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Analysis of Losses in Geostationary Intersatellite Optical Wireless Communication Links

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Abstract

The effective method to create a link between satellites is inter-satellite communication. Data is transmitted from one side to the other via a laser in this groundbreaking method. Optical networks, which offer continuous data transport over vast distances, are networks with high bandwidth efficiency. Inter-satellite optical wireless communication (Is-OWC) is a common method to transfer high-speed data between various satellites in free space. Is-OWC networks have undoubtedly innovated satellite communications networks recently. We have assessed the Is-OWC communication link's capability for high-speed data transfer in this work. In addition, we analyze some of the major obstacles that this technology faces and explain them. This study contrasts how various losses affect a geostationary satellite's receiving antenna's output power. The antenna elevation angle of an earth station needs to be determined in order to connect with satellites. Even if there are a lot of restrictions on satellite communication between the earth station and the satellite in both the uplink and downlink directions, air attenuations, rain, and noise. Therefore, some of the performance-limiting parameters, such as attenuation loss, elevation angle, pointing loss, free space path loss, divergence angle, antenna gain and Q-Factor, are identified in this work along with an attempt to examine how we might improve functionality.

Keywords: Is-OWC, inter-satellite links (ISL), attenuation, pointing loss, free space path loss, elevation angle, divergence angle, antenna gain, q-factor

INTRODUCTION

A satellite is basically any object that orbits a planet in a circular or elliptical path. In more than 50 years, satellite communication has made significant strides toward high-speed transmission [1]. On the other hand, these developments have coincided with notable gains in other IT and telecom systems' performance. A completely new class of civilian and military operations in surveillance, telecommunications, object tracking, and space exploration are made possible by satellite communications systems [2]. Small satellite manufacturing in bulk clusters may be useful for a variety of applications, including water management exploration, mapping in gravity, science missions, and wildfire monitoring, since independent satellites are limited by volume, strength, and space. By leveraging multi-satellite systems, the development of communications satellites would enable a more thorough comprehension of the near-earth environment in addition to a more effective and economical means of reaching space [3]. Once more, networking expansion in space is achievable with wireless optical transmission, which provides high-speed transmission without human interference by exchanging approach and position data and preserving spacecraft point-in-time synchronization [4-6]. Only three geostationary

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satellites are needed to cover the Earth. When these three GEO satellites are linked by optical wireless communication, the earth can be covered by one satellite [7]. Consequently, IS-OWC is a crucial factor to consider while building satellites. This study describes the various studies being conducted in the field of satellite communications to introduce multicommunication based on various orbits. The advantages of IS-OWC systems over radio frequency-based communication include greater bandwidth, faster transfer rates, less electromagnetic interference (EMI), reduced transmission losses, and enhanced [8]. For IS-OWC system there is no need to invest individually and reduce cost as there is any need to choose earth station. An ISL permits earth station of two networks to be interconnected and hence the geographical coverage of the two satellites is combined. So inter-satellite plays an important role in global communication [9]. However, when we transmit data from transmitter to receiver, there are some losses in received power, which must be taken into consideration. In this research work, we try to acknowledge some losses like attenuation loss, free space loss and pointing loss [10-12]. Other factors that affect the overall performance of the system include the distance between the two ends of the link, the power of the transmitted laser, the transceiver antenna aperture, and the elevation angle. In this study, we focus on a study of geostationary inter-satellite OWC link losses through which three satellites are connected at a time to centrally control the total communication.

In the research paper, they say that the free space propagation medium between satellites controls transmission in intersatellite OWC [13]. An essential component of satellite communication is line-of-sight connection. A modest beam divergence or misalignment can result in a significant loss of pointing, acquisition, and tracking (PAT) in a line-of-sight link. Pointing error, which results from the satellite's vibration and base motion, usually has a value of 1 µrad. They find pointing errors separately for transmitter and receiver. However, we find the value of pointing error by choosing system parameters in equation 17. Two satellites serve as the transmitter and receiver in an IS-OWC system and free space serves as a conduit for the light signal to flow through. Satellites in the same orbit are connected using is-OWC technology. Turbulence's effect causes the receiver pointing error angle parameters to grow in value [14]. It is crucial to take into account restrictions like bandwidth, optical power, beam divergence angle, optical losses, BER, receiver sensitivity, and turbulence effects while analyzing Is-OWC performance. For Is-OWC, the primary sources of turbulence are pointing error and scintillation.

In in the study manuscript [15]. they theorize about certain difficulties that lead to subpar performance in inter-satellite communication links, such as beam divergence, sending pointing errors and receiving pointing errors. Using the MATLAB simulator, we attempt to determine the precise value of various faults and determine the actual receiving power.

Only link attenuation for various space scenarios is described in study work [16]. which demonstrates that quantum communication links even include GEO satellites. We express frequency vs. divergence angle using the divergence angle equation presented in this publication. The angle of divergence is inversely related to frequency. The frequency divergence angle will decrease as we increase it, and we can expand our investigation by changing the transmitter's diameter.

The research study describes the block diagram of an uplink, transponder, and downlink component of a communication satellite [17-21]. They also concentrate on "Bangabandhu Satellite-1," Bangladesh's first geosynchronous orbiting (GEO) satellite, examining its prices, features, and ground control facilities.

This paper compares the effects of earth station elevation angle on satellite communication attenuation for geostationary and non-geostationary satellite systems [22]. The findings from MATLAB show that the elevation angle at which the minimum is approximately 5°, however this has little bearing on the maximum transmission path value when $\theta = 0$.

According to a study that examined the outage behavior of optical intersatellite communication cables, longer wavelengths outperform shorter ones [25]. The following factors were examined in the study: selection, equal gain combining, transmitter modifications, source-induced and statistically connected fading. Combining works better when the correlation coefficient is less than 0.5, to be more exact, the EGC technique outperforms the SC strategy.

A quick reference method for choosing satellites according to the highest elevation angle at the center of the historical period is presented in this study [27]. The analysis's findings indicate that the new technique is easier to implement in practice than the two additional algorithms, and the chosen reference satellite has both a sufficient amount of accessible time and a better geometry structure.

The aim of the study is to analyze the losses of geostationary inter-satellite OWC links through which three satellites are connected at a time to centrally control the total communication. The focus of the research work is to examine the received power for a sample Ku-band satellite link that is experiencing a loss. The target of the research is to find the exact value of the elevation angle from which we can get the maximum area coverage on Earth and the focus of this research is to achieve rapid transmission speed by reducing the potential for transmission loss due to free space across the longest distance in satellite communications. An analytical approach will be developed to find losses in geostationary inter-satellite OWC link [22-24]. The research work will aim to analyze the received power for a representative satellite link operating in Ku-band considering various types of losses such as attenuation loss, pointing error, free space path loss and elevation angle. The results are obtained from computer simulation using MATLAB and the results are validated with some experimental data from references.

There are three parts to the satellite communication:

1. Uplink portion (Ground Station)
2. Transponder (Airborne Satellite)
3. Downlink portion (Ground Station)

The following parts make up the uplink section–

- Intermediate Frequency (IF) Modulator
- Band Pass Filter (BPF)
- Up Converter (Mixer, BPF & Uplink Frequency Microwave Generator)
- High Power Amplifier (HPA)
- Transmitting (Tx) Antenna

SYSTEM MODEL

Block diagram of a geostationary satellite communication link is shown in Figure 1.

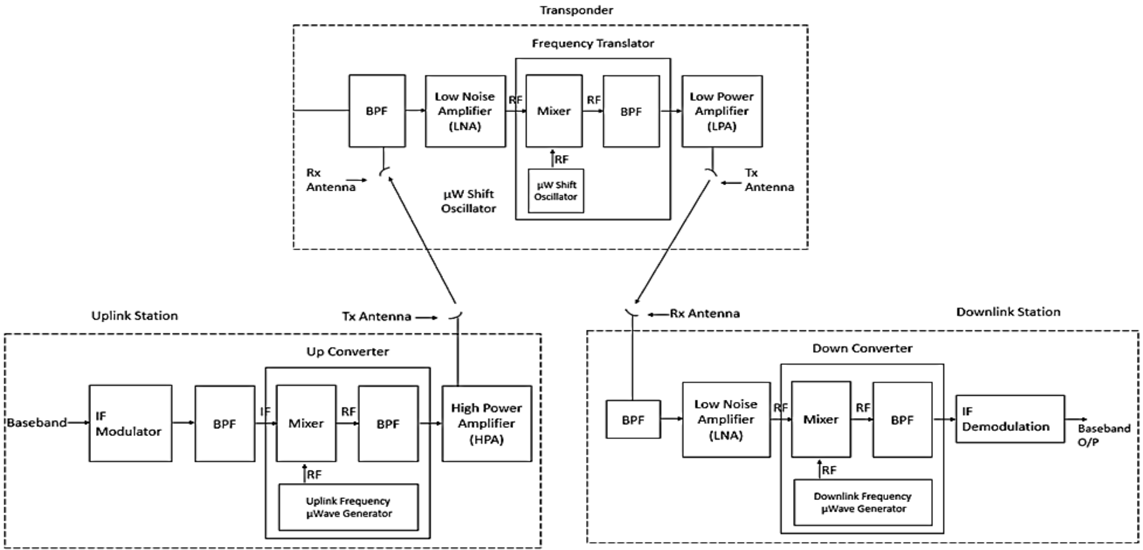

Figure 1. Block diagram of a geostationary satellite communication link [17].

A baseband signal is the signal that the user wishes to sendIt is fed into an intermediate frequency (IF) modulator, which, depending on the situation, uses various modulation processes, like as ASK, FSK, and PSK, to convert baseband frequency to intermediate frequency. A Band Pass Filter (BPF) is used to remove unwanted frequency components from the output IF. The IF is transferred to the UP-Converter, where an Uplink Frequency Microwave Generator and Mixer are used to enhance the IF range (MHz) to Radio Frequency (RF) range (GHz). In this case, intermediate frequency (IF) = (LO – RF) and radio frequency (RF) = (LO + IF). Local oscillator frequency, or LO, is used here. For the RF signal to become more precise uplink frequency there is an additional BPF [26]. Prior to being radiated through a transmission (Tx) antenna, the RF is lastly put through a High-Power Amplifier (HPA) to increase its strength and allow it to travel a great distance.

The following subsections make up the Transponder

- Receiving (Rx) Antenna
- Band Pass Filter (BPF)
- Low Noise Amplifier (LNA)
- Frequency Translator
- Low Power Amplifier (LPA)
- Transmitting (Tx) Antenna

Inferred by Transponder is Transmitter + Responder. The frequency that is transmitted from the uplink section and the frequency that a receiving (Rx) antenna at the transponder receives are the same. Noise filtering is done with a Band Pass Filter (BPF). The Low Noise Amplifier (LNA), a tunnel diode, receives the RF signal after which it amplifies it while maintaining an extremely low noise level.

In order to achieve certain benefits (such reduced antenna size and power consumption), downlink frequency is typically maintained at a level 2 GHz lower than uplink frequency. The frequency translator uses a mixer and microwave shift oscillator to convert frequencies. Again, a BPF is used to get a more accurate downlink frequency.

The downlink frequency is then transmitted through the transponder's transmission (Tx) antenna after passing through a Low Power Amplifier (LPA) to strengthen it for the trip back to Earth.

The following parts make up the downlink section

- Receiving (Rx) Antenna
- Band Pass Filter (BPF)
- Low Noise Amplifier (LNA)
- Down Converter (Mixer, BPF & Downlink Frequency Microwave Generator)
- Intermediate Frequency (IF) Demodulator

The frequency that the transponder transmits, and the receiving antenna receives are the same. Using a Band Pass Filter (BPF), unwanted frequency components are eliminated. After that, the Low Noise Amplifier (LNA) receives the RF signal to be amplified. The RF signal is then fed to the down-converter, where a mixer and downlink frequency microwave generator aid reduce the RF range (GHz) to the IF range (MHz). Baseband frequency is obtained by converting intermediate frequency (IF) using an IF demodulator. This baseband signal is the one that the user transmitted from the uplink part using a transponder.

Figure 2 shows a standard ISL optical link, similar to any other kind of communication system. A continuous wave (CW) laser having an FWHM of 10MHz and a power of 10dBm is called a laser diode. With a period of 2^7–1, Pnseq produces the pseudorandom binary sequence (PRBS) at a high data rate. A modulator externally modulates an input data signal to create return-to-zero (RZ) or non-return-to-zero PRBS signals. One possible irradiation mechanism in the transmitter is a lens or a telescope.

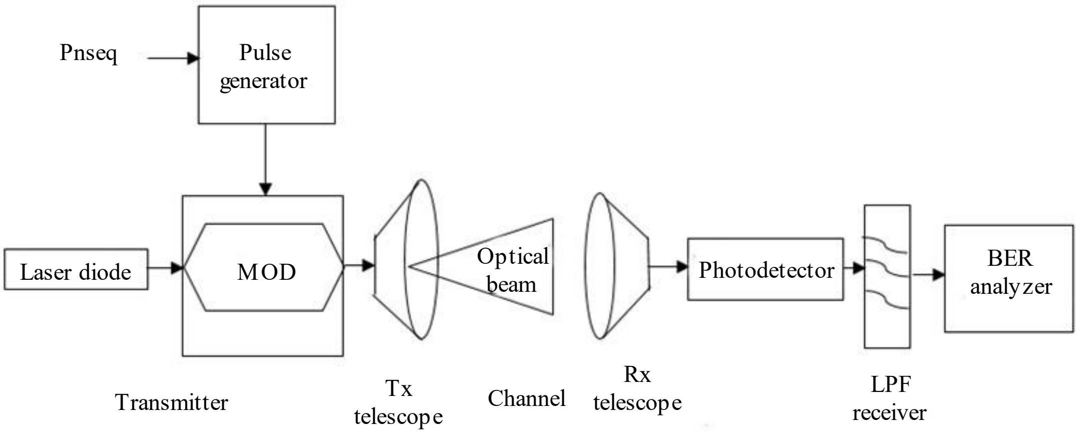

Figure 2. Schematic configuration of a free space inter-satellite optical link [29].

The receiver at the other end of the link receives the signal after traveling over the optical wireless channel (OWC) as a narrow electromagnetic beam.

A bit error rate (BER) analyzer, an optical detector, and a low-pass filter (LPF) make up the receiver subsystem. The output of the photo detector is fed into a low-pass Bessel filter, which eliminates any high-frequency components from the signal and increases the signal-to-noise ratio of the signal that is received. The signal's performance at the receiver has been monitored using a BER analyzer [29].

ANALYSIS OF THE SYSTEM

Constraints including bandwidth, divergence angle, optical power, optical losses, attenuation loss, receiver sensitivity, BER and turbulence effects like pointing error and scintillation must be taken into account while analyzing geostationary intersatellite optical wireless communication networks. Attenuation loss, aiming error, free space path loss, elevation angle, divergence angle, and antenna gain are some of the aspects that this work tries to consider.

The related equation based on block diagram provided in FIGURE 2 and FIGURE 3 is given. Here is the equation's final form and its key derivations [28]. By utilizing the final form, we get the desired outcomes.

Basic link Equation for Received power:

The link's parameters are described as :

- p_t = Transmitted power (w)
- P_r= Received power (dBw)
- g_t = Transmit antenna gain
- g_r = Receive antenna gain
- r = Path distance (meters or km)

The receiving antenna terminals' power of receiver, $\mathbf{P_r}$ is,

$$P_r = p_t g_t \left({}^{1}\!/\!_{l_{FS}} \right) g_r$$

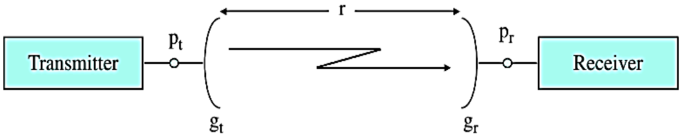

Figure 3. Ku-Band link parameters.

$$\mathrm{P_r} = \mathrm{EIRP}\left({}^{1}\!/_{\mathrm{l_{FS}}}\right)\mathrm{g_r}$$

Or, expressed in dB,

$$\mathbf{P_r}\ (\mathrm{dB}) = \mathrm{EIRP} + \mathbf{G_r} - \mathbf{L_{FS}} \tag{1}$$

Where,

EIRP = Effective Isotropic Radiated Power in dB $\mathbf{l_{FS}}$ = Free Space path loss

Without any loss consideration we can say,

$$\mathrm{P_r}\ (\mathrm{dB}) = \mathrm{EIRP} + \mathrm{G_r} \tag{2}$$

Effective Isotropic Radiated Power:

An essential factor in assessing the radiofrequency link's performance is its effective isotropic radiated power, EIRP[28].

$$\mathrm{EIRP} = \mathbf{P_t} + \mathbf{G_t}\text{ , in d} \tag{3}$$

Where,

- $\mathbf{P_t}$= Transmit power
- $\mathbf{G_t}/\mathbf{G_r}$ = Transmitter/Receiver antenna gain

Antenna gain:

For the specified frequency f in GHz and antenna diameter m in meters

$$\mathrm{g} = \eta_A(10.472\mathrm{fd})^2$$

$$\mathrm{g} = 109.66\mathrm{f}^2\mathrm{d}^2\eta_A \tag{4}$$

Or, in dBi

$$\mathrm{G_t} = \mathrm{G_r} = \mathrm{G} = 10\log(109.66\mathrm{f}^2\mathrm{d}^2\eta_A) \tag{5}$$

Where related parameters are-

- G_t = Transmitter antenna gain
- G_r =Receiver antenna gain
- f = Frequency
- d = Antenna diameter
- η_A = Antenna efficiency

Link Attenuation:

The following equation was employed in the study to measure the attenuation [15]. (A) for inter-satellite and satellite-to-earth links:

$$A = \frac{\mathrm{L}^2(\theta_T^2+\theta_{atm}^2)}{\mathrm{D}_R^2} . \frac{1}{\mathrm{T_T}(1-\mathrm{L_P})\mathrm{T_R}} . 10^{\frac{\mathrm{A_{atm}}}{10}} \tag{6}$$

Atmospheric turbulences can also result in attenuation reduction because they have no effect on the intersatellite communication link, as the equation below illustrates:

$$\mathrm{A} = \frac{\mathrm{L}^2\,\theta_T^2}{\mathrm{D}_R^2} \cdot \frac{1}{\mathrm{T_T}(1-\mathrm{L_P})\mathrm{T_R}} \tag{7}$$

Where,

- A = Attenuation
- L = Link distance
- D_R = Diameter of the received telescope
- T_T = T_R = Transmission factors of telescope
- L_P= Pointing loss
- θ_T = Divergence angle

According to the study's measurements of attenuation for GEO-GEO intersatellite communications, larger optical antenna are needed for greater transmission distances.

$$\theta_T = \frac{\lambda}{D_T} \tag{8}$$

As, $c = f * \lambda$

$$\theta_T = \frac{0.3}{f\, D_T} \tag{9}$$

$$\therefore\ \theta_T \propto \frac{1}{f} \tag{10}$$

Where,
Wavelength = λ
Speed of light = c

So, received power without Attenuation loss is-

$$P_r\ (dB) = EIRP + G_r - L_a \tag{11}$$

Free Space Path loss:
Free space path loss is measured by the equation –

$$l_{FS} = (\frac{4\pi r}{\lambda})^2 \tag{12}$$

Free space path loss in dB,

$$L_{FS} = 20\log(\frac{4\pi r}{\lambda}) \tag{13}$$

All radio waves that propagate in free space or in areas with properties that resemble the uniformity of free space, such the earth's atmosphere, experience free space path loss. It is possible to simplify the dB formula for the free space path loss for particular units utilized while calculating links. Rewriting Equation 12 as a frequency expression,

$$l_{FS} = (\frac{4\pi r}{\lambda})^2 = (\frac{4\pi r f}{c})^2 \tag{14}$$

Regarding the frequency f in GHz and the range r in meters,

$$l_{FS} = (\frac{4\pi r(f\times 10^9)}{(3\times 10^8)})^2 = (\frac{40\pi}{3}.r.f)^2$$

$$L_{FS}(dB) = 20\log(f) + 20\log(r) + 20\log(\frac{40\pi}{3})$$

$$L_{FS}(dB) = 20\log(f) + 20\log(r) + 32.44 \tag{15}$$

Where,

- L_{FS} = free space path loss
- f = frequency of operation
- r = satellite location

So, Received Power without Free Space Path loss,

$$P_r\ (dB) = EIRP + G_r - L_{FS} \tag{16}$$

Pointing Loss

Prior research on Is-OWC has identified a number of difficulties, including beam divergence and aiming problems in both receiving and transmitting, which further reduce transmission capacity and distance. Power loss occurs at the reception side when the transmitter and receiver are not aligned [15]. This further leads to pointing losses, as the following equation illustrates below:

$$L_{pointing} = 4.3229\left(\frac{\emptyset_e}{\Omega_0}\right)^2 \tag{17}$$

Where, $\emptyset_e$ refers to the boundary angle of diffraction which is the limited beam of the transmitter and Ω_0 is beam divergence. Beam divergence refers to spreading of beam during its propagation from transmitter to receiver.

So, Received Power without Pointing loss,

$$P_r\ (dB) = EIRP + G_r - L_p \tag{18}$$

Now, Final Received power is-

$$P_r\ (Final) = EIRP + G_r - L_p - L_{FS} - L_a \tag{19}$$

Elevation Angle

Tangent of the angle of elevation angle,

$$\tan\theta = \frac{H}{D} \tag{20}$$

Where,

H = Height of the object
D = Distance from the object

Q-Factor

Quality factor is used to measure the received signal's quality that is represented by Q. It is in proportion to the system's signal to noise ratio. Inside an optical framework, BER is insignificant for the purpose of calculation and so Q-factor is often used to meet the targeted results[24].

The Friis transmission equation can be used to examine the functional parameters of an intersatellite communication system. The expression for the received optical signal [29]. is expressed as:

$$P_R = P_T G_T \eta_T \eta_R G_R L_T L_R \left(\lambda / 4\pi Z\right)^2 \tag{21}$$

Where,

- P_R = Transmitted Power
- G_T = Gains of the telescopes at transmitter side
- G_R = Gains of the telescopes at receiver side
- η_T = Transmitter optics efficiencies
- η_R = Receiver optics efficiencies
- L_T = Transmitter pointing loss factors
- L_R = Receiver pointing loss factors
- λ = Transmission wavelength
- Z = Transmission range

Free Space Loss, $L = (\lambda/_{4\pi Z})^2$ (22)

The ratio of the number of bit errors that have been identified in the receiver, including the number of bits sent, is used in the above equation to represent the bit error rate (BER). Q is a signal's quality indicator. It is employed to assess the received signals' quality. By analyzing the BER and Q-factor, one can observe how the system is staging. Thus, the ratio of the number of bits sent to the number of bit errors found in the receiver is known as the bit error rate, or BER.

By utilizing equation 21 and equation 22, we get the quality factor.

Quality factor, $Q = \frac{\mathbf{f_r \times L}}{\mathbf{P}_R}$ (23)

Where,

- f_r = Data rate in Mbps
- L = Free space path loss in dB
- P_R = Received power in dBm

RESULTS AND DISCUSSION

We assess the efficiency of geostationary inter-satellite optical wireless communication links in accordance with the analytical methodology presented in section-2 under various loss conditions and an analytical approach is developed to find the quality of signal.

LIST OF PARAMETERS

The computer simulation utilized in this study's analysis of satellite communication losses includes the following parameters. System parameters that are utilized in simulation process is mentioned in Table 1.

Examining the equation discussed in the previous section using MATLAB, we obtain the following results. The received power of a geostationary satellite receiver can be calculated based on equation (2). Without considering any loss, we input some fixed value and obtain the received power curve.

The working frequency of the receiving power plots is set to 12GHz, and the transmitting and receiving antenna diameters are both set to 3m. The results shows in FIGURE 4 and received power is 458.86dBm for transmitting power 1w. Take note in particular of the gradual loss of received power relative to transmitted power. We consider the difficulty posed by this progressive decline.

Now we consider different loss conditions like pointing loss, free space path loss, attenuation loss. From the equation (19) of final received power in section 3, we put the value and get output.

Table 1. System parameters that are utilized in simulation process.

Serial no.	Parameter	Symbol	Value
1	Transmitting Power	P_t	1-10w
2	Received Power	P_r	4-35dBm
3	Transmitting Antenna Gain	G_t	228.9dB
4	Receiving Antenna Gain	G_r	228.9dB
5	Path Distance	r	3.59×10^7m
6	Antenna Diameter	d	3m
7	Frequency	f	12-18GHz
8	Effective Isotropic Radiated Power	EIRP	229.9dB
9	Antenna Efficiency	η_A	0.55
10	Attenuation	A	8.58dB
11	Link Distance	L	500km
12	Diameter of the Transmitter Antenna	D_T	20cm
13	Diameter of the Receiver Antenna	D_R	20cm
14	Transmission factors of Transmitter Telescope	T_T	0.8
15	Transmission factors of Received Telescope	T_R	0.8
16	Pointing Loss	L_p	0.2
17	Divergence angle	θ_T	18.91µrad
18	Free Space Path Loss	L_{FS}	385.1dB
19	Satellite Location	r	35km
20	Boundary angle of diffraction	$\emptyset_e$	3µrad
21	Beam Divergence	Ω_0	17.5°
22	Elevation Angle	θ	10°
23	Height of The Object	H	40km
24	Distance From the Object	D	9-129km
25	Wavelength	λ	800nm

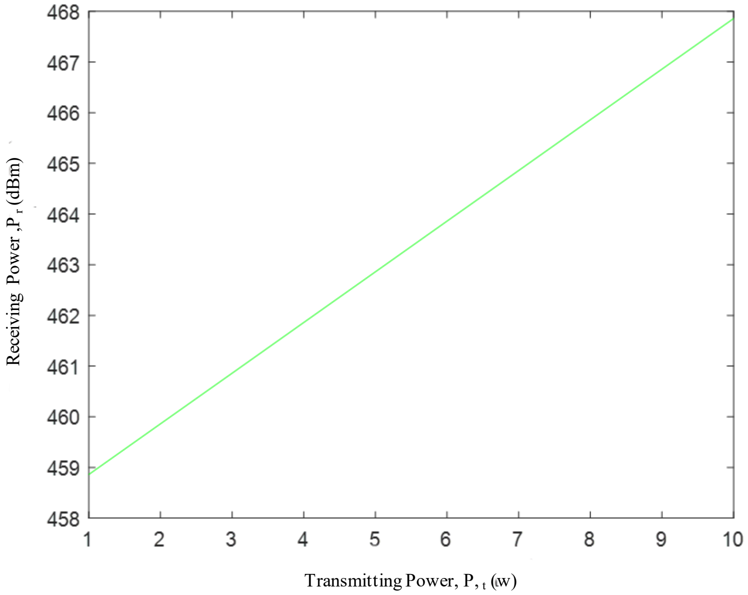

Figure 4. Plots of receiving power versus transmitting power of a satellite.

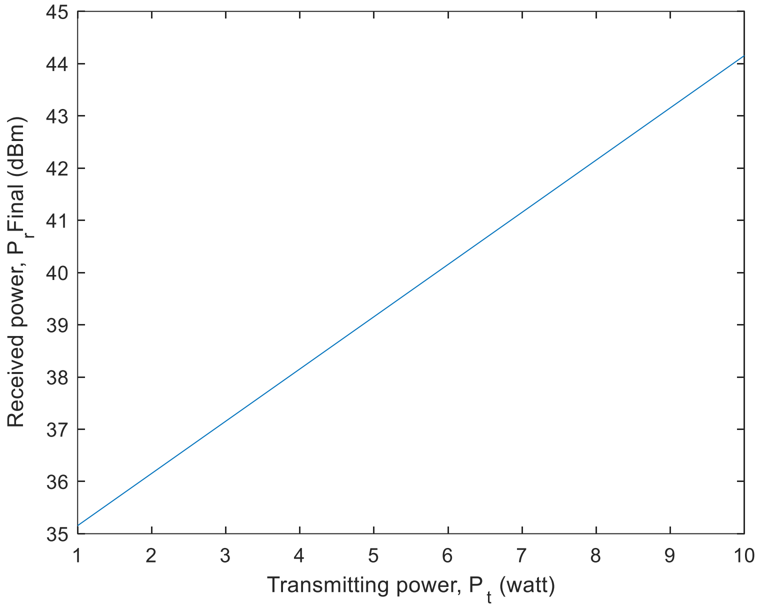

Figure 5. Plots of receiving power versus transmitting power of a satellite with loss consideration.

Figure 5 shows the results by applying the same parameters with loss consideration in equation (19). Diagram of the simulation showed there is huge loss in received power for different types of losses. We get 35.15dBw receiving power when transmitting power is 1w.

It is evident from comparing Figure 4 and Figure 5 that there has been a significant power loss in received power due to pointing loss, free space path loss, and attenuation loss. To enhance the outcomes, we change the frequency 12GHz-18GHz in equation (19). Received power vs transmitting power curve when we varry frequency at ku-band is shown in graph in figure 6.

The gain of the transmitter or receiver will likewise rise as the operating frequency is raised. Receiving power increased because of the rise in gain and EIRP. We range from 12GHz to 18GHz in frequency and compare all received power in one figure to see how frequency changes affect the received power. We observe an increase in received power.

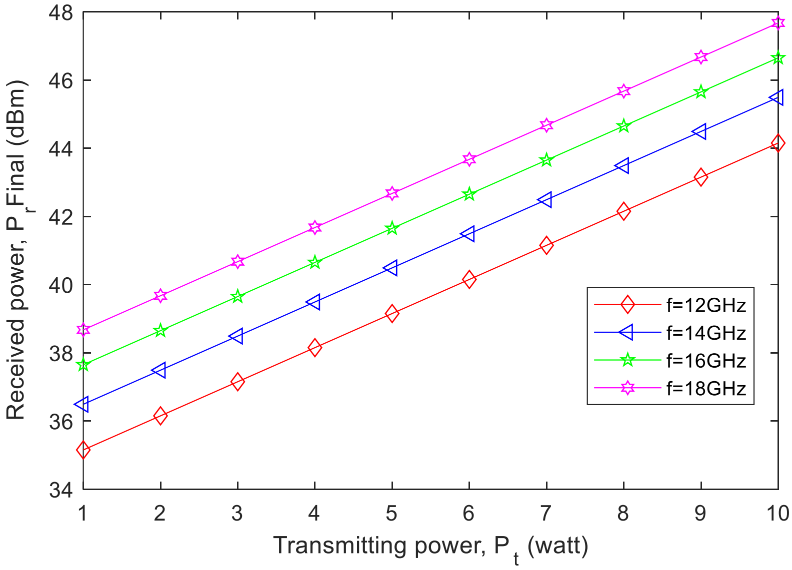

Figure 6. Received power vs transmitting power curve when we varry frequency at ku-band.

We examine all received power in one figure to observe how antenna diameter dt changes (0.5m to 3m) in equation (19), impact the received power.

Figure 7 shows for increasing the value of antenna diameter, received power is also increasing gradually. From the equation (5) we put the value and get the output. The relationship between parabolic antenna gain and antenna diameter is shown in Figure 8.

Now we vary frequency (3GHz-15GHz) in equation (5). When we increase the frequency, antenna gain also increases. Antenna gain versus antenna diameter curve for different frequency is shown in Figure 9.

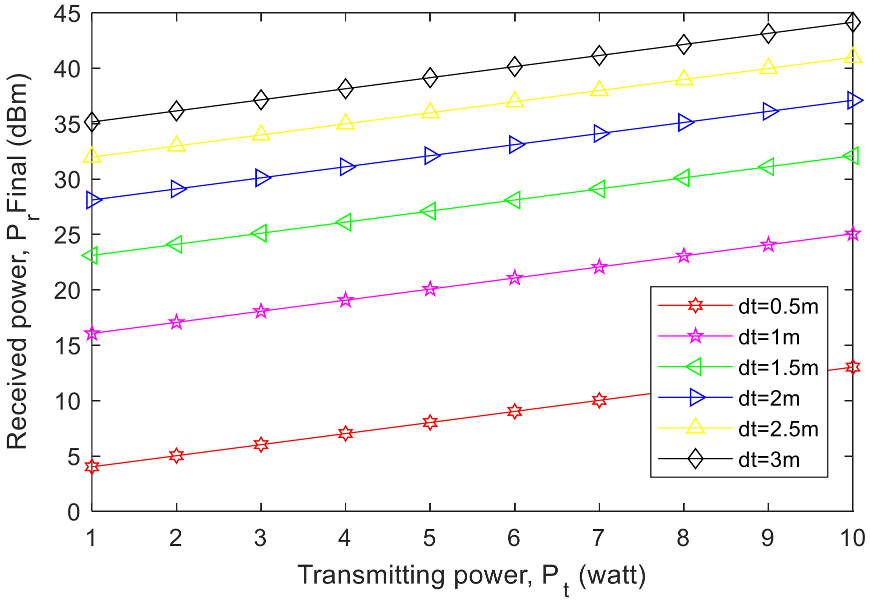

Figure 7. Received power vs transmitting power curve when we varry antenna diameter.

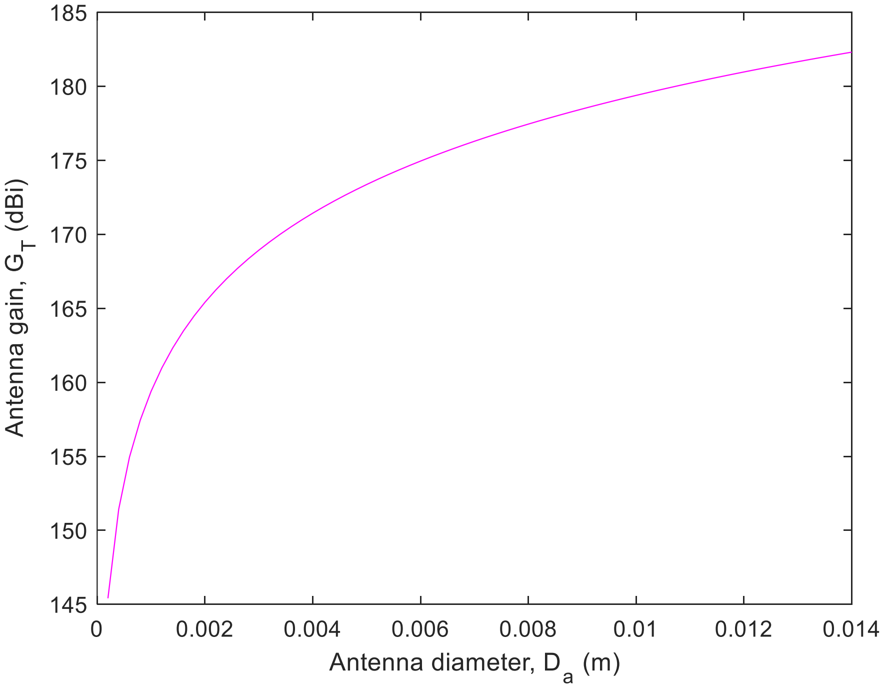

Figure 8. Relationship between parabolic antenna gain and antenna diameter (η_A = 0.55).

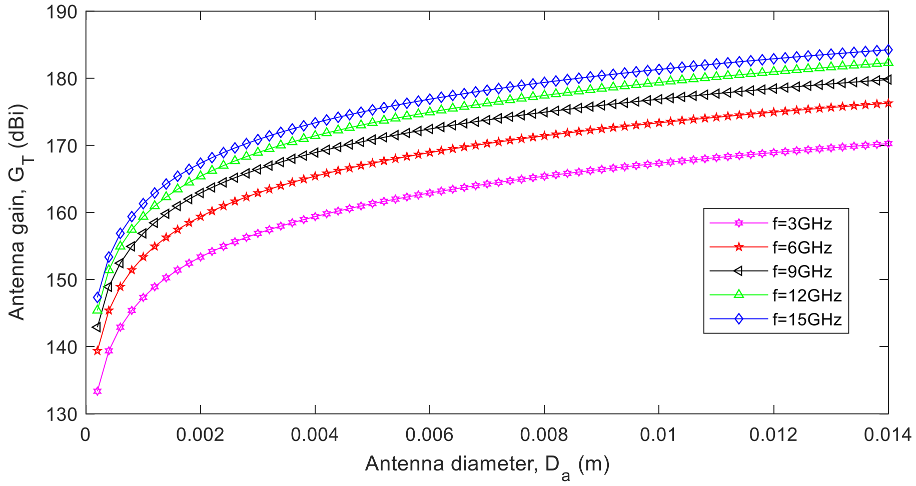

Figure 9. Antenna gain versus antenna diameter curve for different frequency.

Figure 9 presents that the antenna gain will rise in tandem with the frequency increase.

The elevation angle is one of the factors that affect the satellite's transmission path. From equation (20), we find the value of elevation angle. We vary the distance from the object 9km to 129km and for geostationary satellite communication height of the object is 35000km and we see that elevation angle is inversely proportional to the distance from the object.

By varying the elevation angle from 10^o to 80^o, the distance of a satellite in a geostationary orbit was estimated, as shown in FIGURE 10. We noted that the satellite path's maximum distance is 130000 km at latitude 15^o, while its smallest distance is 10000 km at latitude 77^o. In this scenario, the transmission path will be equivalent to the geostationary satellite's altitude. However, when the elevation angle grew, the distance decreased exponentially.

Now we compare all the outputs in one figure by changing the height of the object in equation (20).

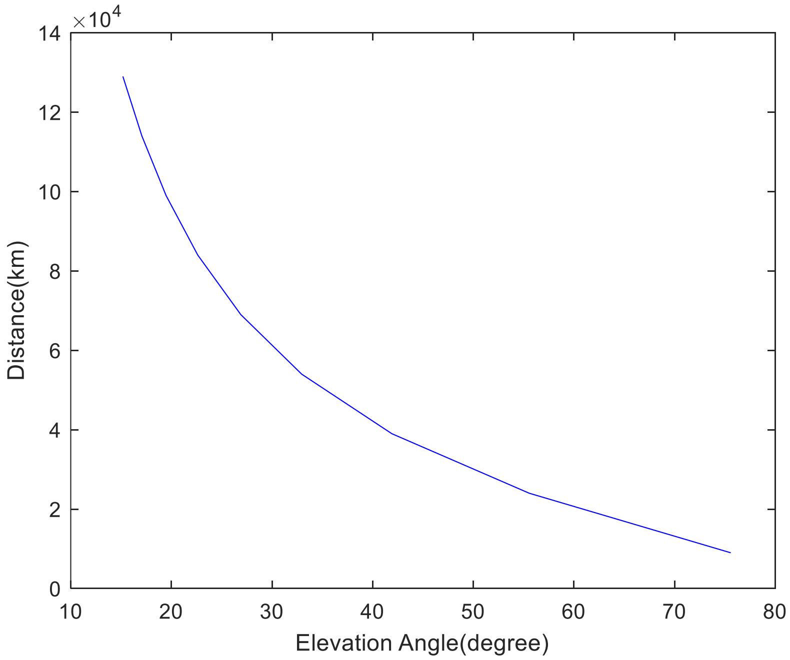

Figure 10. Distance versus elevation angle curve.

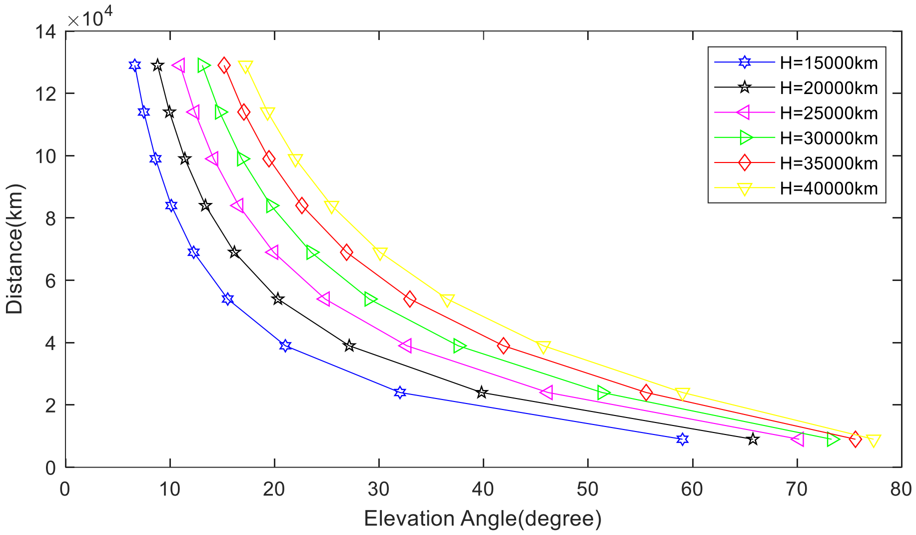

Figure 11. Distance versus elevation angle curve when we vary height of the object.

By varying height of the object, we find different curve, which goes on exponentially in FIGURE 11.

Equation (7) shows the equation of attenuation. From this equation, we can say attenuation directly proportional to divergence angle and we know that divergence angle inversely proportional to frequency. We put the value in equation (7) and get the curve, which is exponentially decreased. Assume Dr=0.3m.

From Figure 12 we notice that, with the increase of frequency attenuation will decrease. By varying the frequency 8GHz to 12GHz, we find maximum attenuation 2.7dB at 8GHz and minimum attenuation 1.2dB at 12GHz.

Now we vary the diameter of receiver telescope 0.3m to 0.5m and observe the output.

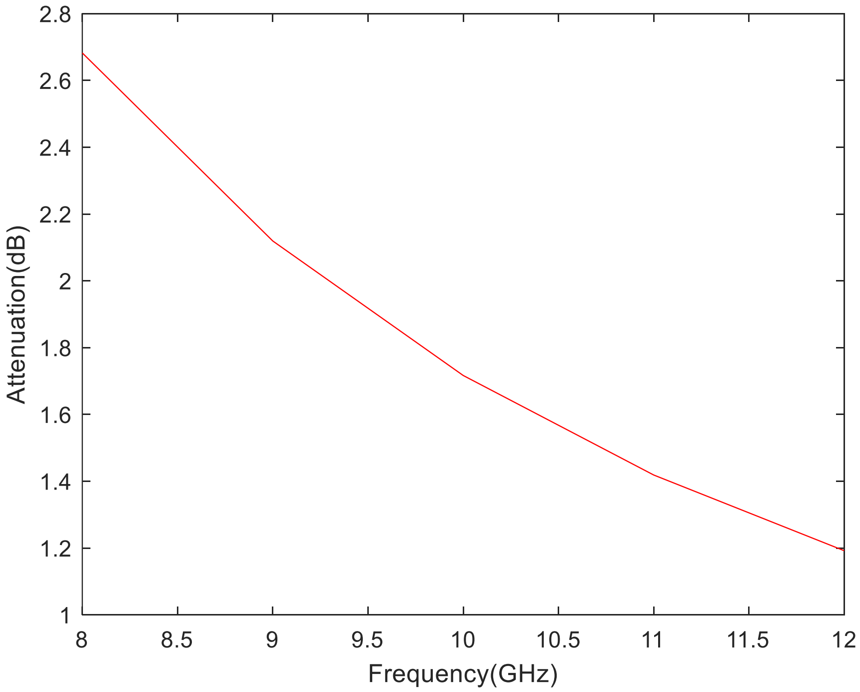

Figure 12. Attenuation versus frequency curve.

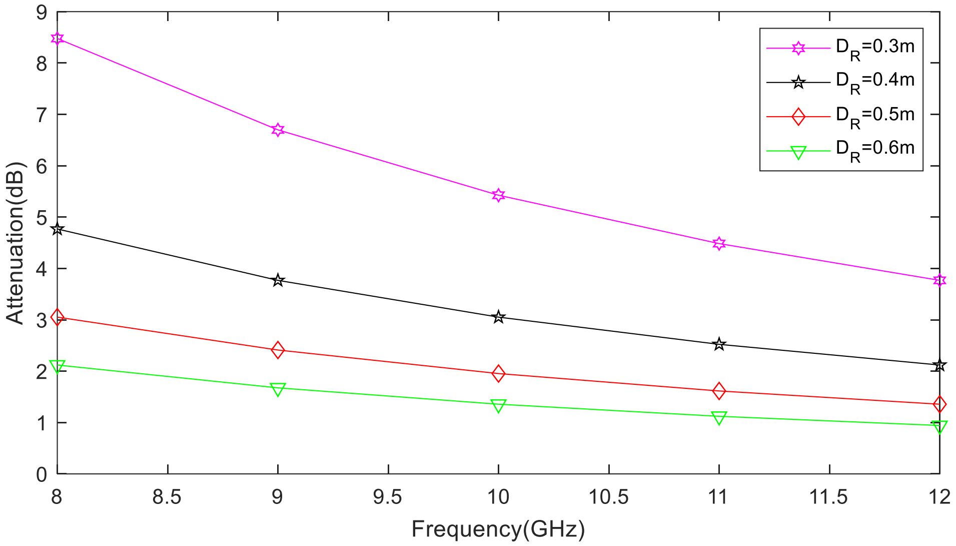

Figure 13. Attenuation versus frequency curve when we vary receiver diameter.

From Figure 13, we observe that increasing antenna diameter can reduce the effect of attenuation loss.

From equation (10), we notice that divergence angle is inversely proportionate to frequency. If frequency increases, divergence angle will decrease. We assume both transmitter and receiver antenna diameter are 0.3m.

FIGURE 14 presents the frequency that will rise if the divergence angle is reduced gradually. We get the maximum divergence angle 7.2^{o} at frequency 8GHz and minimum divergence angle 47^{o} at frequency in 12GHz.

Now in equation (10) we vary antenna diameter D_T from 0.3m to 0.7m to improve the result.

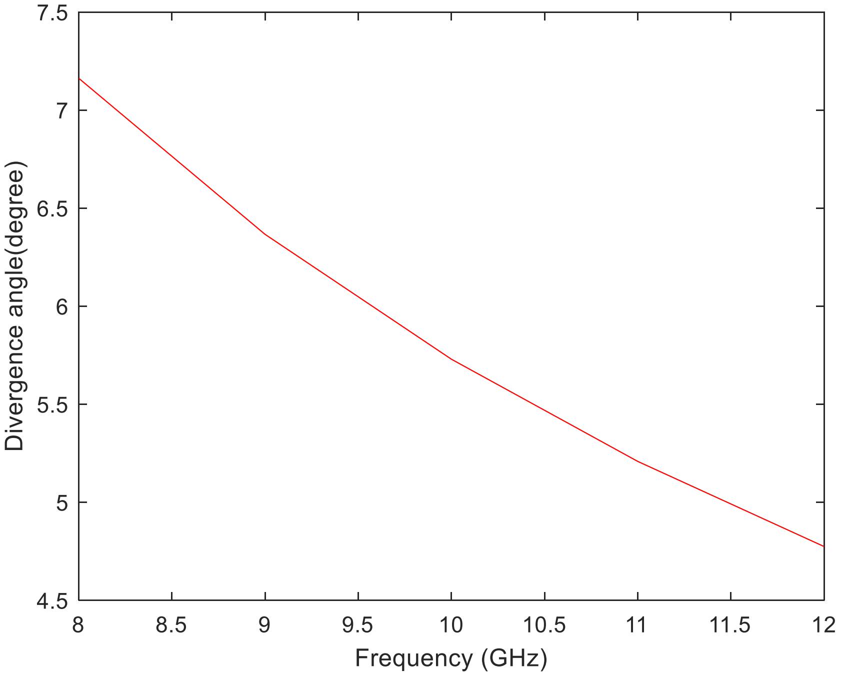

Figure 14. Divergence angle versus frequency curve.

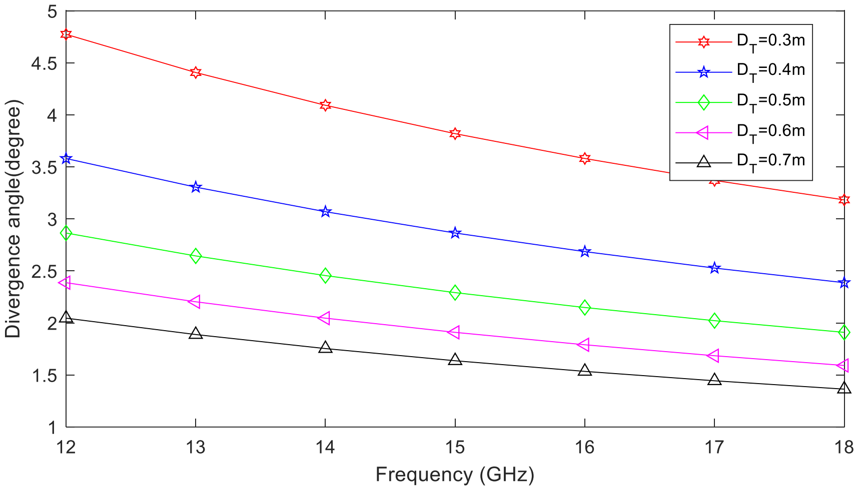

Figure 15. Curve of divergence angle versus frequency at different transmitter antenna diameter.

From FIGURE 15, it is clear that increasing antenna diameter reduce divergence angle.

From the equation (23), various data rates at GEO distances are taken into consideration while analyzing the link's performance. Assume P_T =1-10dbm, G_T =3, G_R =3, η_T =0.8, η_R =0.8, L_T =0.2, L_R=0.2, λ=850nm, Z=73km (inter-satellite link distance).

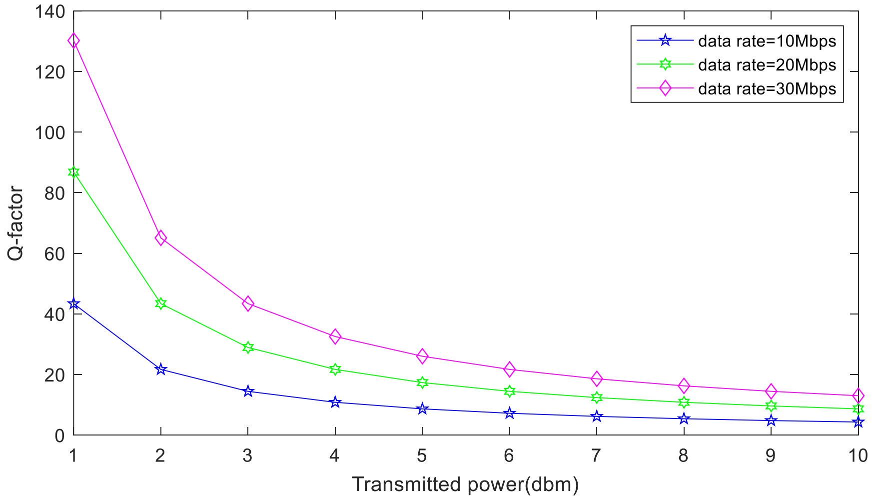

Figure 16. System performance in terms of Q-factor considering different data rates at GEO distances.

The system performance is displayed in terms of Q-factor in FIGURE 16. When we increase data rates, Q-factor also increases.

CONCLUSIONS

As of present day, satellite systems represent the most significant space applications, and satellite communication is the most significant economic sector. Optimizing satellite networks is crucial, especially considering how much it costs to construct, launch, and maintain each satellite. Is-OWC is a groundbreaking method that uses lasers to create a communication link between satellites. It undoubtedly provides many significant benefits, but there are also some difficulties that make its link operate poorly such as beam divergence angle, the angle of elevation, sending pointing errors, receiving pointing errors, etc which increased attenuation loss, pointing loss, and free space path loss. When developing the Is-OWC transmission system, these turbulences must be taken into account. Otherwise, it affects the overall system performance or Q-factor. This paper analyzed attenuation loss, pointing error, free space path loss, Q-factor. We tried to test all possible obstacles and demonstrated how we can improve the results by adjusting other parameters such as frequency, antenna diameter and distance. This investigation proved that we could overcome obstacles and achieve higher performance by changing certain settings. The behavior of all challenges must be analyzed to maintain spatial traffic diversity for future research.

AUTHOR CONTRIBUTIONS

The author attests to having sole responsibility for the study's idea, its results as provided, and the writing of its paper.

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FINANCIAL DISCLOSURE

None reported.

CONFLICT OF INTEREST

The author affirms that she has no significant financial interests in the study that is the subject of this paper.

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