

Limitation of Laser Satellite Communication Due To Vibrations and Atmospheric Turbulences

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Abstract

In this research, we analyze the effects of vibrations and the atmospheric on turbulence for a broadband laser satellite down link (BLSDL). The use of optical radiation as a carrier between satellites and in satellite-to-ground links enables transmission using very narrow beam divergence angles. Due to the narrow beam divergence angle and the large distance between the satellite and the ground station or any object the pointing is a complicated process. Further complication results from vibration of the pointing system caused by fundamental mechanisms : tracking noise created by the electro-optic tracker and vibrations caused by internal satellite mechanical mechanisms. Additionally an in homogeneity in the temperature and pressure of the atmosphere leads to variations of the refractive index along the transmission path. These variations of refractive index as well as introducing other external noise, pointing vibrations, can cause fluctuations in the intensity and the phase of the received signal leading to an increase in link error probability. In this research, we develop a bit error probability (BEP) model that takes into account both pointing vibrations and turbulence-induced high amplitude fluctuations (i.e., signal intensity fading) in a regime in which the receiver aperture antenna (D_0) is smaller than the turbulence coherence diameter (d_0), the results indicate that the satellite broad band laser down link with the receiver can achieve a BEP of 10^{-9} and data rate of 1Gbps with normalized pointing vibration of

$$G_T * \sigma^2, \text{ and turbulence with } \sigma_r =$$

After reducing these limitation of laser satellites and compensates relatively most atmospheric error probabilities due to atmospheric turbulences (BEPS) or variation of refractive index by using forward feeding under fine tracking which designed to decrease the residual jitter influences or by using directional laser beam or introducing feeding forward compensation method and adaptive techniques to reduce the effect of system vibrations [12].

Keywords: satellite communication, optical communication, wireless communication, atmospheric turbulence, pointing jitter.

تحديدات عمل التوابع بالاتصالات الليزرية بسبب الاهتزازات واضطرابات الغلاف الجوي

الخلاصة

في هذا البحث تجري تحليلات على تأثيرات الاهتزازات وتأثير تغيرات الغلاف الجوي على عمل التتابع الناقل ذو المجال الترددي الواسع (BLSDL). ويستخدم الشعاع (الليزري) البصري كحامل بين التوابع وبين التابع - ومحاور المحطات الارضية القادرة على الارسال باستخدام اشعة ذات زوايا ضيقة جدا. بسبب ضيق زاوية انفرج الشعاع وبعد المسافة بين التابع والمحطة الارضية او اي هدف فان عملية التوجيه ستكون معقدة بالاضافة الى التعقيدات الناتجة عن

الاهتزازات في توجيه المنظومة اضافة الى دخول ضوضاء خارجي وبسبب تلك العمليات الاساسية اللان هما: مرور الضوضاء الناتج عن توجيه المسيطر البصري الكهربائي والاهتزازات بسبب النظام الالي الداخلي للتابع اضافة لذلك فان التغيرات غير المتجانسة في درجات الحرارة والضغط للغلاف الجوي يقودنا الى تغيرات في معامل الانكسار وخلال طريق الارسل هذه التغيرات في معامل الانكسار وكذا في حركة الاهتزازات التي يمكن ان تسبب التلمض او التقلب في الشدة والطور للاشارات المستلمة و ثم تسبب زيادة في احتمالية الخطأ لمحور الاتصال. هنا سيظهر شكل احتمالية الخطأ (BEP) الذي كذلك يجب ان يؤخذ بالحسبان فالاهتزازات والاضطرابات الناتجة عن السعات العالية للتلمض (اي شدة الخفوت للاشارة) في النظام الذي يستخدم قطر فتحة هوائي الاخذة (D_0) أصغر من قطر الترابط المضطرب (d_0) النتائج تشير الى ان محور التابع النازل مع الاخذة يمكنه تفعيل نموذج احتمالية الخطأ بقيمة 10^{-9} ونسبة البيانات 1Gb/s. بالاهتزاز المصوب الطبيعي $\sigma_g^2 * \sigma_T^2 = 0.05$ والاضطرابات $\sigma_p = 0.3$ [5] بعد ازالة تلك التحديدات للتابع والازالة النسبية لأغلب الاضطرابات الجوية و ثم لاحتمالية الخطأ بسبب تلك الاضطرابات الجوية وتغيرات في معامل الانكسار باستخدام الطريقة المباشرة او باستخدام الشعاع الليزري المباشر والتتبع الدقيق المصمم لتقليل بقايا التقليل او ادخال طريقة الازالة المباشرة في التغذية وطرق فنية معدلة التي ستؤدي الى التقليل الكبير او الازالة النهائية لتأثيرات اهتزازات المنظومة [12].

I.Introduction

The main aim of the satellite link project is to develop a prototype of a small, power efficient and affordable wideband optical laser satellite communication terminal for applications on space segment (micro-satellites) in LEO/MEO and space-to-ground constellations. Microsatellite constellations in LEO/MEO orbits can inter-communicate and communicate with the ground station or with any object (airplane) by using laser beams as the carrier (Fig. 1). The onboard laser communication equipment takes the form of a terminal including an optical transmitter and a receiver. The main advantages of optical wireless communication are a) it enables very high data rates (large band width) and b) it is small, light and compact c) there are no licensing requirements or tariffs for its use. However, Vibrations caused by beam pointing jitter and internal satellite mechanical sources decrease the average received

signal, which, in turn, increases the bit error probability. An inhomogeneity in the temperature and pressure of the atmosphere in the space to ground leads to variations of the refractive index along the transmission paths. These variations can cause fluctuations in both the intensity and the phase of the received signal, which leads to a further increase in the link error probability...

For this research, we develop a bit error probability (BEP) model that takes into account both vibrations and turbulence-induced log amplitude fluctuations (i.e., signal intensity fading) in a regime in which the receiver antenna aperture D_0 is smaller than the turbulence coherence antenna diameter d_0 . We assume that the receiver has knowledge about the marginal statistics of the signal fading and the instantaneous signal fading state.

Furthermore, we assume that the receiver suffers from insignificant

noise that is statistically dependent on the received signal. This assumption is valid for a receiver which includes a photo detector (PD). However, for a receiver which includes an avalanche photo diode (APD) or an optical amplifier, this assumption yields an upper bound approximation on the receiver's BEP. This approximation is improved for a pointing and turbulence fading channel owing to the fact that most of the errors occur during deep fading events in which much of the noise is independent of the received signal.[1].

II. Satellite-optical link equation

It means that the satellite uplink and down link, The Satellite uplink where the transmitting earth station signal is received by the satellite receiving antenna at a distance Ru is depicted in fig. 1. An isotropic reflector, transmitting the same power PTE as the power radiated by the actual transmitting earthstation antenna, will result in a flux density ϕ_e at the satellite receiving antenna, but the antenna is directional then the power PT*Gt. The reasoning applied for the uplink can also be applied for the down link ,and by simply replacing the subscripts E (earth station) with S (space station), and U (up link) with D(down link). for our case we needs the down link effects of vibrations and atmospheric turbulences, given that

$$\phi_{oE} = \frac{(P_{TS} \cdot G_{TS})}{4\pi R_D^2} \dots (1)$$

Where: The flux density on the earth station
 P_{TS} The power transmitted by the satellite,
 G_{TS} The satellite antenna gain (Directive antenna)

R_D , the distance between space segment and earth segment.

The quantity $P_{TS} \cdot G_{TS}$ is the effective isotropic radiated power (EIRP) of satellite (usually measured indecibels to 1 w (dBw)

The total power received by the earth station

$$P_{RE} = \frac{P_{TS} \cdot G_{TS} \cdot A_R}{4\pi R_D^2} \cdot \frac{1}{L_D} \dots (2)$$

Where A_R effective aperture of earth station with the gain G_{RE} and L_D is the total power loss in transmission path from satellite to earth station.

$$A_R = \frac{\lambda^2 \cdot G_{RE}}{4\pi} \dots (3)$$

$$P_{RE} = \frac{(P_{TS} \cdot G_{TS} \cdot \lambda^2 \cdot G_{RE})}{(4\pi R_D^2 \cdot 4\pi L_D)} \dots (4)$$

If the effective noise temperature of the earth station receiver is T_{RE} , then the noise power at the earth station receiver input be

$n_o = K \cdot T_{RE}$ and if we replace the P_{RE} by C, where C the carrier power, then the equation (4) can be written as:

$$\left(\frac{C}{n_o}\right)_D = P_{TS} \cdot G_{TS} \cdot \left(\frac{\lambda}{4\pi L_D}\right)^2 \cdot \frac{1}{L_D} \cdot \frac{1}{K} \dots (5)$$

$\left(\frac{C}{n_o}\right)_D$ down link carrier - to- noise density ratio

$P_{TS} \cdot G_{TS}$ = satellite EIRP (effective isotropic radiated power)

$\frac{A_R}{4\pi R_D^2}$ = earth station receiving sensitivity (figure of merit),

$\left(\frac{\lambda}{4\pi L_D}\right)^2$ = down link space loss,

L_D = down link transmission-medium losses, K= Boltzmann's constant.

III Vibration Effect

THE Optical communication between two space satellites, as well as, between a satellite and ground station necessitates line-of-sight alignment throughout transmission. At

ranges of hundreds of kilometers this can only be achieved by using a pointing and tracking system. However, noise in the tracking system and mechanical vibrations cause beam jitter or vibration. This can be found in description of the elevation and azimuth pointing angles [9], [10] and [12] In addition assume that the noise is independent of the received signal with zero mean and variance The signal (y) corresponds to the following conditional densities when the bit is on or off

$$P(Y/ON, \theta) = \frac{1}{\sqrt{2\pi\sigma_y^2}} \cdot \exp\left(-\frac{y - P_r \cos(\theta)}{2\sigma_y^2}\right) \dots (6)$$

$$P(Y/OFF, \theta) = \frac{1}{\sqrt{2\pi\sigma_y^2}} \cdot \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \dots (7)$$

where Pr(o)=power of received signal as a function of random pointing angle The elevation pointing error angle can be considered to be normally distributed with a probability density

$$f(\theta_v) = \frac{1}{\sqrt{2\pi}\sigma_v} \exp\left[-\frac{(\theta_v - \mu_v)^2}{2\sigma_v^2}\right] \dots (8)$$

Where θ_v , μ_v and σ_v are the elevation pointing angle, its mean value and its standard deviation respectively. The azimuth pointing error angle is likewise normally distributed with a probability density.

$$f(\theta_H) = \frac{1}{\sqrt{2\pi}\sigma_H} \exp\left[-\frac{(\theta_H - \mu_H)^2}{2\sigma_H^2}\right] \dots (9)$$

Where θ_H , μ_H and σ_H and the azimuth pointing angle, its mean value and its standard deviation respectively. The radial pointing error angle is:

$$\theta = \sqrt{\theta_v^2 + \theta_H^2} \dots (10)$$

Where θ_v , θ_H are the elevation and azimuth angles. We further assume that the azimuth and elevation processes are independent

and identically distributed so the radial pointing error angle can be modeled as a Rician density distribution function [10]. A rigorous derivation of the jitter angular distribution function is found in [10], which gives the pdf of the Gaussian beam as:

$$p(\theta, \varphi) = \frac{\theta}{\sigma_\theta^2} \exp\left[-\frac{(\theta^2 - \sigma_\theta^2)}{2\sigma_\theta^2}\right] I_0\left(\frac{\sigma_\theta^2}{2\sigma_\theta^2}\right) \dots (11)$$

$\sigma(\theta)$ = jitter angle standard deviation by noise effect in the tracking system. Where I_0 is the modified Bessel function of order zero and φ is the error angle from the center. Following [10] and assuming the bias error angle is negligible and hence equating φ to zero yields the familiar Rayleigh distribution function such that:

$$f(\theta) = \frac{\theta}{\sigma_\theta^2} \exp\left[-\frac{\theta^2}{2\sigma_\theta^2}\right] \dots (12)$$

The Bit error rate (BER) described as

$$BER = \int_0^\infty [P(ON)P(OFF/ON, \theta) + P(OFF)P(ON/OFF, \theta)] f(\theta) d\theta \dots (13)$$

Where

$$P(ON/OFF, \theta) = \int_{-\infty}^{\infty} p(y/off) dy \dots (14)$$

$$P(OFF/ON, \theta) = \int_{-\infty}^{\infty} p(y/ON, \theta) dy \dots (15)$$

The relation ship between BER and vibration amplitude ($\sigma_T \cdot \sigma^2$) illustrated as in fig .2

The vibration feeds for ward to the subtraction unit (through buffer amplifier and filter) as an vibration compensator for the optical communication, the disturbance [1] added to the feedback cct., then the o/p from the organizer speed servo feeds to the 1/p of sub. unit which can counteract the impact of vibration perfectly as shown in fig 3.

Iv. Atmospheric Turbulence

Turbulence phenomenon is the result of random changes in the atmospheric refractive index, refractive index variation due to temperature gradients between the atmosphere, the ground, and the ocean, which, leads to, cause air currents and winds that penetrate the upper layer of the atmosphere, the refractive index (n) of the atmosphere is a function of temperature, pressure, wavelength, and humidity. For instance, for a marine atmosphere [4], [17]

$$n_0 = 1 + \frac{77.46p}{T} \left[1 + \frac{77.53 \cdot 10^{-2}}{\lambda^2} - \frac{7733 \cdot q}{T^2} \right] 10^{-6} \dots (16)$$

Where p is the pressure (milliards), T is the absolute temperature in kalven. q is specific humidity (gm-3), and λ is wavelength. Refractive index is the sum of a fixed and a variable component [4], [17]

$n_T(\bar{r}) = n_0 + n(\bar{r})$ Where n_0 is the average refractive index, \bar{r} is a location in space, and $n(\bar{r})$ is the stochastic component generated by the spatial variation of pressure, temperature and humidity. The fundamental statistical parameter is the spatial cross-correlation of the refractive index [6] Which:

$$\Gamma_n(r_1, r_2) = E[n(r_1) \cdot n(r_2)]$$

where E[] signifies the expected value. The power spectral density is the three-dimensional.

Fourier transform of the refractive index spatial cross correlation and is given by [1], [6] as

$$\Phi(K) = 0.033 C_n^2 K^{-11/3} \dots (17)$$

Where C_n^2 is the refractive index structure constant and K is the vector wave number representing spatial

frequencies. K satisfies the inequality where

L_0 and l_0 are inner and outer limits, respectively.

C_n^2 varies from $10^{-13} m^{-2/3}$. STRONG TURBULENCE. Empirical data from the basis of models to ascertain the value of C_n^2 , such as the sum of the height related exponents used in [13].

$$C_n^2(h) = A \exp\left(-\frac{h}{H_A}\right) + B \exp\left(-\frac{h}{H_B}\right) + C h^{1.0} \exp\left(-\frac{h}{H_C}\right) + D \exp\left(-\frac{(h-H_D)^2}{2\sigma_D^2}\right) \dots (18)$$

where A is the coefficient for the surface (boundary layer) turbulence strength and H_A is the height for its 1/e decay, B and H_B similarly define the turbulence in the troposphere (up to about 10 km), C and H_C define the turbulence peak at tropopause, D and H_D define one isolated layer of turbulence, where σ_D is the layer thickness. Simplification of the Maxwell equation is done by Rytov's method [17], [18] by assuming that the field at any point in the medium can be formulated as the product of the free space field and the stochastic complex amplitude transmittance that describes the field perturbation. We define the real part of the logarithm of the perturbation exponent as the log amplitude fluctuation and assign it the symbol X. Hence, it is possible to derive a statistical model of signal fading [17], [18], in which the propagation path length Z satisfies the condition

$l_0 < \sqrt{Z\lambda} < L_0$ where λ is the wavelength, and the turbulence diameter d_0 can be approx $d_0 = \sqrt{Z\lambda}$ [17],[18].

We consider the down link as a plane wave since the laser beam propagates for most of its path through space, and only suffers

from turbulence when reaching to earth.

The covariance for a plane wave (assuming) communication from satellite to ground) is given by [17], [18] as.

$$\sigma_x^2(Z) = 0.56 \left(\frac{2\pi}{\lambda}\right)^{\frac{7}{6}} \int_0^Z C_n^2(x) (Z-x)^{\frac{5}{6}} dx \dots (19)$$

The density distribution function of X is normal [17] as:

$$f(x) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{(x - \mu)^2}{2\sigma^2}\right) \dots (20)$$

The normalized received power is related to the log-amplitude X by

$$I = \exp(2X - 2E[X]) \dots (21)$$

V-WIRELESS COMMUNICATION SYSTEM

The block diagram of an optical wireless communication system is shown in Fig 4. In the transmitter, the data modulates a high power laser using on-off keying (OOK). The modulated laser beam is steered in the direction of the receiver by using the gimbals and fast-steering mirrors. This unit is controlled by the satellite computer, which is fed with the receiver beacon signal. The beacon signal itself is focused by a telescope to illuminate a CCD matrix which informs the computer of the receiver's current location. Finally, the transmitter telescope and beam expander collimates the signal towards the receiver beacon source. The transmitter also emits a beacon signal which is tracked by the receiver. The signal and the transmitter beacon arrive at the receiver telescope, where the location information is detected by the CCD

matrix and fed into the satellite (or airplane or ground station) computer to control the receiver beam-steering device. The optic signal is amplified and filtered before illuminating the photodiode, where the signal is converted to an electronic signal.

The electronic signal is amplified by a trans impedance amplifier (TIA) and then demodulated by the decision – making circuitry. The optical signal received at the receiver is obtained by multiplying the transmitter power by the pertinent gain and loss factors. This can be summed up as[4]

$$P_R(\theta, I) = P_T \eta_T \eta_R \left(\frac{A}{4\pi Z^2}\right)^2 G_T G_R L_A L_T(\theta) I \dots (22)$$

Where P_T is the transmitter optical power, η_T is the optics efficiency of the transmitter and η_R is the optics efficiency of the receiver, λ is the wavelength, G is the optical amplifier gain, and Z is the distance between the transmitter and the receiver. The term in brackets is the free space loss. G_T is the transmitter telescope gain and is given by

$$G_T = \frac{4\pi A_T}{\lambda^2} \dots A_T = \eta_T A = \eta_T \left(\frac{D_T}{2}\right)^2 \cdot \pi$$

where A is the area of the telescope antenna, A_T= effective aperture of the telescope antenna.

$$\therefore G_T = 4\pi \eta_T \frac{D_T^2}{4\lambda^2} \cdot \pi = \pi^2 \eta_T \frac{D_T^2}{\lambda^2}$$

$$\therefore G_T = \left(\frac{\pi D_T}{\lambda}\right)^2, \text{ where } \eta_T = 1, \text{ in fact for calculation } \eta_T \approx (60 - 70) \%$$

$$G_T \approx 6 \left(\frac{D_T}{\lambda}\right)^2, \text{ At all } G_T \approx \left(\frac{\pi D_T}{\lambda}\right)^2 \dots (24)$$

$$\text{And also } G_R \approx \left(\frac{\pi D_R}{\lambda}\right)^2 \dots (25).$$

Where D_T = the transmitter antenna aperture diameter, D_R = the receiver antenna aperture diameter, G_R = the receiver telescope gain, L_A = the atmospheric loss, $L_T(\theta)$ = the transmitter pointing loss factor. The transmitter pointing loss factor (assuming a Gaussian beam) is [4] – [6]

$$L_T(\theta) \approx \exp(-GT \cdot \theta^2) \dots (26)$$

Where θ is the radial pointing error angle as defined in (10)-(12). Bit error probability (BEP) for intensity modulation/ direct detection (IM/DD) on-off keying (OOK) link. In this non coherent detection, the receiver converts the optical power to electronic signals by using P-I-N photo detector (see figure 4). The conversion ratio is defined by the detector responsivity, RPD. Our receiver integrates the received signal for a period of one bit, and at the end of the integration period makes a decision whether the received signal is ON or OFF. We make the decision as y (relative electronic signal). Assume that the noise can be modeled by additive white Gaussian noise that is statistically independent of the received signal, with zero mean and covariance σ_N^2 . The receiver has knowledge of the distribution of the pointing error and turbulence scintillations, as well as of the channel's instantaneous signal fading. The latter can be measured easily owing to low frequency of the signal fading relative to the data rate. After subtracting the background bias, the signal y is described by the following conditional densities when the

transmitted bit is ON or OFF respectively [16]:

$$p\left(\frac{y}{\sigma_N}, \theta, I\right) = \frac{1}{\sqrt{2\pi\sigma_N^2}}$$

$$\exp\left[-\frac{(y - R_{RPD} P_R(\theta, I))^2}{2\sigma_N^2}\right] \dots (27)$$

$$p(y/OFF) = \frac{1}{\sqrt{2\pi\sigma_N^2}} \exp\left[-\frac{y^2}{2\sigma_N^2}\right] \dots (28)$$

The maximum a posteriori probability (MAP) algorithm decode, the bit as: [4]

$$\hat{s} = \underset{(s)}{\operatorname{max}} \left\{ \frac{p(y/s) P(s)}{P(y)} \right\} \dots (29)$$

where $P(y/s)$ is the conditional probability that if a bit s is transmitted, a signal amplitude y will be received; s can take one of two values - ON or OFF; $P(s)$ is the probability that an ON or OFF bit is transmitted, and $P(y)$ is the a priori probability of y . The denominator is identical for all signals, and hence, it does not affect the decision between ON or OFF. In communication systems, the probabilities of transmitting ON and OFF bits are, in most cases equally-probable.

The bit - error probability is given

$$\text{BEP} = \int_{-\infty}^{\infty} \int_0^{\infty} \left(P(\text{on}) \cdot P\left(\frac{\text{off}}{\text{on}}, \theta, I\right) + P(\text{off}) \cdot P(\text{off}) P(\text{on/off}, \theta, I) \right) \cdot f_{\theta}(\theta) \cdot f_X(X) \cdot d\theta \cdot dX \dots (30)$$

Where $P(\text{off/on}, \theta, I)$ and $P(\text{ON/OFF}, \theta, I)$ define the BEP when the ON and OFF bits are transmitted, and are given respectively, by

$$P(\text{off/on}, \theta, I) = \int_{L_A(y, \theta, I) < 0}^{\infty} P(y/\text{on}, \theta, I) dy \dots (31)$$

And

$$P(\text{on/off}, \theta, I) = \int_{L_A(y, \theta, I) < 0}^{\infty} P(y/\text{off}) dy \dots (32)$$

Where: $L_A(y, \theta, \Gamma)$ likelihood function.
In order to simplify (30) we define:

$$u = P_1 G_T \frac{\eta_{FP}}{2\sqrt{2}\sigma_X} \operatorname{erfc}\left(\frac{u}{2\sigma_X}\right)^2 G_R L_A \dots (33)$$

Then substitute

$$u = \frac{\theta^2}{2\sigma^2} \dots (34)$$

$$v = \frac{X - E[X]}{2\sqrt{2}\sigma_X} \dots (35)$$

Using the complementary error function defined below

$$\operatorname{erfc}(a) = \frac{2}{\sqrt{\pi}} \int_a^\infty \exp(-b^2) db \dots (36)$$

Equation (30) can be simplified

$$\begin{aligned} \text{BEP}(\sigma_X, G_T, \sigma^2) &= \frac{1}{2\sqrt{\pi}} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \operatorname{erfc}\left(\frac{u}{\sqrt{2}\sigma_X}\right) \cdot \exp(-u - v^2) \cdot du \cdot dv \dots (37) \\ &+ \sqrt{2}\sigma_X v \end{aligned}$$

general interrelations between BEP, turbulence (represented by the parameter σ_X), and vibration pointing (represented by the normalized parameter $G_T * \sigma_\theta^2$). Figure 5 demonstrates BEP as a function of σ_X for three values of normalized vibration pointing: 0, 0.05, 0.3. It is easy to see that the BEP is almost constant, having value of 10^{-2} for a normalized pointing vibration of 0.3 and that a change in turbulence σ_X from 0 to 0.5 hardly affect the BEP. For lower vibration values, the BEP increases with turbulence, so that above σ_X of 0.25, BEP reaches 10^{-5} even for a vibration of 0.05. Nevertheless, without vibration the BEP can be as low as 10^{-8} for σ_X below 0.09.

Figure 6 depicts the BEP as a function of normalized vibration amplitude for three values of σ_X : 0, 0.2, 0.5. We can see that for high levels of turbulence, the BEP is consistently high and barely sensitive to vibrations rising from a little below 10^{-3} to a little above 10^{-2} as $G_T * \sigma_\theta^2$ increases from 0 to 0.5. For mild turbulence, the BEP can fall as low as 10^{-8} for $G_T * \sigma_\theta^2$ values up to 0.025.

Above $G_T * \sigma_\theta^2$ values of 0.25, the BEP is virtually no longer sensitive to the level of turbulence.

If the satellite is placed on a low earth orbit (LEO) with apogee of 850 km and perigee of 750 km. and consider communication from the satellite to the ground station (downlink), the altitude in our calculation is 800 km above sea level. The most important parameters of the communication system are the bit rate, 1 Gbit/s, the optical wavelength, 1.55 μm , and the optical power transmitted, 2W. All the other parameters are given in detail in Table 1. Figure 7 depicts the performance of the BLSL in terms of BEP as a function of σ_X with normalized pointing vibration of $G_T * \sigma_\theta^2 = 0.05$ and the listed parameters. It can be seen that the BEP increases from below 10^{-11} to 10^{-6} as σ_X rises from 0 to 0.5. Hence, if strong turbulence prevails in the atmospheric channel, BLSL communication would be limited. These results represent the upper bound of the real performance of a BLSL system owing to our assumption of insignificant noise that is statistically dependent on the received signal.

The dashed line represents a jitter of 0 \pm (2), the dashed dotted line shows

the BEP for jitter equal to 0.05 -(3), and the solid line shows performance for jitter 0.3 -(1). for three different levels of turbulence expressed by the parameter σ_f . The dashed line represents a turbulence of 0 -(1), the dashed dotted line shows the BEP for turbulence equal to 0.2 -(2), and the solid line shows performance for turbulence 0.5-(3)

Vii. Conclusions and Summary For Discussion

FINALLY This dealt with the combined effect of satellite vibrations causing pointing errors and atmospheric turbulence on the performance of optical communication satellite networks. The analysis carried out here can be the basis for future studies on laser satellite communication. We have demonstrated that the combination of even minimal pointing vibrations and atmospheric turbulence can dramatically communication performance.

The results of our simulations show that if the σ_f of vibrations is less than 0.1, a BEP of less than 10^{-9} can be achieved in the presence of weak atmospheric turbulence, but when turbulence increases only minimal jitter will enable a BEP below 10^{-9} . Once either jitter is high (above 0.1) or turbulence is no longer weak (above 0.4) that parameter becomes dominant and BEP values reach 10^2 and above, regardless of the value of the second parameter. Furthermore our numerical results (Figs 5 and 6) can be scaled by using equation (25) for turbulence and the ratio $GT * \sigma_f^2$ for jitter.

The simulation results shows that the vibration amplitude has great effect on BER. So a feed forward vibration compensation model is designed with MATLAB/simulink.

The system compensation detection CCD sampling time is 20 seconds and the compensation time happens at about 3.5 second, the vibration amplitude after compensation is decreased to about 30 times and BER in nearly a fix value around 0.25 compared with the non-compensation situation, in which the BER is linearly increasing with the vibration amplitude.

For our modelling, the receiver tracking error was neglected. When the receiver field of view is narrow with respect to the pointing error, the receiver pointing loss factor should be considered. This situation is common when using a receiver with a single mode Er-doped fiber amplifier (EDFA) as an alternative to a receiver with photo diode or avalanche photo diode.

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Table 1: BLSDL parameters

Parameter	Value (Units)
Wavelength	1.55 (nm) band
Wavelength stability	2(nm)
Bit Rate	1.0(Gb/s)
BER	10 ⁻⁹
Laser Power Output	0.5-0.2(Watt)
Aperture Diameter	120(mm)
Focal length	500(mm)
Beam width beacon	500(μ radian)
Detector sensitivity	-47(dBm)@1.0Gbs, 10 ⁻⁹
Star tracker accuracy	<100(μ radian)

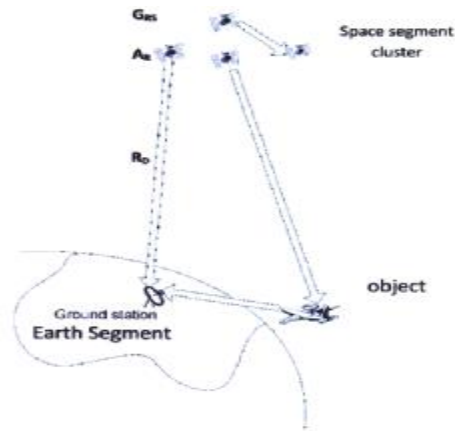


Figure1. The communication between space segment (satellite cluster) ground station and object.

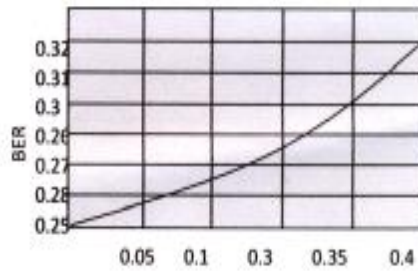


Figure .2 the relation between BER and ($G_T \cdot \sigma^2$).

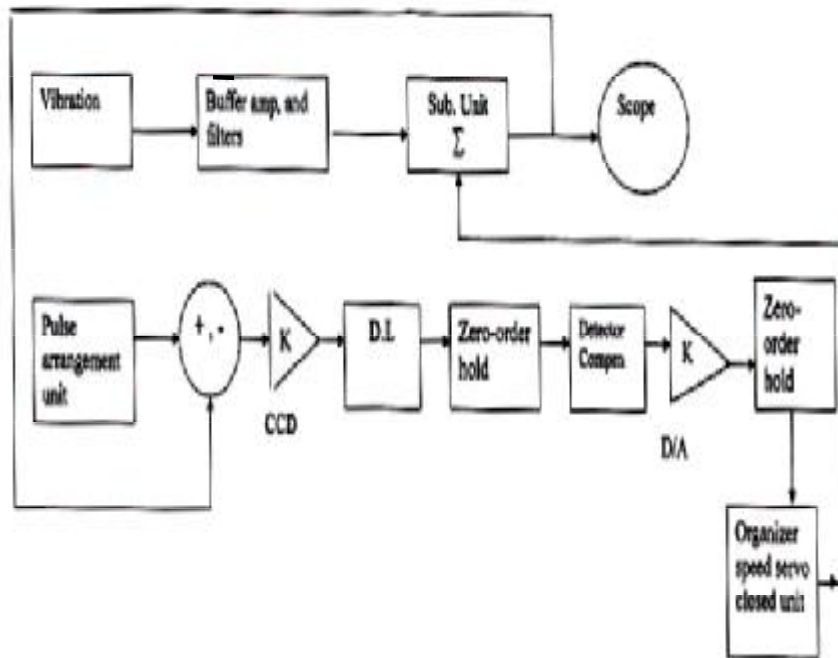


Figure.3 (Forward compensation of vibration under the fine tracking)

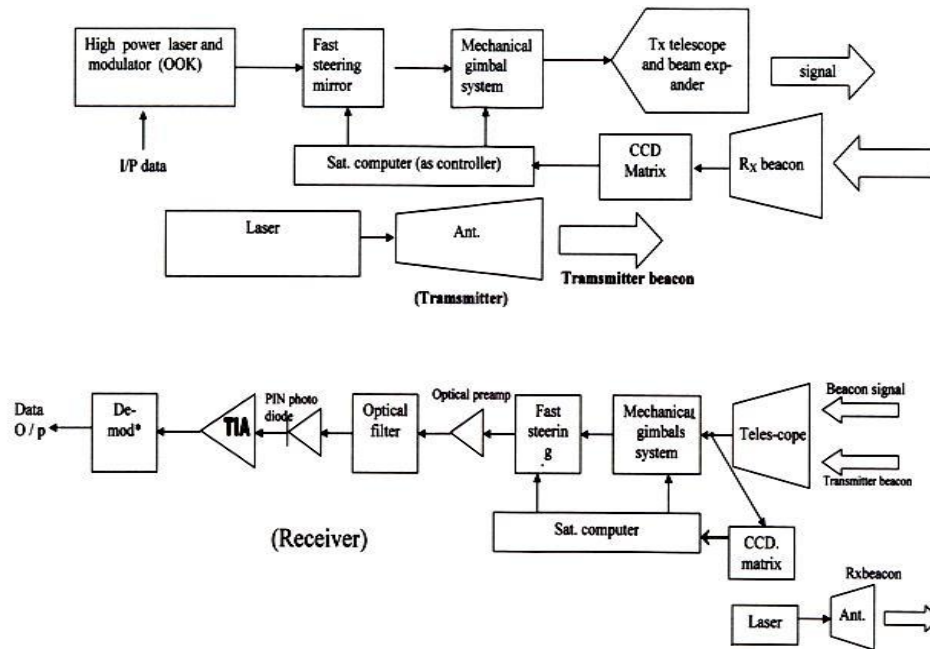


Figure. 4 (Schematic diagram of the wireless communication system)

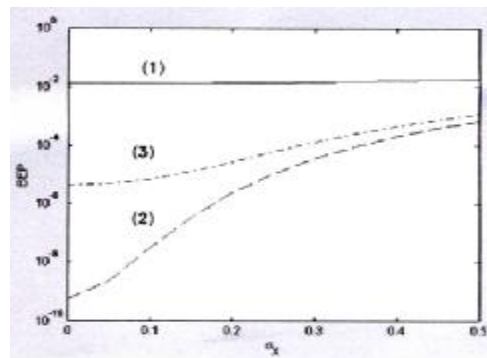


Figure 5. The Bit error probability (BEP) as a function of the turbulence parameter σ_x^2 for three different levels of jitter, expressed as the normalized parameter $G_T * \sigma_\theta^2$.

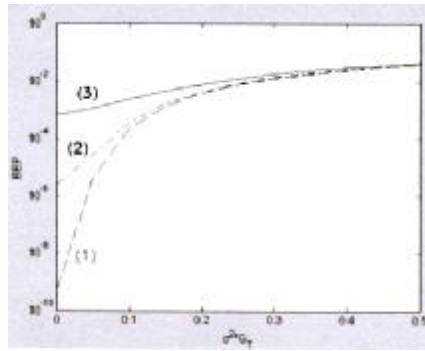


Figure 6. The Bit error probability (BEP) as a function of jitter, expressed as the normalized parameter $GT * \sigma_d^2$.

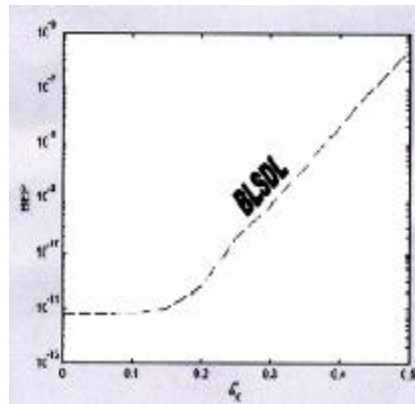


Figure 7. BLSDL BEP as a function of σ_d^2 an altitude of 800 km, above sea level for normalized vibration amplitude of 0.05.