square root module. By simulation in OPTISYSTEM™ a distance of 5000 km with 1.25 Gbps was achieved with the same performance representing an enhancement of 48% when compared to the traditional detection.

1. Introduction

Inter satellite optical wireless communications (IsOWC) systems provide a high bandwidth, small size, light weight, low power and low cost alternative to present microwave satellite systems. The inter satellite optical communications systems will be deployed in space in the near future. The present satellite communications system uses microwave technology for space-to-ground and geosynchronous satellite to low earth orbiting vehicles or platforms. In this future system, the satellite to ground links would remain in the microwave regime. A secondary effort is the development of optical technology for future low earth orbiting (LEO) space communications. Satellites revolve around Earth at their own orbit and there are three commonly used orbits for satellites. Satellite orbits with orbital height of approximately 1000 km or less are known as Low Earth Orbit (LEO). Satellite orbits with orbital heights of typically in the range of 5000 km to about 25,000 km are known as Medium Earth Orbit (MEO). In Geosynchronous Earth Orbit (GEO) the satellite is in equatorial circular orbit with an altitude of 35,786 km and orbital period of 24 h. Three satellites in GEO placed 120° apart over equator cover most of the world for communications purposes [1]. At present there are 6124 satellites orbiting Earth and this number increases year by year [2]. At the same time, the optical wireless communication (OWC) technology has grown and advanced throughout the year. Laser communication is now able to send information at data rates up to several Gbps and at distance of thousands of kilometers apart. This has open up the idea to adapt optical wireless communication technology into space technology, hence IsOWC is developed. IsOWC can be used to connect one satellite to another, whether the satellite is in the same orbit or in different orbits. With light traveling at 3×10^8 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 [3]. By reducing the size of the payload, the mass and the cost of the satellite will also be decreases. Another reason of using optical wireless communications is due to wavelength. RF wavelength is much longer compared to lasers hence the beam width that can be achieved using lasers is narrower than that of the RF system [4]. Due to this reason, Optical wireless communications link results in lower loss compared to RF but it requires a highly accurate tracking system to make sure that the connecting satellites are aligned and have line of sight. In IsOWC different parameter play an important role, one of them is pointing errors. The pointing errors can arise due to mechanical misalignment, errors in tracking systems, or due to mechanical vibrations present in the system. Pointing errors can be thought of being composed of two components: a fixed error, called bore sight, and a random error, called jitter. The behaviors of pointing errors and related issues are treated in [5], where the irradiance probability density function due to bore sight and jitter has been derived. Scintillation is the temporal and spatial variations in light intensity caused by atmospheric turbulence. Such turbulence is caused by wind and temperature gradients that

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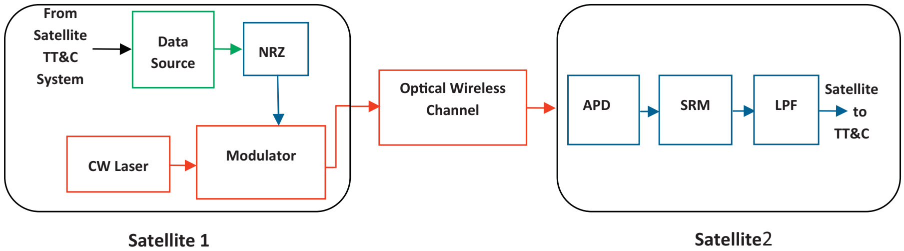

Fig. 1. Basic block diagram of an inter-satellite optical-wireless communications system: CW Laser; LPF, low pass filter; APD, Avalanche Photo detector; TT&C, Telemetry, Tracking and Communication systems.

create pockets of air with rapidly varying densities and therefore fast-changing indices of optical refraction [6]. Here [7] presented the IsOWC link performance on data transfer between Low Earth Orbit satellites. The system performance including bit rates, input power, wavelength and distance on an inter-satellite link were also analyzed. This paper focused [8] on effect of satellite vibration on various parameters like pointing angle, received signal power and hence the BER of the system are studied. Additional losses like Geometrical loss etc. It is a loss that occurs due to the spreading of the transmitted beam between the transmitter and the receiver [9]. It is dependent on beam divergence, elevation angle, diameter of receiver capture surface as well as link distance. Here [10] reported the improved investigation through implementation of a square root module using OPTISYSTEM^{TM} simulator to establish an inter-satellite link (ISL) between two satellites estranged by a distance of 1000 km at data rate of 2.5 Gbps for LEO. In this work, we have presented the simulation investigation of Inter satellite optical wireless communication systems for long distance. The paper is organized as follows: Section 2 contains the system description. Section 3 discusses the results of Inter satellite optical wireless communications system. Finally, Section 4 summarizes and concludes this paper.

2. System description

Optical wireless communications channel is considered to be outer space where it is assumed to be vacuum and free from atmospheric attenuation factors. Optical wireless communications system still consists of three main communication parts which are transmitter, propagation channel and receiver which is shown in Fig. 1, 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 in the optical wireless communications channel that is use to transmit the light signal. Optical wireless communications uses light at near-infrared frequency to communicate. The inter satellite optical wireless communications transmitter receives data from the satellite's Telemetry, Tracking and Communication (TT&C) system. Telemetry, Tracking and Command system of the satellite works along with its counterparts located in the satellite control earth station. 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. CW laser is used in optical communication [11]. The output light emitted by the CW laser is monochromatic, coherent and has high radiance which makes it suitable for long distance free space transmission. 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 [12]. The output light pulses from the optical modulator are transmitted in the transmission medium to the receiving satellite.

In the case of IsOWC system, the transmission is the optical wireless channel. Different from free space optics that is subjected to many losses due to weather and atmospheric attenuation, the optical wireless communications channel is 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. The optical antenna allows wider light beam divergence and detection. An optical antenna is actually a lens or a telescope that is placed before and after the transmission medium as shown in Fig. 2. Optical antenna increases the signal divergence. The receiving end of the inter satellite optical wireless communications signal consists of a photodiode and a low pass filter.

3. Results and discussion

The analysis in this paper is going to be performed by observing two cases: Case (i) described the analysis of inter-satellite optical-wireless communication systems and Case (ii) gave us improved analysis of inter-satellite optical-wireless communication systems.

3.1. Case (i): Performance analysis of inter-satellite optical-wireless communication system

The parameters used in this case are transmission range 5000 km, wavelength 1550 nm, Data rate 1.25 Gbps, transmitter power 60 mW, transmitter aperture diameter 10 cm, beam divergence 0.25 mrad, transmitter pointing error 1 urad, attenuation 0 dB/km, additional losses 1 dB, index refraction structure $5e^{-0.15}\,m^{-2/3}$.

Fig. 3(a) and (b) depicts the measurement of SNR and Q factor at satellite 2 at different space – difference between the two satellites with and without scintillation at an operating wavelength of 1550 nm. From Fig. 3(a), it has been observed that SNR reduces from 26 dB to 0 dB in the range of space – difference of 1000–5000 km between the two satellites without using

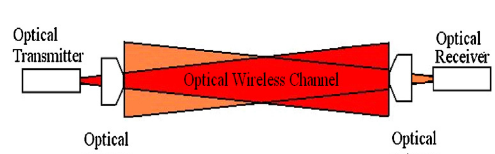

Fig. 2. Optical antenna increase the signal divergence.