New modeling approach of laser communication in constellation and through atmospheric disturbances

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ABSTRACT

Laser communication between satellites in the constellation and from the satellites to ground stations offers a gigantic data rate for the users. This principal advantage drives telecom companies to develop this technology to use it like a carrier signal, the most disadvantage of this technology is the need to very complicated pointing systems between the transmitter and the receiver due to a very small beam divergence, continually moving of satellites in orbits and the distance between the satellites (tens of thousands of kilometers). The laser beam suffers continuously from several factors like atmospheric turbulences, internal and external vibrations. All these factors lead to an increase in the bit errors rate and cause degradation in the communication quality. This paper deals with a new method of modelisation of external effects in transmission of signal light from a ground station to the satellite through atmospheric disturbances. Indeed, an in-depth investigation, of the influences of satellite vibrationsinlaser signal transmission between satellites constellation, has been conducted by studying the effect of the intensity of vibrations on the optical signal amplitude. Some solutions are proposed to improve the efficiency of optical satellites communications.

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1. INTRODUCTION

Using laser beam in optical satellites communication is thought to be the most important technology because of its advantages vs the radio frequency links, such as license-free frequency band, rapid and simple implementation, adaptable transmitter and receiver design, and extremely reliable sensitive data transfer [1], Installation costs are modest, energy requirements are modest, the beam size is narrow, and the bandwidth is wide. This approach allows people to communicate without interfering from electromagnetic fields [2], [3]. Given all these advantages, we use laser beams in satellite communications systems (up-link, down-link, constellation of satellites and inter-satellite link). Data is sent from one spacecraft to another orbiting in the same or separate orbits using free space/vacuum as the propagation medium and optically modulated carrier signals in inter-satellite optical wireless communication (IsOWC) connections. M. Singh, and J. Malhotra [4] inter-satellite connections (ISLs) are critical for maintaining a modest number of ground stations. Without the use of ground stations, traffic can be diverted from spacecraft to another one using ISLs. The iridium system is an operating LEO satellite networks of RF-ISLs [5]. The laser beam on its way from the transmitter to the receiver suffers from many effects that increase the BER and thus decrease the efficiency of the communication system. These effects include atmospheric disturbances in the atmosphere that affect the ascending signal to the satellite, when the signal reaches the satellite and moves between the constellations of satellites, it is exposed to many factors that affect the quality of communication, this factors include internal and external vibrations.

The air turbulence due to changes occurred in temperature and atmospheric pressure. According to the theory of Kolmogorov successive energy, it produces cells in the formation of a turbulent, called "vortices", which have different sizes and refractive indices [6]. S. Liu, j. Yang, X. Guo, *et al.* [7] reports an algorithm of arranging ISLs in the laser/radio hybrid network. A review on different difficulties looked by free space optical (FSO) communications system for inter-satellite links has been deliberated in [8]. C. Wang *et al*. [9], the author present detailed analysis of ISL observations. In particular, he implement observation model refinements and highlight the contribution of ISL measurements. M. Toyoshima [10] introduces the trends of space laser communications for constellations. G. Curzi *et al*. [11] the author aim at the perspective of matching technical needs and technology availability for large constellations, while providing at the same time a detailed survey of the up coming satellite constellations, By introducing a representative list of RSSC missions, I. Sanad *et al.* [12] provides an overview of what is currently understood about satellites networks configurations and orbit types used for satellite remote sensing constellation (RSSC) missions. The work in [13] establish a model for a trusted device quantum key distribution (QKD) spacecraft in low earth orbit (LEO) and test its efficacy in various network configurations examine the importance of inter-satellite QKD connections in addition. T. Savitri *et al.* [14] describe a method to address a complex coverage area by using sparse satellite constellation design with a limited coverage capability. The results of [15] show how the on-axis scintillation index of annular Gaussian beams and BER change in vertical directions for laser satellite communications networks. The performance of optical wireless system that employs M-ary PPM of a Gaussian beam, in terms of BER when the optical wireless system is operated in an anisotropic non-Kolmogorov turbulent atmosphere are specified in Y. Ata *et al* [16]. For GEO and MEO laser satellite connections, a modern and theoretical time series synthesizer of the log-amplitude of the laser signal due to scintillation is proposed in [17]. H. Singh *et al.* [18] presents turbulent atmospheric channels with zero and non zero boresight pointing errors and elucidates the effect of phase noise on performance of FSO communication. M. Yasser *et al.* [19] presents the FSO link system and channel models. Mathematical analysis and close-form expressions for SER and outage probability are proposed.

In this work, for the first time, we report new modeling approach of laser communication in constellation and through atmospheric disturbances in the communication bitween ground station and satellite through Atmospheric week and strong turbulances and between the satellites in constellations including a modelation of internal vibrations of the satellite sub-systems in a constellations and studing the effects of this vibrations on the quality of the optical signal (SNR, BER). With the suggestion of some possible solutions to reduce the negative effects of these vibrations.

The paper is organized as follows, various atmospheric effects like, beam broadening, turbidity, astronomical refraction and scintillation are discussed in section 2, atmospheric turbulence model are presented in section 3, laser communications in constellations of satellies under the effects of the internal satellites vibrations are discussed in section 4, simulation results are discussed in section 5, a proposed solutions to mitigate the undesirable effects of vibrations are presented in section 6, finally, the conclusion is presented in section 7.

2. LASER COMMUNICATION THROUGH ATMOSPHERIC CHANNEL

2.1. Description of the atmospheric turbulence

There are many previous studies that dealt in depth with the chemical components of the atmosphere and the effects of wind and sea-level rise on the spread of electromagnetic waves and laser beams [2], [20]. The atmosphere is a complicated structure with a high level of sophistication. It is clear that the whole range of processes that constitute the atmosphere and its relationship with laser radiation must be known before useful optical devices for activity in the atmosphere can be planned. The atmosphere chemical composition has been well explained in the reference [20], [21]. The atmospheric turbidity reported in [22]. References [23]-[26] explain the astronomical refraction and air turbulence.

2.2. The effect of turbulence on the optical beam

Most research employed the "frozen" turbulence hypothesis to simulate laser radiation in the atmosphere [23]. The approach includes the assumption that the time change at any place is produced by the uniform beam movement of the entire atmosphere due to prevailing wind [23], [27], [28]. The evolution of turbulence in the atmosphere causes changes in the internal structure of the atmosphere. The evolution of turbulence through time causes changes in the internal structure of the atmosphere, which are ignored.

2.2.1. Beam broadening

Let us consider the beam size in free space as W and the intensity at the distance L is given by the formula: (see Figure 1)

$$I(x,\rho) = I_0\left(\frac{W_0}{W}\right)^2 exp\left[-\frac{2\rho^2}{W^2}\right] \quad (1)$$

where W is the beam width in free space and W_b is the beam width in turbulence [23], [29], I_o is the intensity of the incident beam on the beam axis, W_o is the beam size at the transmitter, ρ is the transverse distance from the beam axis

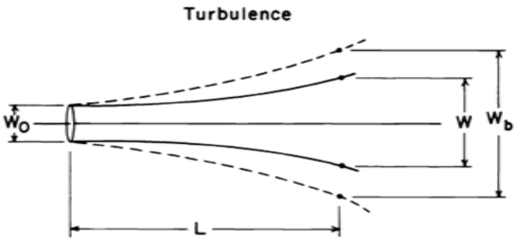

Figure 1. Beam spread

The beam size W for a collimated beam in free space is given by:

$$W^2 = W_0^2 + \left(\frac{2L}{kW_0}\right)^2 \quad (2)$$

The beam size W_b in the turbulence is given by:

$$W_b^2 = \frac{W^2}{2\int_0^{\infty} exp[-t^2-(1/2)D_s t^{5/3}]tdt} \quad (3)$$

2.2.2. Spatial coherence

The loss of spatial coherence on the laser beam is another significant consequence of disturbance in the open skies. Nonlinear phase variations can result from uneven refractive indices at wide scales. Thereby reducing the coherence of the wave front radiation. The structure function of the phase fluctuation $D_s(\rho_1,\rho_2)$ is defined as [23], [30]:

$$D_s(\rho_1,\rho_2) = E[|s(\rho_1) - s(\rho_2)|^2] \quad (4)$$

where $\rho_1$and ρ_2 are position vectors in the plane of observation across the beam and $s(.)$is the phase at that point. For weak turbulence, [31] gives a simple result for the phase structure function

$$D_s(0,\rho) = 2.91 b_1 C_n^2 z \rho^{5/3} \quad (5)$$

where the value of b_1 ranges from 1.0 for a plane wave to 0.375 for a spherical wave.
The phase correlation between the two points ρ_1 and ρ_2 of the wave-front decreases with the distance $\rho = |\rho_1 - \rho_2|$. For plane waves or spherical waves, the coherence can be expressed as:

$$\gamma(z,\rho) = exp\left[-\left(\frac{\rho}{\rho_0}\right)^{5/3}\right] \quad (6)$$

where $\rho_0$is the radius of phase coherence which is presented as:

$$\rho_0 = (b_2 C_n^2 k^2 z^2)^{-3/5} \quad (7)$$

where b_2=1.45 for a plane wave and 0.55 for a spherical wave. When $\rho \geq \rho_0$**,** the random phase angle variation is greater than π**,** It is thought that the wave-front has lost its spatial coherence [23], [30].

2.3. Effect of turbidity on optical radiation

Light is absorbed and scattered by atmospheric elements such as gases and dust. As a result, the turbidity of the atmosphere must be considered when designing an effective laser device, and must consider the reduction of the direct beam energy when the light propagates in the atmosphere.

2.3.1. Absorption and scattering loss

Water, carbon dioxide, and ozone molecules are the primary atmospheric absorbers [32]. The absorption of light by the atmosphere is a wavelength-dependent phenomenon. In databases like MORTRAN, the wavelength dependence of attenuation under various weather situations is usually provided [33].

2. ATMOSPHERIC TURBULENCE MODEL

Turbulence is caused by random fluctuations in the atmosphere's refractive indices. The temperature difference between the atmosphere, the ground, and the ocean produces the change in refractive index, which causes airflow and wind to enter the top layer of the atmosphere. Temperature, pressure, length of wave, and humidity all affect the fixed refractive index n_0 [34].

$$n_0 \approx 1 + \frac{77\mathrm{p}}{T}\left[1 + \frac{7.53.10^{-3}}{\lambda^2} - 7733\frac{\mathrm{q}}{T}\right]10^{-6} \tag{8}$$

where q is specific humidity (gm^3), λ is wavelength, T is temperature (K), p is air pressure (millibars).

When dealing with random motion of the refractive indices, Kolmogorov's model is commonly applied. The refractive indices, according to this idea, is the sum of fixed and variable components [35]. $n_T(r) = n_0 + n(r)$; Where n_0 is the median indice of refraction, r is the position in space, and $n(r)$ is the random component produced by the spatial variation of pressure, temperature and humidity. The basic statistical parameter is the spatial cross-correlation of the refractive index, which is defined as [36]:

$$\Gamma_n(r_1, r_2) = \mathrm{E}[n(r_1), r(_2)] \tag{9}$$

where E[ ] Signifies the expected value.

The power spectral density is the three-dimensional Fourier transform of the spatial correlation of the refractive index, given by the references [37]-[39] as:

$$\Phi(K) = 0.033 C_n^2 K^{-11/3} \tag{10}$$

where C_n^2 is the indice of refraction [17], and K satisfies the inequality $2\pi/L_0 < K < 2\pi/l_0$; l_0 is the internal limit and L_0 is the external limits.

The inertial range of the Kolmogorov spectrum defined by (11) is limited by internal and external constraints. C_n^2 Differs between $10^{-13}m^{-2/3}$ for severe disturbances to $10^{-17}m^{-2/3}$of weak disturbances. Empirical data forms the basis of a model for determining C_n^2 values, such as the sum of highly correlated indices used in reference [36].

$$C_n^2(h) = A\, exp\left(-\frac{h}{H_A}\right) + B\, exp\left(-\frac{h}{H_B}\right) + Ch^{10}\, exp\left(-\frac{h}{H_C}\right) + D\, exp\left(-\frac{(h-H_D)^2}{2d_C^2}\right) \tag{11}$$

where A is the coefficient of turbulence intensity on the surface (boundary layer), H_A is the altitude of its 1/e attenuation, B and HB denote the troposphere disturbance, C and HC denote the highest point of the troposphere disturbance level, D and HD define an isolated turbulent layer, and dc is the thickness of the layer.

A random Maxwell wave equation is used to compare the index of refraction function with the electromagnetic model. Rytov's approach achieves the simplification of Maxwell's equations [40], [41]. The field is supposed to be a combination of the free space field and the random complex amplitude transmittance representing the field disturbance.

$l_0 < \sqrt{Z\lambda} < L_0$ where λ is the wavelength and the turbulent coherence diameter d_0 can be approximated by reference [40], [41]. $d_0 < \sqrt{Z\lambda}$. We think of the downlink as a plane wave because most of the path of the laser beam travels through space and is only affected by turbulence when it approaches earth. References [31], [40], [41] give the covariance of plane waves as:

$$\sigma_X^2(Z) = 0.56\left(\frac{2\pi}{\lambda}\right)^{7/6}\int_0^Z C_n^2(x)(Z-x)^{5/6}dx \tag{12}$$

The density distribution function of *X* is normal, as shown [40]:

$$f_X(X) = \frac{1}{\sqrt{2\pi\sigma_x}}exp\left(-\frac{X-E[X]^2}{2\sigma_X^2}\right) \tag{13}$$

Normalized received power is related to logarithmic amplitude *X*:

$$I = exp(2X - 2E[X]) \tag{14}$$

After studying the spread of the laser beam in the atmosphere and analyzing the effects of atmosphere components on the light signal, the signal now reaches the satellite and travels through a constellation of satellites to reach the satellite located above the receiver. In this part, we will analyze the transmission of this signal between the satellites, and the various effects of the light beam.

3. NETWORK COMMUNICATION MODEL

A satellite constellation is a set of related satellites that operate together to form a network. The LEO constellation of satellites is configured to act as a network to provide more coverage [42], [43]. The considered optical inter-satellite network model includes transmitter satellite, repeater satellites, and receiver satellite all networked together [44].

4.1. Signal model

We arrive at a model in this subsection that connects the laser signal transmitted by the first spacecraft in the constellation to the signal received by the last spacecraft. The optical signal obtained by the constellation's second spacecraft is:

$$\mathrm{PR} = \mathrm{K}.\mathrm{L} \tag{15}$$

where

$$K = \eta_T.\eta_R\left(\frac{\lambda}{4.\pi.Z}\right)^2.G_R.G_T.P_T \tag{16}$$

The optical signals received by satellite (n+1) in the network is [45]

$$\mathrm{P_R(n+1)} = \prod_{\mathrm{i=1}}^{\mathrm{n}}\mathrm{K_iL_i} \tag{17}$$

with:

$$K_i = G_i\eta_{Ti}\eta_{Ri+1}\left(\frac{\lambda}{4\pi Z_i}\right)^2 G_{Ti}G_{Ri+1} i = 2,3,\dots,n, \tag{18}$$

Where G_i is the gain of the network's spacecraft relays *i*. P_T is the optical strength of the emitter, *Zi* is the spacing among spacecraft *i* and *i+1*. *n* represent the number of spacecraft in the constellation, η_{Ti} is the photonics efficiency of the emitter spacecraft *i* in the constellation and η_{Ri} is the photonics efficiency of the reception spacecraft *i* in the constellation.
The targeting loss factor is determined as [46]:

$$L_i = \exp\left(-G_{T_i}\theta_i^2\right) \tag{19}$$

where θ_i is the angle of radial pointing inaccuracy.
The transmitter gain of satellite *i* in the network is:

$$G_{Ti} = \left(\frac{\pi D_{Ti}}{\lambda}\right)^2 \quad (20)$$

where D_{Ti} is the size of the emitter aperture in the *i* satellite in the constellations.
The receiver gain of the *i* satellite in the satellites constellation is [45]:

$$G_{Ri} = \left(\frac{\pi D_{Ri}}{\lambda}\right)^2 \quad (21)$$

where D_{Ri} is the size of the receiver aperture in the *i* satellite in the constellations. if all satellites are the same

$$G_{Ti} = G_{Tj} = G_{Ti} \forall i, j \quad (22)$$

The optical signals received by satellite (n+1) in the network is

$$P_R(n+1) = \exp\left(-G_T \sum_{i=1}^{n} G_{Ti}\theta_i^2\right) \prod_{i=1}^{n} K_i \quad (23)$$

From (24)

$$P_R(n+1) = \exp\left(-G_T X\right) \prod_{i=1}^{n} K_i \quad (24)$$

where

$$X = \sum_{i=1}^{n} \theta_i^2 \quad (25)$$

Each θ_i contains two normal processes (azimuth and elevation), so *X* includes 2*n* normal processes. The process distribution composed of the sum of squares of normal processes with equal variances is chi-square. If all satellites are the same, the standard deviation of the radial pointing error angle of all satellites is equal to [47]:

$$\sigma_i = \sigma_j = \sigma_1 = \sigma_X \; \forall i, j. \quad (26)$$

Therefore *X* is a chi-square distribution with probability density:

$$f(X) = aX^{-1+n} \exp\left(-\frac{X}{2\sigma_1^2}\right) U(X) \quad (27)$$

where

$$a = \frac{1}{(\sigma_1\sqrt{2}) m^{2n} \Gamma(\text{n})} \quad (28)$$

The gamma function is:

$$\Gamma(\text{x}) = \int_0^\infty \text{t}^{\text{x}-1} \exp(-\text{t})\, \text{dt} \;\; 1 \le \text{x} \le 2 \quad (29)$$

The average optical power received in the *n* satellite is

$$S = a \prod_{i=1}^{n} K_i \int_0^\infty x^{-1+n} exp\left(-G_T x \frac{x}{2\sigma_1^2}\right) dx \quad (30)$$

After solving (30):

$$S = \frac{\prod_{i=1}^{n} K_i}{\left(G_T 2\sigma_1^2 + 1\right)^n} \quad (31)$$

3.1. Performance models
The SNR model is [47]:

$$SNR = \int_0^\infty \dots \int_0^\infty \frac{[RP_R(\theta_1 \dots \theta_n)]^2}{\sigma_{NT}^2(\theta_1 \dots \theta_n)} f(\theta_1) \dots f(\theta_n) d\theta_1 \dots d\theta_n \quad (32)$$

where R is the response of the detector at the receiver satellite.
To simplify the (32), We suppose that the primary source of noise is in the constellation's final satellite. Then (32) becomes:

$$SNR \approx \frac{R^2 P_T^2}{\sigma_{N2}^2 G_2^2} \int_0^\infty \dots \int_0^\infty [K_2^{2n} exp(-2G_T \sum_{i=1}^n \theta_i^2)] f(\theta_1) \dots f(\theta_n)\, d\theta_1 \dots d\theta_n \quad (33)$$

Repeating the same procedure in (12) to (18) for (31)

$$SNR \approx \frac{R^2 P_T^2}{\sigma_{N2}^2 G_2^2} \frac{K_2^{2N}}{(1+4G_T\sigma_1^2)^n} \quad (34)$$

The noise-to-signal ratio NSR to obtain a closed form [47]:

$$NSR = \frac{\sigma_{N2}^2 G_2^2}{R^2 P_T^2} \int_0^\infty \dots \int_0^\infty \left[\frac{1 + K_2^2 \exp(-2G_T\theta_n^2) \prod_{i=1}^{n-1} K_{i+1}^2 \exp(-2G_T \sum_{i=1}^{n-1} \theta_{i+1}^2)}{K_2^{2n} exp(-2G_T \sum_{i=1}^n \theta_i^2)} \right] f(\theta_1) \dots f(\theta_n) d\theta_1 \dots d\theta_n \quad (35)$$

Repeating the procedure in (35):

$$NSR = \frac{\sigma_{N2}^2 G_2^2}{R^2 P_T^2} \left[\frac{1}{K_2^{2n}(1-4G_T\sigma_1^2)^n} + \dots + \frac{1}{K_2^2(1-4G_T\sigma_1^2)} \right] \quad (36)$$

In (35) provides us another factor for analyzing constellation efficiency.

4. RESULTS AND DESCUSSIONS

In this section, we give some results based in a parameters showen in Table 1. From the Figure 2, we can assume that the spatial coherence decreases when the altitude of the transmitter increases and decreases also with the strongest of the turbulence, for a C_n^2=10^{-9} for weak turbulence the spatial coherence is greater than the strong turbulence with C_n^2=10^{-7}; so the altitude from the sea level and the strongest of the turbulence degrade the coherence of the propagating wave front. This leads to deterioration in the receiver, the beam pattern begins to decompose into different regions of high and low intensity. Absence of beam efficiency at the receptor can result in areas of spontaneous variability with low signal strength for sufficiently long path lengths and high optical turbulence amplitude, resulting in severe signal attenuation.

Table 1. Parameters used in this analyse

Parameter Name	Parameter Symbol	Parameter Value
Link range	L	≈8x10^2 Km
Optical received signal	P_R	-
Distance between the satellites	Z	40,000 Km
Electronicbandwidth	B	2 GHz
Transmitter/receiveroptics efficiency	η_T, η_R	80%
Wavelength	Λ	0.635 μm
Turbulence force	C_n^2	10^{-7}
Altitude	A	-
Received light intensity probability	$P_w(I)$	-
Number of satellites in the constellation	N	20
The radial pointing error angle's	σ_i	-
The size of the receiver aperture in the *i* satellite in the constellations	D_{Ri}	0.2m

Figure 3 illustrates how the magnitude of disturbance C_n^2 varies depending on the channel's different parameters, such as wind velocity, height, and environmental conditions. The C_n^2 was estimated between 0 and 20 km in this study and not greater since the value of $C_n^2$is minimal at high latitudes. The intensity force is calculated using various altitudes and wind speeds. Wind speeds shear at the ground, affecting the atmosphere's refractive index and resulting in substantial disturbance output. Low turbulence is defined as a wind speed of 9 m/s, whereas moderate turbulence is defined as a wind speed of 18 m/s. This graph clearly shows that the highest value of C_n^2 is located near to the surface, and that as altitude grows, its value decreases, and this negatively affects the quality of the spread of the light signal.

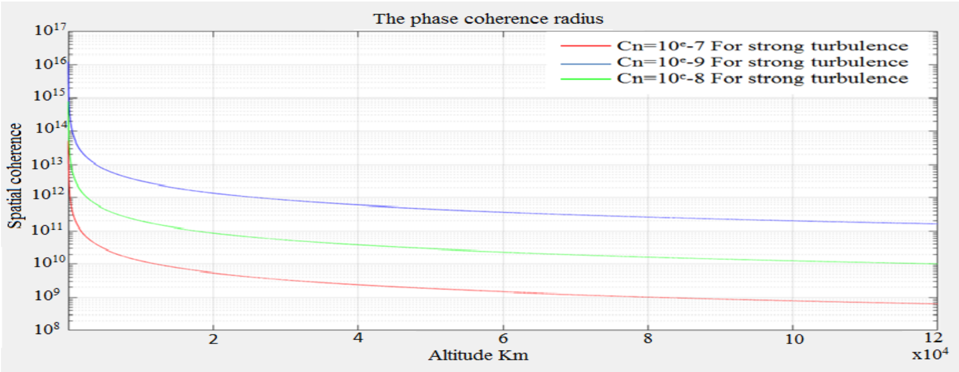

Figure 2. Spatial coherence vs. altitude (Km) and turbulence

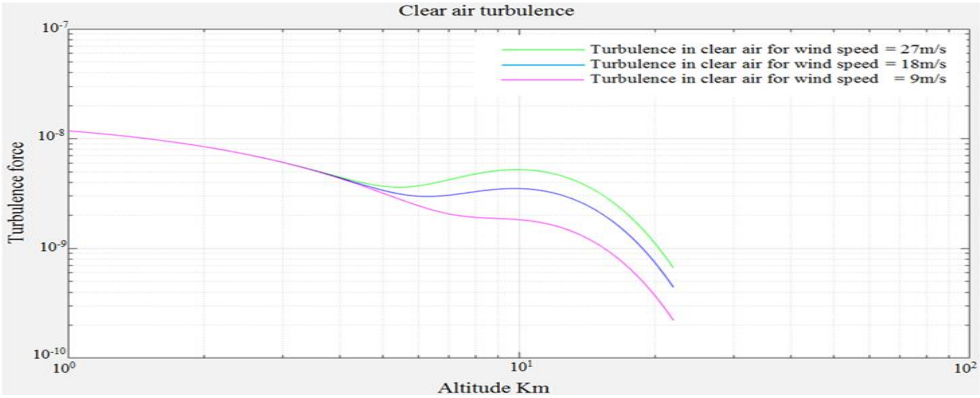

Figure 3. The force of turbulence vs. the altitude and the wind speed

From the Figure 4, we notice that scintillation (log-irradiation) is completely related to the angle of Zenith as shown in Figure 4 so any change, even very small, causes a complete loss of optical radiation and thus a explains the basic advantages of the use of lasers in communication. This is the great resistance against interference, which gives great safety to transmit the signal from the transmitter to the receiver. This result also explains the need for a very accurate tracking system that ensures connectivity in the event of movement and continuous vibration of the satellites.

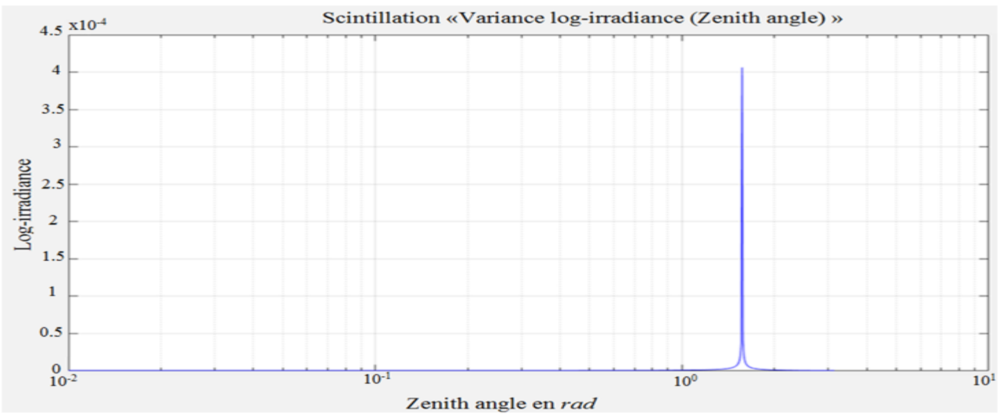

Figure 4. Log-irradiance as a function of zenith angle

From Figure 5, we notice that the wavelength considerably affects the scintillation the increase in the wavelength causes a decrease in the scintillation and the decreasing in the wavelength causes an increasing in the scintillation. We also note that the wind speed affects scintillation, if the wind speed increases, the scintillation decreases and if the wind speed decreases, the value of the scintillation increases. This is due to the effect of wind speed on the strength of the air turbulence. Log-irradiance has a good value at a wavelength of less than 100 µm, and after the wavelength 1 *mm* it becomes negligible and close to zero.

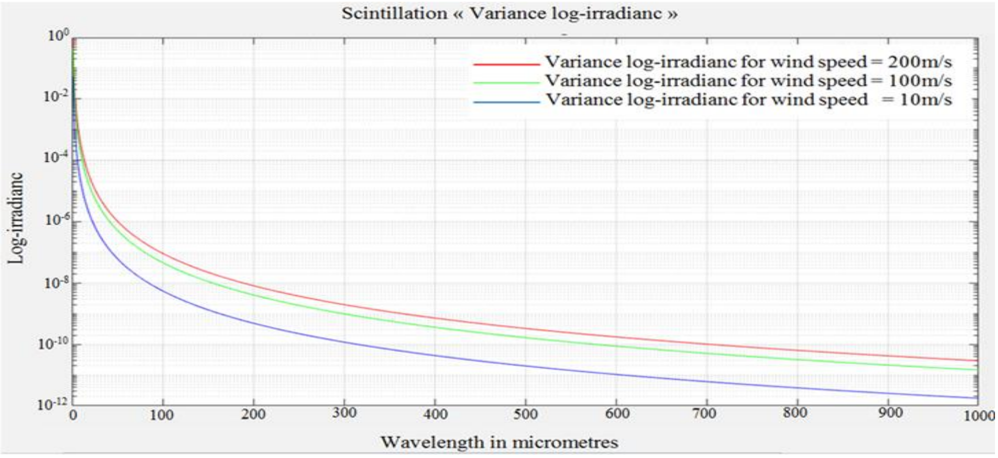

Figure 5. Log-irradiance vs. wavelength variance "Yura and McKinley model"

The normalized NSR is seen in Figure 6 as a result of the vibration amplitude and the number of satellites in the constellation; in this case, the spacecrafts is 20. It is significant to mention that even in the absence of disturbances; NSR reduces as the constellation expands due to the aggregation of noise in the passes among spacecraft. The obtained laser light as a function of the vibration amplitude normalized to the square root of the transmitter gain and the number of spacecraft in the constellation can be seen in Figure 7. Indeed, as the constellation grows, an increase in vibration intensity greatly reduces the obtained signal, which is due to the accumulation of vibrations from the first satellite to the last one.

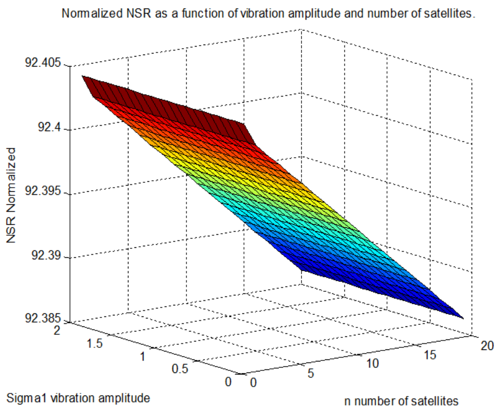

Figure 6. Normalized NSR as a function of vibration amplitude and number of satellites

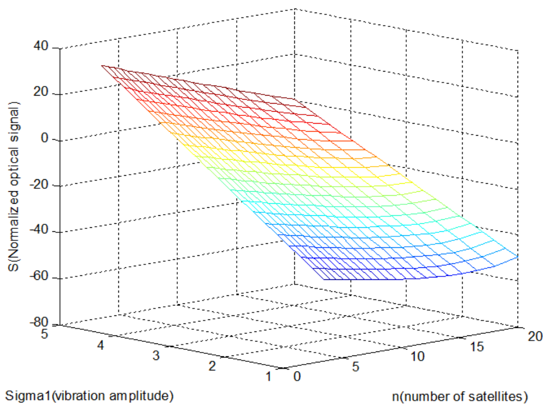

Figure 7. The received optical signal as a function of the vibration amplitude

5. PROPOSED SOLUTIONS TO REDUCE THE EFFECTS OF ATMOSPHERIC TURBULENCE AND VIBRATIONS ON THE PERFORMANCE OF OPTICAL COMMUNICATION

In this section we propose some solutions briefly to reduce the negative effects of vibrations and atmospheric turbulence, the proposed solutions to reduce the effects of satellite vibrations on the performance of optical communications are bandwidth adaptation, power control and channel diversity like what is mentioned in the references [44], Wavelength diversity and Temporal diversity are discussed in references

[3], [6], [48], [49], Multiple emitters is mentioned in the reference [50]. In the following we will explain the most important solution which is: Vibration Isolator.

6.1. Vibration isolator

The techniques of micro-vibration isolation system can be classified into three main categories, passive, active, semi-active isolation [51]. A mechanical low-pass filter with a classic control mechanism is used in passive isolation system. Vibration control devices, force actuators, and displacement sensors are examples of active isolators. Passive isolators are used to minimize vibration distortion in high-frequency areas where the tuning mechanism's interference reduction capability is inadequate. Active isolators are used to dampen low frequency and high amplitude sounds that other devices are unable to block.

6. DISCUSSION AND SUMMARY

This article discusses the impact of pointing system vibration and atmospheric turbulence on the performance of optical communications in up-link and satellite networks. New modeling approach of laser communication in constellation and through atmospheric disturbances has been developed and compared with others proposed in the literature. We have demonstrated that The primary constellation performance parameter is the disturbance intensity, and the constellation size scale is a smaller one.

The results of our simulations show that scintillation (log-irradiation) is completely related to the angle of zenith, so any change, even very small, causes a complete loss of optical radiation, this result translates into one of the most important advantages of optical communication mentioned in previous studies [52], [53]. The wavelength and the wind speed considerably affect the scintillation in our modulation the increasing in the wavelength and the wind spead causes a decreasing in the scintillation and gradually approach a value of 0, the reference [15] study also the affect of the propagation distance on the scintillation index. With an increasing propagation distance, the scintillation index is weakened by the loss of spatial coherence due to the focusing effect being.

The results of our simulations model show that the rise above the sea surface leads to a decrease in the strength of the air turbulence from $c_n^2 = 10^{-7.95}$ for the strong air turbulence to $c_n^2 = 10^{-8.7}$ for the medium air turbulence, regardless of the wind speed Until we reach a height of 400 m, the force of the turbulence change as a function of wind speed also. Compared with result obtained by S. Arnon [35] the strength of turbulence decrease dramatically from $c_n^2 = 10^{-13}$ to $c_n^2 = 10^{-17}$ until the hight of 5000 Km the wind speed affect also the strongest of turbulence. Finally, in light of these results, we suggested some solutions to reduce these effects of atmospheric turbulence and the internal satellite vibrations in constellation to increase the effectiveness of the laser communication system.

7. CONCLUSION

This paper has discussed the laser communication in the constellation of satellites and through atmospheric disturbance. A new modeling approach of laser communication was developed and simulated using Matlab software. The study carried out her can be the basis for future analyses of laser communication through the atmosphere and in the constellations of satellites. This analysis points out that the performance of the network is determined by the satellite that vibrates the most among the satellites in the network, the laser communication in space needs a very complicated pointing system.

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