Optimization of Transmitter Aperture by Genetic Algorithm in Optical Satellite

Karim Kemih, Yacine Yaiche, Malek Benslama

Abstract**—**To establish optical communication between any two satellites, the transmitter satellite must track the beacon of the receiver satellite and point the information optical beam in its direction. Optical tracking and pointing systems for free space suffer during tracking from high-amplitude vibration because of background radiation from interstellar objects such as the Sun, Moon, Earth, and stars in the tracking field of view or the mechanical impact from satellite internal and external sources. The vibrations of beam pointing increase the bit error rate and jam communication between the two satellites. One way to overcome this problem is the use of very small transmitter beam divergence angles of too narrow divergence angle is that the transmitter beam may sometimes miss the receiver satellite, due to pointing vibrations. In this paper we propose the use of genetic algorithm to optimize the BER as function of transmitter optics aperture.

Keywords**—**Optical Satellite Communication, Genetic Algorithm, Transmitter Optics Aperture

I. Introduction

GLOBAL communication from any place on Earth is an attractive goal. One method to achieve this aim is to network satellites together to provide global coverage and access. By this method the information is transferred from the ground to the nearest satellite above and relayed among satellites to the satellite above the destination.[1]. The last satellite then transmits the information to the destination.

Optical intersatellite links have some advantages compared with microwave intersatellite links. The advantages of the optical intersatellite links are:.

- smaller size and weight of the terminal,
- less transmitter power ,
- large bandwidth
- greater immunity to interference,
- a larger data rate,
- acceptability of denser satellite orbit population.

The main disadvantage of optical intersatellite links is the complexity of the pointing system. Pointing systems use two complementary information sources in order to point the information beam in the right direction. The “rough” pointing is based on ephemeredes data (the position of the satellite according to the orbit equation). The fine pointing is based on an electro optics tracking system. The performance of the tracking system is often limited by background radiation. High intensity background radiation is received while tracking the receiver satellite when interstellar objects such as sun, moon, earth, and stars are in the tracking field of view.[2] Due to noise in the tracking system and mechanical vibrations, the transmitter beam to the receiver satellite vibrates. Such vibrations of the transmitted beam in the receiver plane decrease the received signal. The decrease of the signal increase the bit error rate (BER). It is important in satellite optical communication to dissipate minimum power and to obtain minimum BER. This aim can achieved with very small transmitter divergence angle to assure maximum received power. The disadvantages of too narrow a divergence angle in a simplistic manner are that the transmitter beam may sometimes miss the received satellite due to pointing vibrations. Also, for small divergence angles, the transmitter optics aperture is big and expensive.[3] The optimum value of the received power as a function of the optimum beam divergence angle. Based on the above it is important to design the system for real requirements. Such design reduces the price of the mission and increases the reliability of the system Arnon et all have developed a bit error probability (BEP) model [4] that takes into account both vibrations and turbulence-induced log amplitude fluctuations (i.e., signal intensity fading) in a regime in which the receiver aperture *Do* is smaller than the turbulence coherence diameter *do* by using a least square methods. In this paper, we use the performance of genetic algorithm to optimize nonlinear problem in order to improve bit error probability (BEP) model. The obtained results show that the presented method is successful.

II. Vibration Model

The satellite lasers vibrate continuously because of the environments sources. These sources can be divided into two types; source external and interns [1][5-6].

A. External sources

These sources are numerous and different, one can quote however the most known:

- The asymmetry of the terrestrial attraction;

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- The attraction of the sun, the moon, the ground and other celestial bodies;
- pressure of solar radiation;
- The aerodynamic trail.

B. The source internal

These source comprise:
- The vibration and impacts due to the internal noises;
- Vibrations of the antennas of the aiming systems;
- Noise of the system of continuation;
- Operations of the constituent subsets the satellite.

III. EQUATION MODEL

In this paragraph we will take again the mathematical formalism to develop in [4] which determines the relations existing between different parameter tells that: amplitudes of the vibration, the signal report ratio on noise, the factor of the optimal gain, the optimal transmitter aperture telescope to introduce the genetic algorithm.

The optical power P_R received by the receiver satellite is

$$P_R = K.L \tag{1}$$

where

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

and where
λ is the wavelength,
P_T is the transmitter optical power,
Z is the distance between satellites,
η_T is the optics efficiency of the transmitter,
η_R is the optics efficiency of the receiver,
G_R is the receiver gain defined by equation :

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

D_R is the receiver aperture diameter
G_T is the transmitter gain defined by equation:

$$G_T \approx \left(\frac{\pi.D_T}{\lambda}\right)^2 \tag{4}$$

D_T is the transmitter aperture diameter.
The pointing loss factor L is gain by
L is the pointing loss factors,this factor defines the attenuation of the received signal due to inaccurate pointing,

$$L = \exp\left(-G_T.\theta^2\right) \tag{5}$$

where :
θ is the radial pointing error angle.
F_G is the original factor gain defined by equation:

$$F_G = \frac{G_T}{G_{T0}} \tag{6}$$

where:
G_{TO} is the original transmitter gain defined by equation:

$$G_{T0} \approx \left(\frac{\pi.D_{T0}}{\lambda}\right)^2 \tag{7}$$

D_T is the original transmitter aperture diameter .
The receiver is assumed to include an optical detector in direct detection mode with modulation format of on-off-keying (OOK). In such systems the BER for an optimal threshold receiver is

$$BER \approx \frac{1}{2}\int_0^{\infty}\left(1 - erf\left(\frac{R.(P_1(\theta)-P_0(\theta))}{\sqrt{2}.(\sigma_1(\theta)-\sigma_0(\theta))}\right)\right).f(\theta)\,d\theta \tag{8}$$

where:
$P_1(\theta)$are the received optical signal
$\sigma_1(\theta)$ received noise standard deviation for receiving "1",
$P_0(\theta)(\theta)$ are the received optical signal
σ_0 the received noise standard deviation for receiving "0",
R is the responsivity of the detector.
erf is the error function is

$$erf(x) = \frac{2}{\sqrt{\pi}}.\int_0^x \exp\left(-y^2\right)dy \tag{9}$$

The elevation pointing error angle $f(\theta)$ is normally distributed with a probability density

$$f(\theta) = \frac{\theta}{\sigma_\theta^2}\exp\left(-\frac{\theta^2}{2\sigma_\theta^2}\right) \tag{10}$$

σ_θ is the tracking signal vibration amplitude is described by:

$$\sigma_\theta^2 = \frac{1}{SF^2.SNR} \tag{11}$$

where SF is the slope factor of the tracking system
SNR is the signal-to-noise ratio of the tracking system.
.In order to simplify we make the following three approximations.

1- the relation between the standard deviation for receiving 1 and 0 is constant and is described by H= $\sigma_1(\theta) / \sigma_0(\theta)$.
2- The signal for receiving 0 equals zero.
3- The signal for receiving 1 equals P_T.

Under the above assumptions and, the BER can be expressed in simpler form as :

$$BER \approx 0.5 - \frac{1}{\sqrt{\pi}}\int_0^{\infty}\left[\int_0^{(Q.F_G.\exp(-G_{T0}.\theta^2 F_G)}\exp\left(-y^2\right)dy\right]\frac{\theta}{\sigma_\theta^2}\exp\left(-\frac{\theta^2}{2\sigma_\theta^2}\right)d\theta \tag{12}$$

where Q :

$$Q = \frac{P_T.\eta_T.\eta_R.\left(\frac{\lambda}{4.\pi.Z}\right)^2.G_{T0}.G_R}{\sqrt{2}.\sigma_0(\theta)(1+H)} \tag{13}$$

Following Chen and Gardner, we define a new variable

$$u\sqrt{2}.\sigma_\theta = \theta \tag{14}$$

Then becomes

$$BER \approx 0.5 - \frac{2}{\sqrt{\pi}} \int_0^\infty \left[\int_0^{\left(Q.F_G.\exp(-2.G_{T0}.\sigma_\theta^2.u^2 F_G\right)} \exp\left(-y^2\right) dy \right] u.\exp\left(-u^2\right) du \tag{15}$$

we define two new variable as

$$k=Q.F_G \tag{16}$$

and

$$s = 2.\sigma_\theta^2.G_{T0} / Q \tag{17}$$

so that becomes

$$BER \approx 0.5 - \frac{2}{\sqrt{\pi}} \int_0^\infty \left[\int_0^{\left(k.\exp(-s.k..u^2\right)} \exp\left(-y^2\right) dy \right] u.\exp\left(-u^2\right) du \tag{18}$$

Recently a class of method, known as pseudo-random appeared, presenting a significant probability of convergence towards an optimum total of the function to be optimized. The genetic algorithms form part of it.

IV. The Genetic Algorithm

A genetic algorithm (or GA) is aa search technique used in computing to find true or approximate solutions to optimization and search problems. Genetic algorithms are categorized as global search heuristics. Genetic algorithms are a particular class of evolutionary algorithms that use techniques inspired by evolutionary biology such as inheritance, mutation, selection, and crossover (also called recombination).

Genetic algorithms are implemented as a computer simulation in which a population of abstract representations (called chromosomes or the genotype or the genome) of candidate solutions (called individuals, creatures, or phenotypes) to an optimization problem evolves toward better solutions. Traditionally, solutions are represented in binary as strings of 0s and 1s, but other encodings are also possible. The evolution usually starts from a population of randomly generated individuals and happens in generations. In each generation, the fitness of every individual in the population is evaluated, multiple individuals are stochastically selected from the current population (based on their fitness), and modified (recombined and possibly mutated) to form a new population. The new population is then used in the next iteration of the algorithm. Commonly, the algorithm terminates when either a maximum number of generations has been produced, or a satisfactory fitness level has been reached for the population. If the algorithm has terminated due to a maximum number of generations, a satisfactory solution may or may not have been reached [9].

Reproduction allows recombination of the genetic patrimony of the parents into their descendants who, in this way, take advantage of the peculiar characteristics of both the parents. Apart from these two mechanisms a third one, mutation, is acting from time to time. Mutation avoids existence of populations too much uniforms through the accidental change of part of the genetic patrimony. This mechanism actually contributes to guarantee a certain degree of variety in a population.

In analogy with the biological process, a genetic algorithm determines a solution for an optimization problem, his application in satellite constellation increases day in day.[7-8]. A solution to the problem is defined *individual* and it is represented by a *chromosome*. In turn the chromosome is represented by a string of different *genes*, each one associated to a value of a problem variable. A group formed from a predetermined number of individuals is called a *population*. The different temporal configurations of a population during the evolutionary process are called *generations* of individuals or chromosomes.

Every individual must be endowed with an ability of survival, influencing the composition of the population of the following generations. This ability is measured with a *fitness function*, which represents the degree of adaptation of any individual to the environment and it is expressed by a selected function of all the values associated to its genes. A genetic algorithm tries to improve the average value of the fitness function from generation to generation using the followings three genetic operators:

- Selection: The individuals are selected according to their values of fitness function. In particular, a greater probability of reproduction is associated to the individuals of higher value and this allows, as a consequence, a greater probability of transmission of their proper genetic patrimony to the following generations.
- Crossover: The individuals are selected in pairs to generate new individuals that exchange part of the parents' genetic patrimony.
- Mutation: Every gene of the chromosome of the new population can suffer an accidental mutation with a certain probability.

In this paper, to get a concise chromosomal structure and a good level of accuracy, we have decided to define nonbinary chromosomes, working directly with the real values of the parameters under consideration. That is, each chromosome is associated to a given K. In such way the length of the chromosome is constant and equal to N.

The function of evaluation of an individual chromosome (fitness function) must keep track of objective to minimization of the BER. The operators of crossover and mutation are directly tailored to the adopted chromosomal representation. In the case under consideration, the exclusive use of the canonical crossover operator, substantially consisting in cutting in one or more crossover points the two parent chromosomes and in exchanging the relevant genetic material, would limit the optimization to the configurations obtainable by only combining, in various ways, always the same values, except for some new values introduced from time to time by mutation. For this reason we introduce a crossover operator that consists in a linear combination of the two selected chromosomes.

Particularly, after having chosen the two chromosomes to apply the crossover, the two descendant chromosomes are determined by linearly combining, component to component, the two chromosomes parents as follows

pson1 = λpparent1 + (1 – λ)pparent2 ;

pson2 = λpparent2 + (1 – λ)pparent1 .

Where λ is chosen in the interval [0,2]. In fact, from experimental tests this turned out to be the best range in which to choose the value of λ. The probability value to perform this linear crossover rather instead the canonical one must be decided initially. After having operated the crossover, every individual of the population, according to a predetermined probability, is submitted to mutation. It consists in the simple substitution of the value of some gene, also selected according to a predetermined probability, with a value chosen uniformly random in the interval of variability of the previous value. Since the algorithm evolves using only the criterion of the percentage of coverage, then, generation after generation, BER with K near to the minimum are more likely to appear.

The best solutions found from the genetic algorithm can be far from the "good" ones (Pareto-optimal). Of course, increasing the size of the population and the number of generations, in theory, augments the probability to get solutions near to a good one, but, on the other hand, it surely increases the whole computation time. To avoid, therefore, need to introduce a number of individuals and/or a number of generations excessively high, an algorithm of local optimization has been introduced. In this way we can have a greater probability to determine a good solution or, as much as possible, a nearly good one without excessively increasing computation time.

The algorithm of local optimization is founded on selecting and changing, step by step, the values of the various parameters: only one parameter at a time is changed, maintaining unchanged all the others. Particularly, after starting from a solution determined with the genetic algorithm, the first parameter, with a preset discretization step, is varied in all its field of variability and a "better" value of it is determined (i.e. the value which allows to obtain a greater percentage of coverage). Then, the second parameter is varied and so on. After having examined all the parameters, the algorithm may start again from the first one. The algorithm stops as soon as a termination criterion is satisfied (for instance it can concern the maximum number of iterations to operate). Clearly, such algorithm as any other local search algorithm can be of some help only if it is acting in cooperation with a meta-heuristic procedure. In our case it has been designed so as to improve the solutions produced by the genetic algorithm.

V. SIMULATION RESULT

In this section, we present the different result. Let consider all the input parameters chosen as follows (Table 1):

TABLE 1
OPTIMIZATION PARAMETERS

Parameter name	Parameter symbol	value
Avalanche multiplication maximum value	M	200
Noise temperature of electronic system	T	500°K
Transmitter power	P_T	10mW
Receiver telescope diameter	D_R	0.3m
Transmitter telescope diameter	D_{T0}	0.2m
Receiver optics efficiency	η_T	0.8
Transmitter optics efficiency	η_R	0.8
Distance between the satellite	z	45000 km
Electronic bandwidth	B	1.5Ghz
Effective ratio of the ionization	K_{eff}	0.001
Slope factor	SF	1 10^6 rad^{-1}
number of generation		150
number of individual		50
linear crossover probability		80%
individual mutation probability		15%
gene mutation probability		5%

Fig. 3 shows the variations of the BER according to the SNR. The BER varies conversely with the variation of the SNR.

Fig. 4 : represent variation of the factor FG according to the signal report/ratio on noise SNR of the system. From this curve, one notices that FG varies proportionally with the SNR. So one can conclude that the Gt profit is not constant as it is the case for the profit initial Gt0, but varies proportionally with the SNR for adapted to the variations of this report/ratio From equation (18) we define the value of K to obtain a minimum BER, starting from these values one calculation the value of factor of the gain F_G which given by the relation (16). from equation(4), (6), (7), (11) and (17) we have:

$$S=\frac{2G_{T0}}{SF^2 SNRQ} \quad \text{and} \quad D_T=D_{T0}\sqrt{\frac{K}{Q}}$$

The variations of the opening optimal of the transmitting telescope according to the SNR are represented in the figure (5). It is noticed that the opening optimal varies proportionally with the SNR.

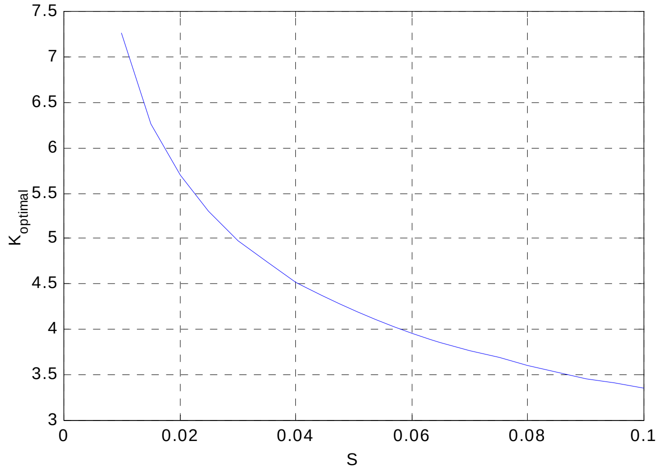

Fig. 1 $K_{optimal}$ vs S: One notes that the Koptimal factor varies conversely with S. For value of variable between 0.01 and 0.1, Koptimal varies between 7.28 and 3.34

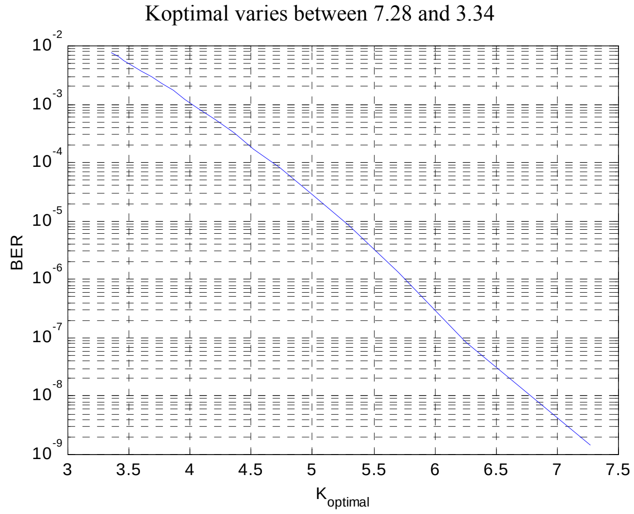

Fig. 2 Represents the variation of bit error rate(BER) according to K_{opimal} , It note that the system with value optimal of K gives very low value of the BER

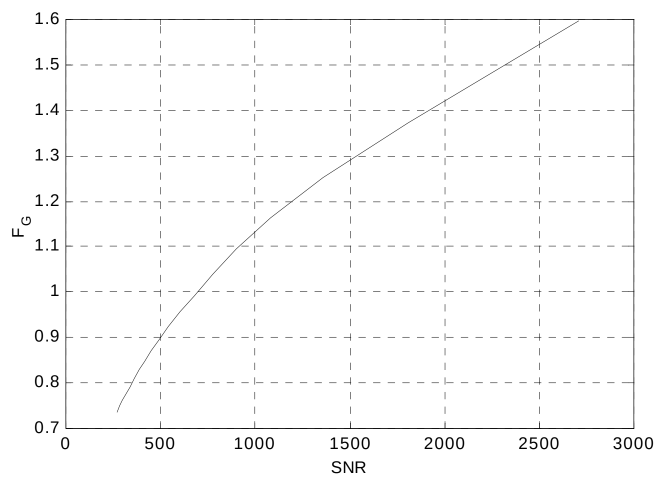

Fig. 3 F_{G} vvs SNR

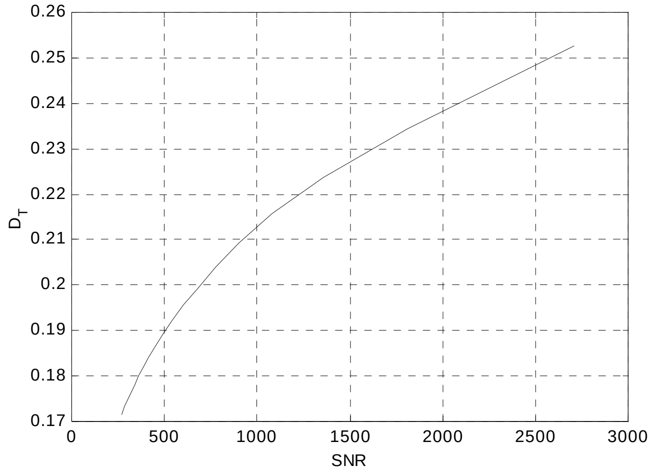

Fig. 4 D_T vs SNR

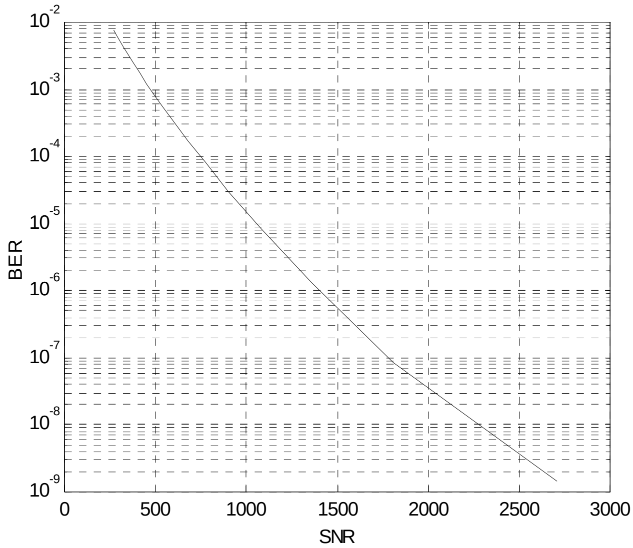

Fig.5 BER vs SNR

VI. Conclusion

In laser satellite network, the adaptation of the aperture of the transmitting telescope to the amplitudes of the vibration is a crucial operation since the latter enable us to obtain a lower rate of bit of error while dissipating the possible minimum of power. in this paper, we have used the performance of genetic algorithm to optimize nonlinear problem in order to improve bit error probability (BEP) model for optimization of transmitter aperture. The obtained results show that the presented method is successful.

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