

Improve the Performance of Transferring WiMAX OFDM Signals Over Laser Communication Links Based on Optimum Gain of Laser Transmitter

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Abstract

A high-altitude platform (HAPs) that can provide high data-rate wireless services is one of the most modern technologies where a WiMAX (IEEE 802.16) base station carried and implemented over its board. HAPs can be considered as a supporting network that wireless broadband services across far distances on the Earth are transferred. The network providing a WiMAX coverage on grounding subscribers includes users on the ground, several HAPs and a satellite. An analog radio frequency (RF) over laser communication (LC) is an optical link, and it is considered as a transmitter link between the HAPs and the satellite in which the WiMAX base station is located. A laser transmitter and an optical receiver are needed to comprise a LC system. Both of them must be strictly aligned to achieve a line of sight link. On the other hand, the transmitter-receiver alignment is probably being defied due to electronic noise and mechanical vibration in the control system causing laser path loss and pointing errors. In other words, the received signal is fading due to the outcome of pointing errors, thus, link performance defects. The goal of this paper is to improve the performance of wireless mobile communication network through minimizing the outage probability of the WiMAX link. This can be done by finding the optimum value of laser transmitter gain, which is finally derived in this paper as a function of θ_r , the radial pointing error angle. Lastly, results and performance of outage probability are evaluated by using computer simulation in MATLAB 11.

Keywords: High-altitude platforms (HAPs), WiMAX, OFDM, Outage probability, Optimum laser transmitter gain, Quadrature amplitude modulation (*M-QAM*).

الخلاصة

المنصة عالية الارتفاع (HAPs) توفر خدمات لاسلكية ذات معدل معلومات عاليه هي واحدة من أكثر التقنيات الحديثة حيث محطة الواي ماكس (IEEE 802.16) WiMAX تحمل وتنفذ على سطحها. المنصات عالية الارتفاع ممكن اعتبارها كشبكة دعم من خلالها يمكن نقل خدمة الاتصالات ذات النطاق العريض عبر مسافات بعيدة عن الأرض. الشبكة التي تجهز تغطية كاملة للمستخدمين لإشارة WiMAX وتتألف من القمر الصناعي، عدة منصات عالية الارتفاع ومستخدمين على الأرض. إشارة الترددات الراديوية التماثلية عبر اتصالات الليزر هو وصلة بصرية ويعتبر وصلة نقل بين المنصات عالية الارتفاع وبين القمر الصناعي حيث وجود محطة الواي ماكس WiMAX. نظام الاتصالات الليزرية يتألف من ناقل ومستلم ضوئي. يجب ان تكون المحاذاة بينهما ذات دقة عالية لتحقيق خط الارتباط البصري. من ناحية أخرى، محاذاة الناقل والمستلم للإشارة ربما تواجه تحدى بسبب الضوضاء الإلكترونية والاهتزازات الميكانيكية في نظام السيطرة مما يسبب في فقدان مسار الليزر وتشكيل أخطاء. بعبارة أخرى، الإشارة المستلمة سوف تتلاشى بسبب نتيجة تشكيل الأخطاء ولهذا يحصل خلل أو ضعف في الاتصال. الهدف من هذا العمل هو تحسين أداء شبكة الاتصالات اللاسلكية من خلال تقليل احتمالية القطع الاتصال لإشارة WiMAX. ويمكن القيام بذلك من خلال إيجاد القيمة المثلى لربح مرسل الليزر، والتي أخيراً اشتقت في هذا العمل كدالة (θ_r)، زاوية الخطأ الملقط النصف قطري. في الختام النتائج وأداء احتمالية القطع نفذت باستخدام الماتلاب 2011.

الكلمات المفتاحية: المنصات العالية الارتفاع (HAPS)، واي ماكس، OFDM، احتمالية الانقطاع، الكسب الأمثل لنقل الليزر، التضمين السعوي الرباعي.

1. Introduction

The commercial demand for high data-rate mobile wireless communication services has been growing, recently. Thus, the need to develop and invent new communication technologies, providing a high data transmission have been accelerated and stimulated. Although, mobile wireless broadband services are carried out by a satellite system or grounded-based, the difficulty in finding a suitable terrestrial location of the base station, heavy installation, maintenance cost, environmental effects and backhaul infrastructures are the most drawbacks that the ground base station suffers. A high power required is an obstacle for satellite systems (Shlomi, 2009; Nicholas *et al.*, 2013). To this end, a high-altitude platform (HAP) in the form of aircraft has been studied and researched, recently, and considered as an

alternative solution for base station location carrying communications. HAPs are located in the stratosphere with an altitude approximately between (17 and 22) Km above the ground. The task of HAPs is to provide commercial communication services to terrestrial subscribers due to their long potential endurance (Anggoro *et al.*, 2007). HAPs have many features as well as long endurance including, great capacity, low transmission delay, reasonable power consumption. Furthermore, a large number of terrestrial base stations can be replaced by a single aerial platform (David *et al.*, 2011).

A Worldwide Interoperability for Microwave Access, WiMAX, is a telecommunications technology based on the IEEE 802.16 standard. This technology can be delivered by HAPs to provide wireless broadband services to commercial clients using a variety of transmission modes. Laser communication (LC) is considered in this paper due to the fact that it makes very high data-rate communication between satellites and HAPs using laser light beams propagation through free space to carry information (Shlomi, 2003). Moreover, LC provides many positive aspects including, high bandwidth, intrinsic narrow beam-width, communication privacy, small equipment size, light weight, simple transceiver, low power consumption and no regulatory restrictions for frequency use (Larry *et al.*, 2005). However, the laser beam has extremely narrow divergence angle making it very sensitive to electronic noise and mechanical vibration in the control system (Anna *et al.*, 2004; Morio, 2006). Therefore, any change of alignment between transmitter laser beam and the receiver (base station) generated a pointing error, and this causes the received signal to fade. Consequently, the loss (outage) of communication services occurs.

In this paper, HAPs network architecture, which takes the role of terrestrial base stations collect and deliver the WiMAX services across distances on Earth, is presented. HAPs have transparent transponders that convert the WiMAX RF signals to optical signals and reverse. In this work, WiMAX quality of service (QoS) is evaluated based on showing the performance of outage probability (OP), bit error rate (BER) and signal to noise ratio (SNR). Outage probability is the probability that the received power level is inadmissible low during specified time duration (Andrea, 2006). Therefore, we determine WiMAX QoS by minimizing the (OP), (BER) and maximizing the (SNR). The performance of the network configuration described later in Section 2 takes into account the effects of laser transmitter parameters (pointing error statistics and jitter angle) as well as parameters of the laser link. In this vein however, (Shlomi, 2009) proposed a network configuration for WiMAX traffic delivery, including a satellite, several HAPs and subscribers on the ground, and derived the laser transmitter gain that minimize the outage probability (OP) of the WiMAX link. In (Nicholas *et al.*, 2013), the authors presented a novel HAP network which provides WiMAX services across far distances on Earth, and they examined their proposed system model with incorporating laser path loss and pointing error effects.

The remaining of this paper is organized as follows: Section 2 shows the system model based on multiple HAPs. In section 3, the outage probability and general optimal laser transmitter gain are derived. In section 4, the proposed derivation to find the optimum laser transmitter gain is discussed and presented in a new way. In section 5, the performance of the proposed approach is evaluated using computer simulation in MATLAB 11. Finally, some concluding remarks are given in section 6.

2. System Model

Figure 1 depicts a system configuration that consists of a satellite, several aerial platforms (HAPs) and subscribers on the ground. Distances between HAPs and the satellite range from hundreds to thousands of kilometers. The satellite builds in the WiMAX base station, a controller system and an optical transmitter which comprises of a high power laser, a modulator uses to modulate a laser radiation and a telescope. Each HAP connects with the satellite via an analog WiMAX RF signal carried over a laser communication link. The analog WiMAX RF signal takes the role to modulate the laser beam (radio-over-fiber transmission). An optical receiver is located on the HAP, and it includes a telescope, a filter, a positive-intrinsic-negative (PIN) photo-detector and a trans-impedance amplifier (TIA). Each of the components mentioned has its task, see (Shlomi, 2009). In order to maintain a viable communication link (proper line-of sight alignment), a tracking mechanism and pointing subsystem are implemented in both of the transceivers of the communication link (Syed *et al.*, 2008).

The WiMAX standard is based on orthogonal frequency-division multiplexing (OFDM). OFDM is a digital multicarrier modulation that utilizes a large number of closely spaced orthogonal subcarriers (Masood *et al.*, 2008). This modulation scheme splits high data-rate streams into low data-rate streams and then transmitted over a number of narrowband subcarriers in parallel. As a result, a frequency selective channel is transformed into a number of flat fading subchannels (Tomoaki, 2003). The channel bandwidth is in the range of 1.25MHz up to 20MHz, and the number of subcarriers in a channel (N) ranges from 128 to 2048. Each subcarrier is modulated with a suitable modulation format such as quadrature amplitude modulation (M -QAM) or quadrature phase shift keying (QPSK), where M ranges between 4 and 64 (John, 2004).

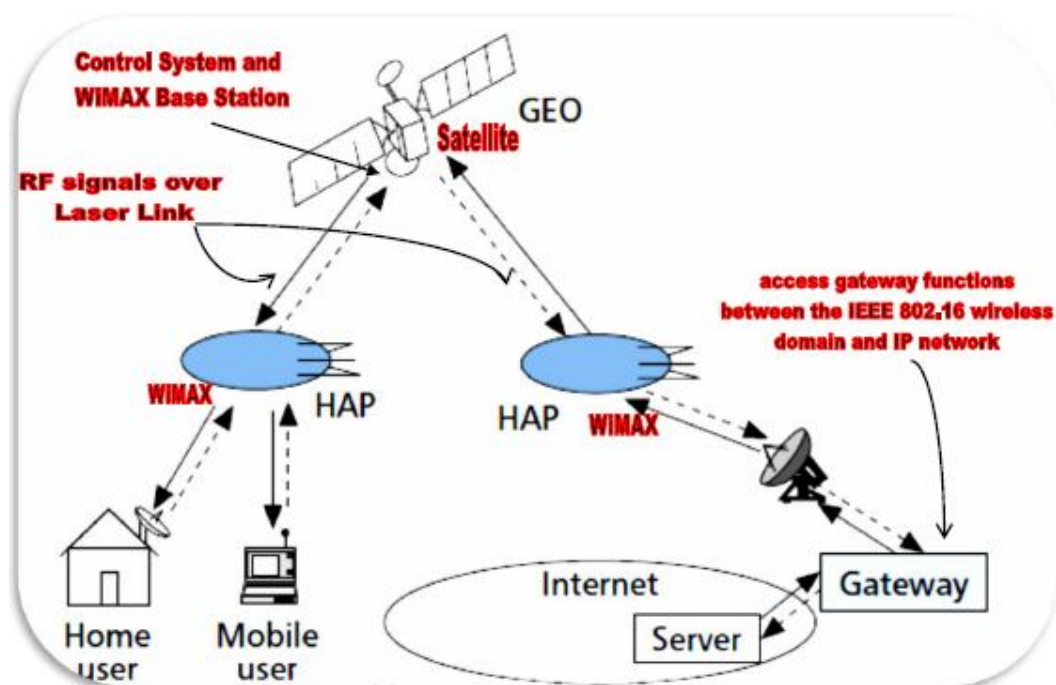


Figure 1: System model consisting of a satellite and several HAPs.

As mentioned formerly, an appropriate pointing subsystem and tracking mechanism are needed to have a viable communication link. However, both mechanical vibration and electronic noise in the tracking and pointing system cause the received spots from the laser beams to wander on the detector planes.

Subsequently, pointing error statistics effects must be taken into account. The probability density functions (Pdf) for elevation and azimuth pointing error angle are based on independent Gaussian distribution, as shown in equations (1) and (2), respectively (Harilaos, 2008).

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

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

where θ_v , θ_H , μ_v , μ_H , σ_v and σ_H are elevating and azimuth pointing angles, their means and standard deviations. The jitter angle standard deviation (σ_θ), and the radial pointing error angle (θ) are given in (3) and (4).

$$\sigma_\theta = \sigma_v = \sigma_H \quad (3)$$

$$\theta = \sqrt{\theta_v^2 + \theta_H^2} \quad (4)$$

The radial pointing error angle is modeled as a Rician density distribution since we assume that the azimuth and elevation processes are **I.I.d** (*independent and identically distributed*) (Chien *et al.*, 1989). The Rician distribution has a Pdf as

$$f(\theta, \varphi) = \frac{\theta}{\sigma_\theta^2} \exp\left(-\frac{\theta^2 + \varphi^2}{2\sigma_\theta^2}\right) I_0\left(\frac{\theta\varphi}{\sigma_\theta^2}\right) \quad (5)$$

Assuming now the bias error angle (φ) is negligible and modifying θ to θ_T in free-space loss, yields the well-known Rayleigh distribution function for the transmitter pointing error angles (Chien *et al.*, 1989). The Pdf of the Rayleigh distribution is given as

$$f(\theta_T) = \frac{\theta_T}{\sigma_\theta^2} \exp\left(-\frac{\theta_T^2}{2\sigma_\theta^2}\right) \quad (6)$$

3. Outage Probability and Laser Transmitter Gain

The optical power signal received by the optical receiver (photo-detector) on board the HAP is described by the well-known Friis transmission formula (Stephen *et al.*, 1995; Anna *et al.*, 2004).

$$P_{R-O}(\theta_T) = P_{T-O} \eta_T \eta_R L_a \left(\frac{\lambda_o}{4\pi d_o}\right)^2 G_{T-O} G_{R-O} L_T(\theta_T) \quad (7)$$

where P_{T-O} is the optical power of the transmitter, η_T and η_R are the optics efficiency of transmitter and receiver, respectively, L_a is the atmospheric loss. G_{T-O} is the optical transmitter gain, G_{R-O} is the optical receiver gain, $L_T(\theta_T)$ is the transmitter pointing loss factor, λ_o is the laser wavelength and d_o is the distance between HAP's optical receiver and satellite's optical transmitter. The transmitter pointing loss factor can be approximated by (Shlomi, 2003), as

$$L_T(\theta_T) = \exp(-G_{T-O}\theta_T^2) \quad (8)$$

The transparent transponder located at the HAPs converts the optical received signal into RF signal, so the RF transmitter power can be given by

$$P_{T-RF}(\theta_T) = K_{O-RF} (P_{R-O}(\theta_T))^2 = K_{O-RF} (\beta_1^2 G_{T-O}^2 \exp(-2G_{T-O}\theta_T^2)) \quad (9)$$

where K_{O-RF} is the ratio between the RF power and the square of optical received power, and

$$\beta_1 = P_{T-O} G_{R-O} \eta_T \eta_R L_d \left(\frac{\lambda_o}{4\pi d_o} \right)^2 \quad (10)$$

Finally, the RF electrical signals are delivered to the end mobile users on the ground, and the received power is given by

$$P_{R-RF}(\theta_T, d_{RF}) = G_{T-O}^2 \beta_2 d_{RF}^{-2} (\exp(-2G_{T-O} \theta_T^2)) \quad (11)$$

where

$$\beta_2 = \left(\frac{\lambda_{RF} \sqrt{G_1}}{4\pi} \right)^2 K_{O-RF} \beta_1^2 \quad (12)$$

Simplifying equation (11), yields

$$\theta_T = \sqrt{-\frac{1}{2G_{T-O}} \ln \left(\frac{P_{R-RF} d_{RF}^2}{\beta_2 G_{T-O}^2} \right)} \quad (13)$$

where d_{RF} is the distance between the HAP and mobile users, $\sqrt{G_1}$ is the product of transmitted and received antenna gains in the line of sight direction, and λ_{RF} is the wave length of RF signal.

Now, the outage probability (OP) is defined as the probability that the received power falls below a specified threshold, $P_{\min}$ at a given distance d . The performance or quality of channel is accepted and satisfied if the received power above the threshold, $P_{\min}$. Otherwise, it is unacceptable (Andrea, 2006). From equations (6) and (13), the outage probability is given by

$$P_{outage}(P_{R-RF}(\theta_T, d_{RF}) < P_{\min}) = 1 - \int_0^{\sqrt{(-1/2G_{T-O}) \ln(P_{\min} d_{RF}^2 / \beta_2 G_{T-O}^2)}} \frac{\theta_T}{\sigma_\theta^2} \exp\left(-\frac{\theta_T^2}{2\sigma_\theta^2}\right) d\theta \quad (14)$$

To simplify equation (14), we solve the right side integration, yielding

$$P_{outage}(P_{R-RF}(\theta_T, d_{RF}) < P_{\min}) = \left(\frac{P_{\min} d_{RF}^2}{\beta_2 G_{T-O}^2} \right)^{\left(\frac{1}{4G_{T-O} \sigma_\theta^2} \right)} \quad (15)$$

In order to find the value of G_{T-O} which minimize the outage probability, we take the first order derivative to the equation (15) with respect to the laser transmitted gain G_{T-O} and equating the results to zero, yielding

$$G_{T-O} = \sqrt{\frac{P_{\min} d_{RF}^2}{\beta_2 \exp(-2)}} \quad (16)$$

Equation (16) is considered a general equation, and it can be solved to provide the transmitter telescope gain when $P_{\min}$, β_2 and d_{RF} are all given.

4. The Proposed Approach to Optimum Laser Transmitter Gain

We propose and derive in this section another approach to find an optimum laser transmitter telescope gain required to achieve the minimum threshold RF received power ($P_{\min}$) for the ground users. This can be done by deriving a mathematical model for the minimum optical transmitter power ($P_{T-O \min}$) from the satellite transmitter required to keep communication links in a good condition. The optical transmitter power is given in equation (17).

$$P_{T-O}(\theta_T) = P_{T-Oav} \eta_T G_{T-O} L_T(\theta_T) \quad (17)$$

Substituting (8) into (17), yielding

$$P_{T-O}(\theta_T) = P_{T-Oav} \eta_T G_{T-O} \exp(-G_{T-O} \theta_T^2) \quad (18)$$

To find the minimum of $P_{T-O}(\theta_T)$, we differentiate both sides of equation (18) with respect to G_{T-O} and equating the result to zero

$$\begin{aligned} \frac{\partial P_{T-O}(\theta_T)}{\partial G_{T-O}} &= P_{T-Oav} \eta_T [G_{T-O}(-\theta_T^2) \exp(-G_{T-O} \theta_T^2) + \exp(-G_{T-O} \theta_T^2) * 1], \\ 0 &= P_{T-Oav} \eta_T \exp(-G_{T-O} \theta_T^2) \{G_{T-O}(-\theta_T^2) + 1\}, \\ 0 &= \{G_{T-O}(-\theta_T^2) + 1\}, \\ G_{T-O} &= \frac{1}{\theta_T^2} \end{aligned} \quad (19)$$

The derivation is led to result that the optimum laser transmitter antenna gain is only a function of pointing error angle, θ_T . Taking now the second order derivative to (18) with respect to G_{T-O} in order to show whether the minimum optical transmitter power (P_{T-Omin}) can be obtained or not. The minimum is obtained if and only if the second order derivative is greater than zero (positive). The derivation is shown in (20).

$$\frac{\partial^2 P_{T-O}(\theta_T)}{\partial G_{T-O}^2} = P_{T-Oav} \eta_T \left[(-\theta_T^2)(G_{T-O}(-\theta_T^2) \exp(-G_{T-O} \theta_T^2) + \exp(-G_{T-O} \theta_T^2) * 1) \right] \quad (20)$$

Substituting (19) into (20) and canceling the common factors, yielding

$$\frac{\partial^2 P_{T-O}(\theta_T)}{\partial G_{T-O}^2} = P_{T-Oav} \eta_T [\theta_T^2 \exp(-1)] > 0 \quad (21)$$

As can be seen from (21), the second order derivative is positive for any value of θ_T . This is an indication that the minimum optical transmitter power is obtained at the value of $G_{T-O} = 1/\theta_T^2$.

The WiMAX standard parameters that based on OFDM are now considered in our model in equations (15) and (16). The WiMAX network utilizes a cellular configuration consisting of clusters such that each cluster includes n_c cells that are supported by HAPs. The approximate entirety bandwidth is the channel use in each cell multiplied by cluster size (Shlomi, 2009). The symbol error rate of each subcarrier is given by

$$SER \leq 4Q\left(\sqrt{\frac{3SNR}{M-1}}\right) \quad (22)$$

and $Q(\cdot)$ is the complementary error function

$$Q(y) = \frac{1}{\sqrt{2\pi}} \int_y^\infty \exp\left(-\frac{x^2}{2}\right) dx \quad (23)$$

where M is the constellation size ($M = 2^m$, m is number of bits) ranging between 4 and 64, and $\overline{SNR}$ is the average signal to noise ratio given by (Andrea, 2006), as

$$\overline{SNR} = \frac{\overline{P_s}}{(N_{RF} + N_o)} T_s \quad (24)$$

where T_s is the symbol duration time, $\overline{P_s}$ is the average symbol power, N_{RF} and N_o are the noise power density due to the front end of the RF subscriber receiver and the

optical receiver, respectively. The value of $N_o \ll N_{RF}$, so in most cases, N_o is negligible (Shlomi, 2009). The minimum received power level for ground user, $P_{\min}$, to maintain an accepted performance can be calculated as follows:

$$P_{\min} = n_c \bar{P}_s N \quad (25)$$

From equations (15), (22) and (25), the outage probability is given by

$$P_{\text{outage}}(P_{R-RF}(\theta_T, d_{RF}) < P_{\min}) \leq \left(\frac{(N_{RF} + N_o) n_c N (M-1) (Q^{-1}(SER/4))^2}{3 \beta_2 G_{T-O}^2 d_{RF}^{-2} T_s} \right)^{\left(\frac{1}{4 G_{T-O} \sigma_\theta^2} \right)} \quad (26)$$

5. Simulation and Results

The typical set of parameter values that have been used in our simulation result is shown in Table (1). The simulation results for $(T_b = 25 * 10^{-9} \text{ sec}, \theta_T = 1 * 10^{-6} \text{ rad})$ with different M -QAM scheme are shown in Table (2). Note that T_b is the bit duration time and $T_s = m * T_b$. We notice that G_{T-O} doesn't change as M increases, since it is only a function of θ_T .

Table (1) System Practical Parameters

Symbol	N_{RF}	L_a	n_c	N	d_o	λ_o
Value	$5 * 10^{-19} \text{ W / Hz}$	0.9	7	1024	40000 km	$1.55 \mu\text{m}$
Symbol	N_o	K_{O-RF}	SER	η_T	η_R	λ_{RF}
Value	10^{-22} W / Hz	140 dB	10^{-6}	0.9	0.9	8.57 cm

Table (2) Simulation Results

m	M	T_s (μs)	SER	BER	SNR	P_s (nW)	$P_{\min}$ (μW)	P_{R-O} (nW)	P_{T-RF} (W)	G_{T-O}	$P_{T-O \min}$ (W)
2	4	0.05	10^{-6}	$2 * 10^{-6}$	25.2638	0.25269	1.8113	13.375	0.0179	10^{12}	5.2449
4	16	0.1	10^{-6}	$4 * 10^{-6}$	126.3191	0.63172	4.5282	21.147	0.0447	10^{12}	8.2926
6	64	0.15	10^{-6}	$6 * 10^{-6}$	530.5402	1.7688	12.679	35.386	0.1252	10^{12}	13.8763

Table (2) shows an acceptable performance of the proposed scheme with maintaining low bit error rate ($2 * 10^{-6}$ for 4-QAM), ($4 * 10^{-6}$ for 16-QAM) and ($6 * 10^{-6}$ for 64-QAM). Moreover, high power signal to noise ratio are obtained. In addition to the results presented in table (2), the performance evaluation of optical transmitter power P_{T-O} as a function of optical transmitter telescope gain G_{T-O} is also plotted. It can be seen from Figure (2), the optical transmitter power decreases from close to 10^3 to close to 5.2249 which is the minimum power required and then goes up to 10^3 for an increase in the G_{T-O} from $2 * 10^9$ to $8.2 * 10^{12}$ with (4-QAM). In Figure (3), the optical transmitter power decreases from close to 10^3 to close to 8.2926 which is the minimum power required and then goes up to 10^3 for an increase in the G_{T-O} from $3 * 10^9$ to close to $8 * 10^{12}$ with (16-QAM).

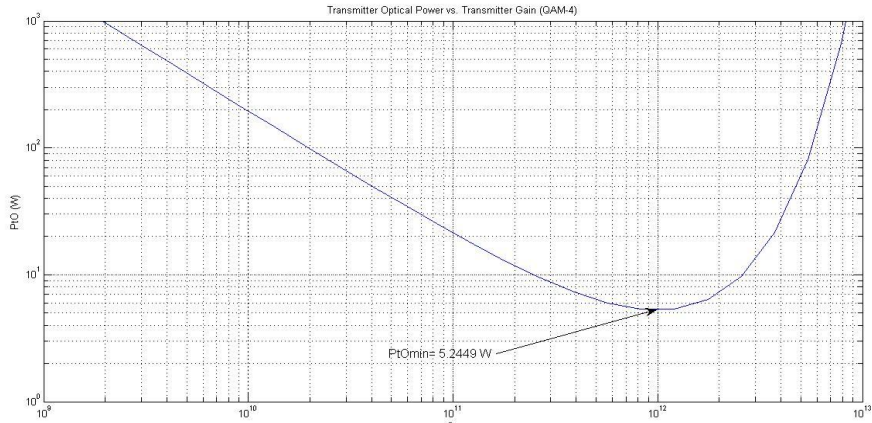


Figure 2: P_{T-O} versus G_{T-O} , 4-QAM

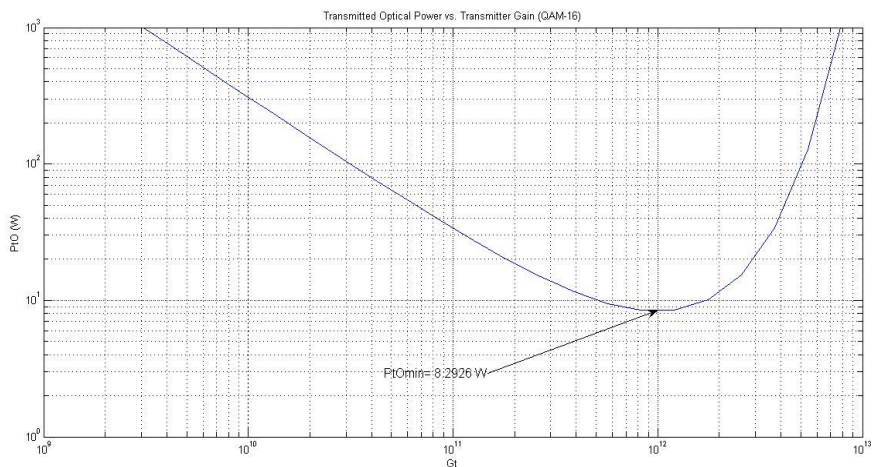


Figure 3: P_{T-O} versus G_{T-O} , 16-QAM

Figure (4) also illustrates the optical transmitter power versus optical transmitter gain knowing constellation size is equal to 64. P_{T-O} decreases from 10^3 to close to 13.8763 which is the minimum power required and then goes up to 10^3 for an increase in the G_{T-O} from 5×10^9 to close to 7×10^{12} .

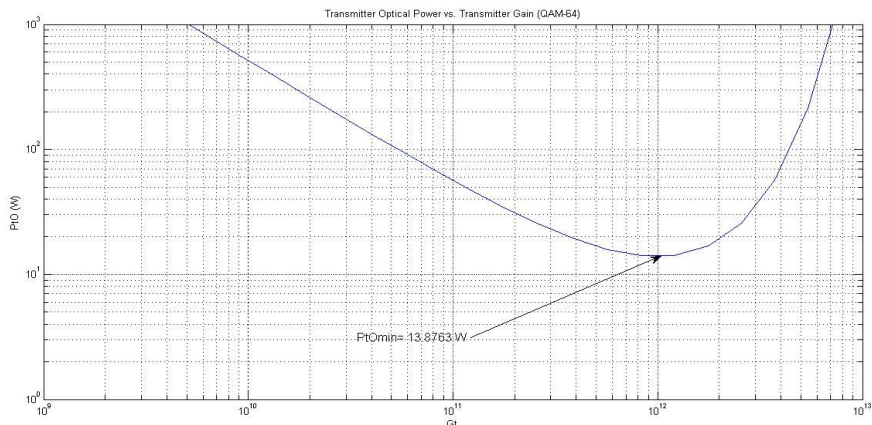


Figure 4: P_{T-O} versus G_{T-O} , 64-QAM

Figure (5) shows the performance of outage probability with respect to jitter angle standard deviation with different M -QAM. It can be seen from the plot that the outage probability rises dramatically from 10^{-50} to 10^{-1} for an increase in the jitter

angle from $6.7 \times 10^{-8} \text{ rad}$ to close to $1.5 \times 10^{-6} \text{ rad}$. Perfect performance (outage probability $= 10^{-50}$) is obtained when $\theta_T = 6.7 \times 10^{-8} \text{ rad}$ which represents an optimal value.

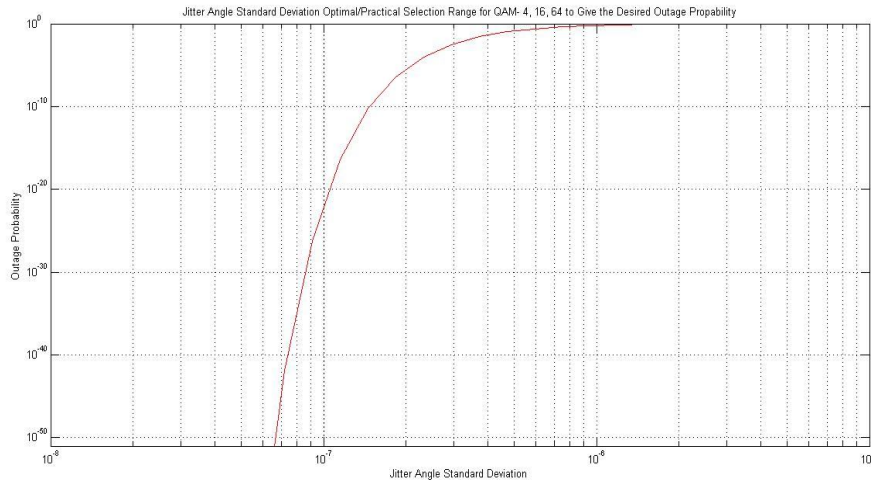


Figure 5: Optimal/Practical Selection Range for Satellite's Laser Transmitter Designers

It can be shown from the former figures that high optical power must be transmitted from satellite transmitter if the transmitter telescope gain is low to maintain reliable performance. However, minimum optical power is needed at the point in which the optimum transmitter antenna gain is calculated. As a result, the value of optimum G_{T-O} is 120 dB required to transmit minimum optical power from the satellite and to ensure the received power at ground users above the threshold, $P_{\min}$.

Figure (6) depicts another performance evaluation for our system model that is signal to noise ratio versus transmitter jitter angle standard deviation with different $M-QAM$. It is given to engineering designers an appropriate selection to range of jitter angle (σ_θ) that provides a desired signal to noise ratio to maintain our system in reliable performance. The best performance is obtained (SNR=1000) when $\sigma_\theta = 9 \times 10^{-7}$ for 64-QAM.

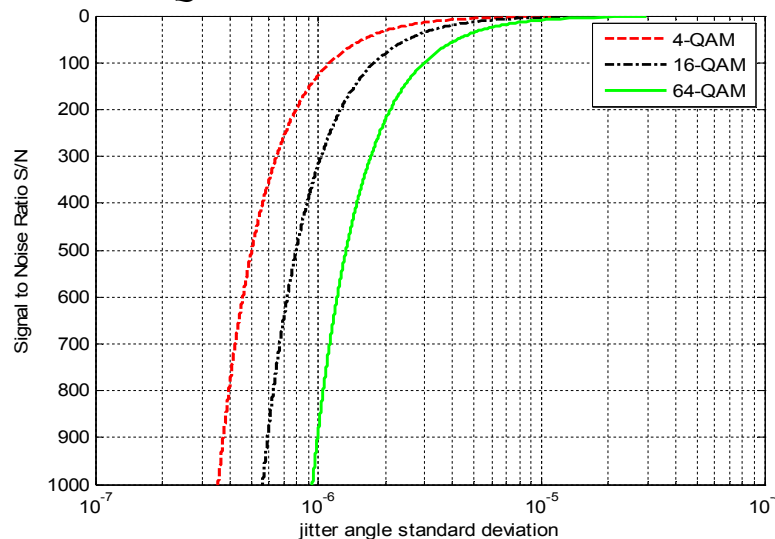


Figure 6: Optimal Jitter Angle Standard Deviation Selection Range to give desired Signal to Noise Ratio

However, Figure (7) illustrates signal to noise ratio with respect to the received power at mobile users with different M -QAM. It can be seen from both figures (6) and (7) that reducing the pointing jitter angle (σ_θ) results, increasing in the average symbol power received at ground users. Thereby, signal to noise ratio rises and the performance improved.

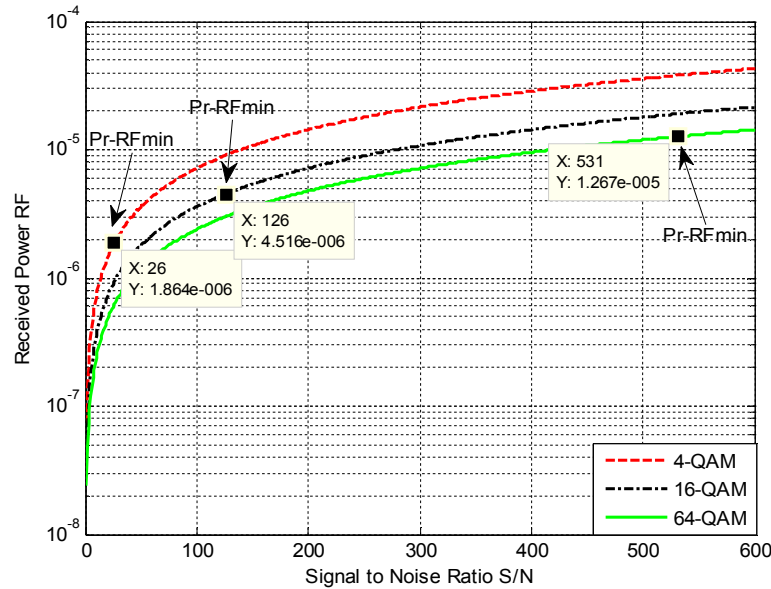


Figure 7: Received Radio Frequency Power versus Signal to Noise Ratio

6. Conclusion

In this paper, it is obvious from the results transferring WiMAX RF signals over laser communication links between satellite and HAPs can be truly implemented. The optimum value of laser transmitter gain (G_{T-O}) that depends only on pointing error angle (θ_T) was derived to minimize the outage probability and to achieve the minimum threshold RF power ($P_{\min}$) required for the ground users. As can be seen from the table result the increments of values (P_{R-O} , $P_{T-O\min}$, P_{T-RF} and $P_{\min}$) are approximated to be linear. The optical transmitter power (P_{T-O}) was seen to be identical for three values of constellation size M , and its minimum is occurred at the optimum value of G_{T-O} which is 120 dB in our case.

Any small increment percentages in jitter angle decrease the alignment between transmitter laser beam and the receiver field of view. This makes the outage probability scaling goes up making our system completely lost, thus, proper tracking and pointing systems need to be considered. However, there is a more flexibility to choose different values of jitter angle standard deviation up to the value that gives perfect or ideal performance to our system with outage probability (10^{-50}) as demonstrated in Figure (5). Most importantly, Figures (5) and (6) illustrate how important jitter angle standard deviation to satellite's laser transmitter designers. The performance of the system with respect to outage probability is founded to be the same for $M = 4, 16$ and 64 QAM once $P_{T-O\min}$ is determined. The signal to noise ratio as a function of the received power at mobile users was plotted as shown in Figure (7). Finally, the results show that the received power and signal to noise ratio increase as the constellation size increases, meaning that the high modulation order provides most powerful SNR performance.

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