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Study and Analysis of Optical Intersatellite Links

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***Abstract*—**Optical Intersatellite Links (OISLs) are wireless communications using optical signals to interconnect satellites. It is expected to be the next generation wireless communication technology according to its inherent characteristics like: an increased bandwidth, a high data rate, a data transmission security, an immunity to interference, and an unregulated spectrum etc. Optical space links are the best choice for the classical communication schemes due to its distinctive properties; high frequency, small antenna diameter and lowest transmitted power, which are critical factors to define a space communication. This paper discusses the development of free space technology and analyses the parameters and factors to establish a reliable intersatellite links using an optical signal to exchange data between satellites.

***Keywords*—**Optical intersatellite links, optical wireless communications, free space optical communications, next generation wireless communication.

I. Introduction

THE transport of the broadband technology via the satellite communications systems was the first step for arising the satellite networks [1], [2]. However, to achieve the user requirements such as the military applications and the commercial services, a high number of satellite orbits around the Earth as more satellites are being launched [3]. So, intersatellite links (ISLs) are playing a very important role for transfer data and information between satellites. Therefore, the earth stations number will be decreased [4], [5], and two earth stations are needed to establish the link between them via intersatellite links where ISLs decrease the number of hops (uplinks and downlinks). Also, there is a gain in transmission delay [6]; thus, ISLs become an essential part in space technology. To exchange data between satellites, this interconnection can be realized between satellites in the same orbit (intraorbital) or in different orbit (interorbital) as shown in Fig. 1.

The first intersatellite links used microwaves radio frequency (RF ISL) operated in two frequency bands: Ka-band and V- band. It is useful in mobile satellite systems (MSS) such as Iridium Next and Artemis, but with the fast development of satellite communications which require a huge bit rate [6], it is very important to move towards the optical ISLs as it is known by their advantages such as: high data rate, a large bandwidth, long communication distance, small antenna diameter and lowest transmission power with a low cost, more reliability and information security. Also, it is easy for multiplexing, demultiplexing, switching, and routing flexibility of the network applications.

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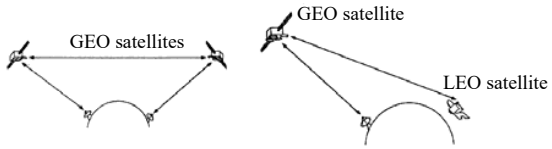

(a) GEO-GEO (b) GEO-LEO [4]

Fig. 1 ISL configuration

The first optical ISL between satellites using laser light was established between European Space Agency's (ESA) Artemis satellite and French Earth observation satellite SPOT-4, using SILEX (Semiconductor Laser Inter-Satellite Link Experiment) [2], [3].

For optical ISLs, three technical parameters are necessary to establish a connection between satellites; first one is the frequency bands where it is in the range of TeraHertz (THz) to attain a very high data rate (Table I). This is the most basic consideration for the signals transmission, which is subjected only to free space loss because the optical path is outside the atmosphere, consequently there is no absorption of the signals.

TABLE I
Optical Frequency and Transmitted Power [2]-[7]

Type of Laser	Wavelength (μm)	Transmitted Power
Laser Diode		
AlGaAs m	0.8–0.9	About 100 mW
InPAaGa	1.3–1.5	About100 mW
Nd:YAG	1.06	0,5 o 1 W
Nd:YAG	5,532	100 mW
Gas Laser		
CO_2 10.6 m	10.6	Several tens of Watts

Second one is the multiple access which is a technique for sharing the satellite transponder capacity to avoid the interference between incoming signals from others satellite for several earth stations [8], and the channel capacity is given by: $C= B \log_2(1+S/N)$, where B is the bandwidth, and S/N is signal to noise ratio. We can use the multiple wavelengths to increase the capacity of the system when the demand is close to or exceeds the capacity of one single optical channel [5]. The last technique is the modulation, and it is very important to choose the optimum modulation format [9] in terms of a maximum theoretical capacity. This concept provides also excellent security features that make it immune to jamming and interception [10]. This paper focuses on an overview about the intersatellite optical wireless communication to transfer data and information between satellites, discusses in details and explains the reasons of selecting optical transmission. Section II presents the applications and the different kind of the optical links, while Sections III and IV

discuss the different types of optical transmitters and optical receivers for intersatellite links. Section V gives an analysis of the optical link parameters, and Section VI is simulation of interest parameters. Last section is a conclusion of all the simulations and results and future perspective for the optical intesatellite links.

II. Optical Intersatellite Links (OISL)

OISL become leading in telecommunications and data transfer networks, which are widely used to transfer data and information with a high level of information security due to the narrow beamwidth (typically 5 µradians). This is an advantage for protection against interference between signals [6]. Also, due to its high transmission capacity where it is very important to satisfy the increasing demand of the user requirements, OISL can define two types of optical systems. The most useful is the LASER (Light Amplification by Stimulated Emission of Radiation) whose advantages are: high capacity, long communication distance and lowest transmitted power [11], and the second one is LED (Light Emitting Diodes). Many researches and studies are done now to use LED in ISL for short distance and to transport low data rate between neighboring satellites [12]. For example, IrDA (Infrared Data Association) standardized the infrared for the remote control and low speed links and it is well-known for the use of LED in free space communications [7]. There are three basics phases to establish an OISL:

- Acquisition: The beam scans the region of space where the receiver is expected to be located, this is need a wide beam to reduce the acquisition time, which requires a high power optical transmitter, typical time for this phase is about 10 s [6]-[13].
- Tracking: it comes when the receiver receives the signal, then a tracking phase and transmits in the direction of the received signal. On receiving the return signal from the receiver [14], the transmitter also enters the tracking phase, then, the beams are reduced to their nominal width, and it must allow the movements of the platform and relative movements of the two satellites [15].
- Communications: establishment of the link and exchanging information between the two satellites [7]-[16].

The big problem facing the OISL between two satellites is the satellite vibration and the relative velocity between the two satellites, which is not zero [17].

III. Optical Transmitter

The optical transmitter is to generate the optical signal, and imposes the information-bearing signal, then launches the modulated signal into the direction of the receiver. The semiconductor light sources are commonly used in state-of-the-art optical communication systems [18]. The light generation process occurs in certain semiconductor materials due to the recombination of electrons and holes in p–n junctions, under direct biasing. Depending on the nature of the recombination process, where different semiconductor light sources are classified such as light-emitting diodes (LEDs) in which spontaneous recombination dominates or semiconductor lasers in which the stimulated emission is a dominating mechanism [19]. This means that there are three basic processes in semiconductor materials, as illustrated in Fig. 2, by which the light interacts with matter: absorption, spontaneous emission, and stimulated emission. In normal conditions, the number of electrons in ground state (with energy E_1) N_1 is larger than the number of electrons in excited state (with energy E_2) N_2, and in the thermal equilibrium their ratio follows the Boltzmann's statistics:

$$E_P = \left(E_2 - E_1\right) = hv \tag{1}$$

where: E_p is the photon energy, h is Planck constant: 6.626 10^{-34}J.s, and v is the optical frequency [10].

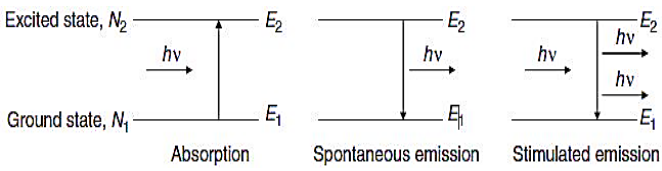

Fig. 2 Illustrating the interaction of the light with the matter

IV. Optical Receiver

The purpose of the optical receiver is to convert the optical signal into electrical signal and to recover the transmitted data [20], where three different stages are identified: front-end stage, the linear channel stage, and data recovery stage. The front-end stage is composed of a photodetector and a preamplifier. The most commonly used front-end stages are high-impedance front-end and transimpedance front-end as shown in Fig. 3.

The photodiode is an integral part of both front-end stage schemes. The principal role of the photodiode is to absorb the photons from incoming optical signals and convert them back to the electrical signals through the process opposite to the one taking place in optical transmitter. The common photodiodes are p–n photodiode, p–i–n photodiode, avalanche photodiode (APD), and metal–semiconductor–metal (MSM) photodetectors [9]-[21].

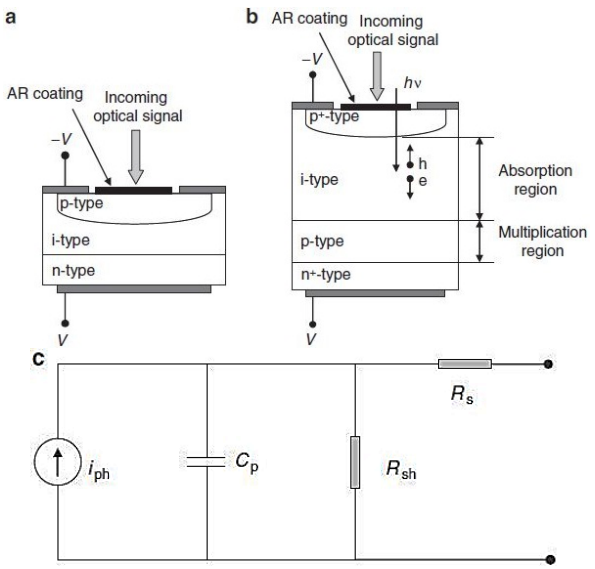

Fig. 3 The semiconductor photodiodes (a) p–i–n photodiode and (b) avalanche photodiode (c) The equivalent p–i–n photodiode model

V. Intersatellite Links Equation and Calculations

The purpose of this paper is to analyze the OISL system performance by using laser transmitter with transmission wavelength λ=1550 nm as shown in "(2)" in dB:

A. Received Power

It is well known that the received signal power P_R uses the transmitted power P_T, the transmitter gain G_T, the receiver gain G_R, the free space loss L, the transmitter efficiency τ_T, and receiver efficiency τ_R:

$$P_R = P_T G_T G_R L \tau_T \tau_R \tag{2}$$

B. Receiver Antenna Gain

$$G_R = \left(\pi D_R / \lambda\right)^2 \tag{3}$$

C. Free Space Loss

$$L = \left(\lambda / 4\pi d\right)^2 \tag{4}$$

D. Transmitter Antenna Gain

$$G_T = 32 / \theta_T^2 \tag{5}$$

where D_T is the transmitter antenna diameter (m), D_R is the receiver antenna diameter (m), d is the communication distance(m), λ is the optical wavelength (m), and θ_T is the Transmitter divergence angle, where it is given by $\theta_T = 1.22(\lambda/D_T) = 18.91$ µradian [9].

By substitution in (2):

$$P_R = P_T \left(2D_R^2 / \theta_T^2 d^2\right) \tau_T \tau_R \tag{6}$$

Here we can simulate $P_R = f(d)$ as shown in Fig. 4.

Fig. 4 shows that the received power P_R decreases as the communication distance d increases with a fix antenna diameter D_R, but large antenna aperture can increase the received power P_R.

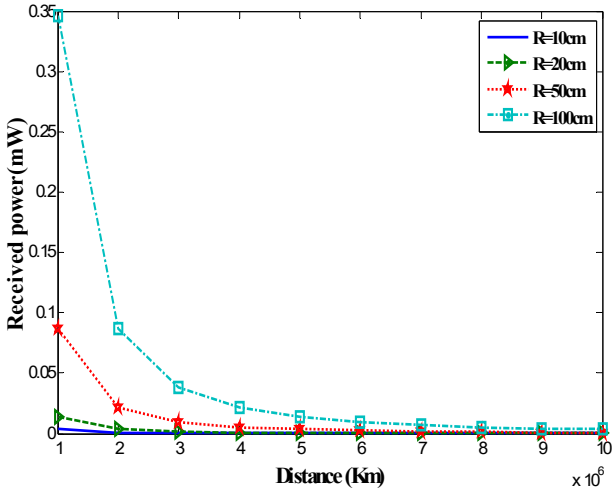

Fig. 4 Received power P_R vs communication distance d

E. Data Rate

$$R_b = P_T \tau_{opt} (D_R^2/\theta_T^2 d^2) (4/hvS) \tag{7}$$

where R_b is the bit rate (bit/s), τ_{opt} is optical efficiency, and S is the receiver sensitivity.

F. Link Margin

It is an important parameter in optical communications link analysis. The link margin is defined as the ratio between the received power and required power [10], the required power is given by: $P_{req} = h\upsilon\, S\, R_b = S\, R_b\, hc/\lambda$. Finally, the link margin M defined as:

$$M = P_R / P_{req}$$

By substitution:

$$M = P_T / \left(R_b h\upsilon S\right)\left(2D_R / \theta_T^2 d^2\right) \tau_T \tau_R \tag{8}$$

VI. Simulation and Results

We can use these equations to analyze the relation between various parameters of the system. To draw the graph of one parameter versus another, the other parameters are fixed, and the two equations are solved.

A. Relation between Range d and the Radius D_R

In this section, we will study the performance of the communication distance with different antenna size for various value of transmitted power.

$$d = \left\{P_T / \left(R_b h\upsilon SM\right)\left(2D_R / \theta_T^2\right) \tau_T \tau_R\right\}^{1/2} \tag{9}$$

Fig. 5 shows that transmitting power can increase the communication distance.

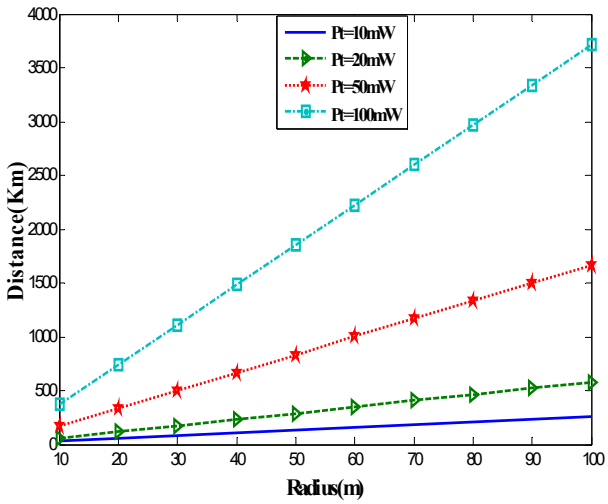

Fig. 5 Communication distance d vs antenna radius D_R

B. Relation between Link Margin and Communication Distance d

Here, we need to determine the influence of the communication distance *d* to the link margin for various transmitter power P_T, thus we use "(8)".

Fig. 6 shows that the communication range d increases as the link margin *M* decreases with a fixed transmitter power, but high power can increase the link margin *M*.

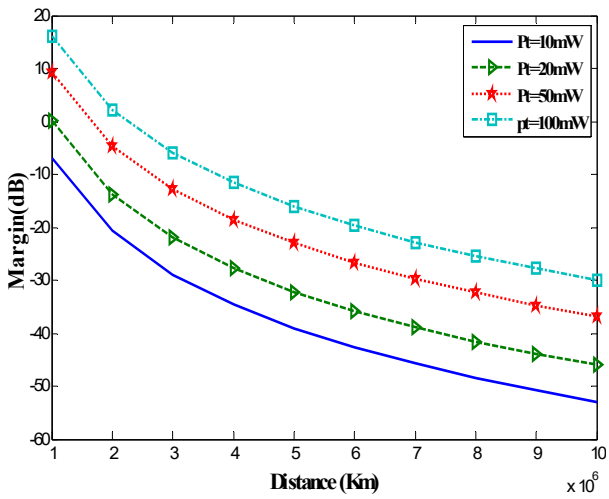

Fig. 6 Margin vs communication distance

C. Relation between Bit Rate R_b and the Communication Distance d

Here, we will analyze the transport of high bit rate for a long distance with various transmitted power (7).

Fig. 7 shows that the communication distance *d* increases as the bit rate R_b decreases, but for long distance it needs high power to increase the data rate.

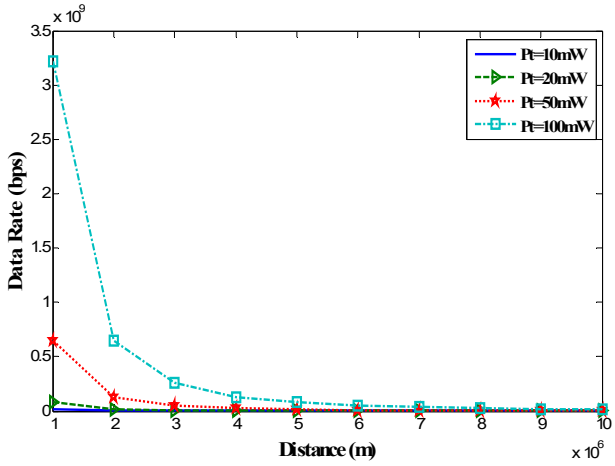

Fig. 7 Bit rate vs communication distance

D. Relation between Bit Rate R_b and the Transmitted Power P_T

In this case we will analyze the influence of the transmitted power P_T in the bit rate R_b for different distances (7).

Fig. 8 shows that the data rate R_b increases simultaneous with the transmitted power P_T, but it needs higher power to transmit higher data rate for a long distance.

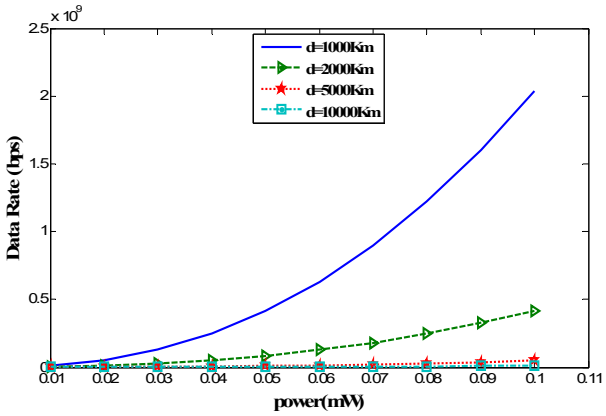

Fig. 8 Data rate R_b vs transmitted power P_T

E. Relation between Data Rate R_b the Antenna Diameter D_R

In this section, we need to define the size of the antenna for various transmitted power (7). Fig. 9 shows that the radius D_R increases as the data rate R_b increases for a fix transmitted power P_T, but it needs a high power to transmit a high data rate.

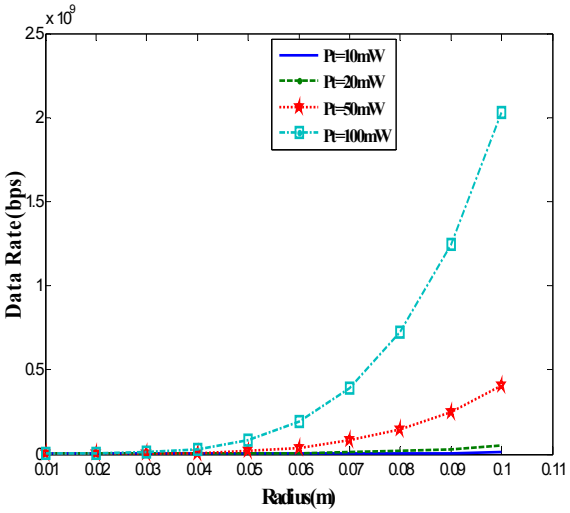

Fig. 9 Data rate vs radius

VII. Conclusion

With the fast development of the space communications technology, there is an inexorable need for the ever-increasing bandwidth for high-speed data transmissions. The existing RF intersatellite links in communication technologies can transmit data with a bit rate around the Mbps. However, to achieve the user's requirements for high data transmissions rates, optical links for space communications especially using laser communication, where the data transmission rates are in the Gbps, would be adopted. Besides providing higher data rates, OISL is also good for information security as compared to RF ISL. The tight beam of a laser provides a good low probability for detecting and intercepting and reduces the jamming probability of the signal from an adversary. Moreover, it allows the reuse of frequencies, where two users can operate at the same frequency without interference. Compared to RF communications, OISL communication systems are faraway faster in bandwidth efficiency and in data transmission security. The transition to switch from RF ISL communications to OISL communications for next-generation communication networks is imminent.

References

[1] Niu, Xueyu, Huijie Qiao, and Jie Liu. "Optical solution to interorbit ISLs in satellites constellations communication network." *Asia-Pacific Optical Communications*. International Society for Optics and Photonics, 2006.

[2] Purvinskis, R. A. J. (2003). *Interplatform links*. University of South Australia.

[3] Khalighi, Mohammad Ali, and Mustafa Uysal. "Survey on free space optical communication: A communication theory perspective." Communications Surveys & Tutorials, IEEE 16.4 (2014): 2231-2258.

[4] Fletcher, G. D., T. R. Hicks, and Bernard Laurent. The SILEX optical interorbit link experiment. *Electronics & communication engineering journal*3.6 (1991): 273-279.

[5] Chan, Vincent WS. "Optical satellite networks." *Journal of Lightwave Technology* 21.11 (2003): 2811.

[6] Heine, Frank, et al. Optical intersatellite communication operational. *Military communications conference, 2010-milcom 2010*. IEEE, 2010.

[7] Maral, Gérard, and Michel Bousquet. *Satellite communications systems: systems, techniques and technology*. John Wiley & Sons, 2011.

[8] Wood, Lloyd, Will Ivancic, and Klaus-Peter Dörpelkus. "Using light-emitting diodes for intersatellite links." *Aerospace Conference, 2010 IEEE*. IEEE, 2010.

[9] Djordjevic, Ivan, William Ryan, and Bane Vasic. *Coding for optical channels*. Springer Science & Business Media, 2010.

[10] Bjarklev, Anders, Dipak Chowdhury, Arun Majumdar, Masat aka Nakasawa, Carlo G. Someda, and Hans-Georg Weber. Optical and Fiber Communications Reports.

[11] Sindhubala, K., & Vijayalakshmi, B. (2015, February). Ecofriendly data transmission in visible light communication. In *Computer, Communication, Control and Information Technology (C3IT), 2015 Third International Conference on* (pp. 1-4). IEEE.

[12] Li, S., Tan, S. C., Lee, C. K., Waffenschmidt, E., Hui, S. Y., & Tse, C. A Survey, Classification and Critical Review of Light-Emitting Diode Drivers.

[13] Wu, P., Lian, J., & Lian, B. (2015, July). Optical CDMA-based wireless indoor positioning through time-of-arrival of light-emitting diodes. In *Optical Communications and Networks (ICOCN), 2015 14th International Conference on* (pp. 1-3). IEEE.

[14] Gafford, J. B., Wood, R. J., & Walsh, C. J. (2016). Self-Assembling, Low-Cost, and Modular mm-Scale Force Sensor. *Sensors Journal, IEEE*, *16*(1), 69-76.

[15] Hranilovic, S. (2006). *Wireless optical communication systems*. Springer Science & Business Media.

[16] Willebrand, H., & Ghuman, B. S. (2002). *Free space optics: enabling optical connectivity in today's networks*. SAMS publishing.

[17] Pahlavan, K. (2011). *Principles of wireless networks: A unified approach*. John Wiley & Sons, Inc.

[18] Cho, H., Shin, J. W., Cho, N. S., Moon, J., Han, J. H., Kwon, Y. D., ... & Lee, J. I. (2016). Optical Effects of Graphene Electrodes on Organic Light-Emitting Diodes. *Selected Topics in Quantum Electronics, IEEE Journal of*, *22*(1), 1-6.

[19] X. Y. Niu, H. J. Qiao, and J. Liu, "Optical solution to interorbit ISLs in satellite constellations communication network," Proc. SPIE, vol. 6354, pp. 63543I, 2006

[20] Marshoud, H., Kapinas, V. M., Karagiannidis, G. K., & Muhaidat, S. (2015). Non-Orthogonal Multiple Access for Visible Light Communications. *arXiv preprint arXiv:1504.00934*

[21] Chen, Z., & Haas, H. (2015, June). Space division multiple access in visible light communications. In *Communications (ICC), 2015 IEEE International Conference on* (pp. 5115-5119). IEEE.

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