Performance Evaluation of O3B Satellite Communication

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Abstract: One of the potential strategies that may be utilized instead of terrestrial networks in remote and/or challenging terrain conditions is the Over Three Billion (O3b) satellite network. It has a high throughput depending on the frequency range and the weather. A geostationary satellite (GEO) is preferred over a low-earth satellite (LEO) because the LEO requires a tracking ground system, which increases the influence of elevation angle on the LEO. O3b is a hybrid network that combines GEO and LEO benefits. By using a high frequency band, it is sensitive to changes in the weather. Rain and cloud attenuation are the two primary atmospheric attenuation factors that affect the O3b satellite's link budget in wet conditions. The impact of rain and cloud attenuation on the O3b's throughput, SNR, and BER has been examined and simulated in this article. Rain is the most effective atmospheric attenuator on the satellite connection, according to simulations. The rain and cloud attenuation increase with frequency. The large elevation angle effect and substantial free space losses demonstrate that the 60 GHz band is not utilized in O3b satellite communications. Using 28 GHz allows for excellent throughput at elevation angles exceeding 20o, allowing for additional flexibility in communication between the ground and satellite segments. MATLAB is used for all simulations.

Keywords: O3b, Atmospheric loss, Rain attenuation, Elevation angle, Satellite communication

1. Introduction

Wireless communication has become indispensable in modern life due to the proliferation of mobile devices and the expansion of IoT networks because of the increase of wireless application, increasing in several wireless devices such as mobiles and tablets, and the appearance of Internet-of-Things (IoT) networks [1]. There are many types of wireless networks, each of them is used to serve several types of communication types such as terrestrial networks like mobile cellular networks, wireless networks and Wireless Sensors Network (WSN) [2], and satellite communication [3]. Satellite communication is the system that gives a Line-of-Sight (LoS) communication using the Radio Frequency (RF) link from/to the space segment which is the satellite and the Ground Segment (GS) which may be a satellite receiver, terrestrial Base Station (BS), and/or a mobile user directory [4].

In the past, satellite communication is used in the applications that need broadcasting such as Television, Radio, and Internet signals to widening the spot beam of these applications to reach thousands and millions of people around the world [5]. Nowadays, using satellite communication is not restricted to broadcasting purposes, but it is used for providing Internet communication in the difficult terrain environment where there is no chance of establishing an Internet infrastructure [6]. It can also be used to expand the use of terrestrial networks by allowing the cooperation between satellite networks and the near available terrestrial one to perform together with a Heterogeneous Network (Het-Net) [7].

Given the limitations of terrestrial infrastructure in remote and challenging environments, the O3b MEO satellite network emerges as a promising alternative, particularly when leveraging mmWave bands such as 28 GHz. This study evaluates how environmental parameters, especially rain and cloud conditions, influence link performance in terms of BER, SNR, and throughput. Like any other type of wireless network, a satellite network needs several numbers of RF to communicate and propagate the signal. It usually reaches GHz bands to give high throughput, high bandwidth, and to allow signals faces the struggles that may face during traveling along with the long-distance from satellite to GS [8]. In general, there are three types of positions (orbits) that the satellite-related to as shown in Figure 1. which are the Geostationary Orbit (GEO) which is located around 35,786 km from Earth's surface. It is used widely in broadcasting applications because of the high distance above the earth. This high distance allows observing the satellite as a fixed point that simplifies the operation in the receiver because it sees it as a fixed point. So, this leads to no need for tracking antenna on the GS.

The GEO satellite should travel in the same direction as the earth with a speed that makes the time of one revolution equals 24 hours [9] [10]. The Medium Earth Orbit (MEO) is in the range from 2,000 to 35,786 km above the Earth's surface. It is closer to the earth than GEO but it does not show as a fixed point from the GS and the GS needs a tracking antenna to track the satellite [11]. The same concepts are used in the Low Earth Orbit (LEO) which is below the MEO, it ranges about 160 to 2,000 km above Earth and needs the same receiver of MEO [12].

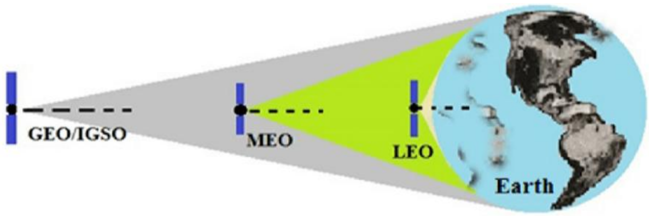

Figure 1: Satellite orbit types [8]

LEO and MEO links typically experience lower latency and reduced free space loss compared to GEO, but not necessarily stronger signals, because of the large distance that GEO signals travel longer distances, but LEO and MEO orbits require multiple satellites to provide global coverage. There is another type of satellite orbit that starts to be used in 2013 to serve billions of people with the Internet in the far and difficult terrains area. This type is called Over 3-Billions (O3b) satellites [13]. This orbit is Easy to deploy and gives fast, flexible, and affordable connectivity because of its low distance compared to GEO and its use of the Ka-band with 12 steerable spot beam antennas. It offers optimized bandwidth efficiency reaching up to 1.2 Gbps per beam and 84 Gbps available per 8 satellite constellation [14] [15].

Frequency bands for satellite services are shared with terrestrial services which are used to avoid interference. Thus it required a large antenna and sensitive receiver at the earth station [12]. Because of this, using Ka-band and Ku-band [16], is an advantage of the O3b satellite because of their huge spectrum available to use and the decrease in sizes for the GS and the satellite itself [17] [18]. The increasing demand for mobile communication especially in dense networks and also in difficult terrain environments leads to thinking about techniques to be used to overcome the limitations that come from this high demand. One of these limitations as described is the scarcity of the spectrum available to meet the huge number of users in the same region. This challenge can be addressed by employing millimeter-wave (mmWave) frequency bands to allow the use of GHz frequencies. But unfortunately, these bands suffer from short traveling capability which means that they are affected by environmental conditions.

One of these environmental conditions is the atmospheric effect especially in rainy countries where the rain level and cloud level is in medium conditions and high conditions. These atmospheric conditions affect the quality of the mm wave signal used in the O3b satellite network. For frequencies above 10 GHz (Ku-band, Ka-band) that O3b works on, rain and clouds impose a serious impact on the signal attenuation [19] which affect the signal quality and throughput level. Besides this, increasing the attenuation level of the signal means decreasing the throughput that the system can deliver to the end-user where the throughput is very important for the Internet connection. Another problem of the use of satellite communication and leads to thinking about using the O3b network is the difficulties to make terrestrial infrastructure in difficult terrain to gives accessibility to the Internet. Using O3b, in this case, can overcome the connectivity limitation of the terrestrial one and also decreasing the latency in communication when using GEO satellites due to the long distance of the satellite from the GS. Another problem of using long satellite distance in rainy and cloudy environments is the effect of the elevation angle of the satellite on the Ka-band performance due to its effects on rain and cloud attenuation. This also leads to a decrease in the system capacity due to the weak signal traveling. The contributions of the paper are:

- To discuss theoretically the use of O3b satellite network to be used instead of terrestrial networks.
- To simulate the performance of the O3b satellite under different types of losses such as rain losses and clouds in different mmwave bands.
- To evaluate the relation between elevation angle and type of attenuations for different mmwave frequency bands.

The remainder of this paper is section II describes the system proposed and methodology. Section III gives the simulation results and discussion. Section IV concludes the work and gives some ideas for future development.

2. Proposed Method

In Figure.2 shows the proposed scenario of this paper. The scenario considers an O3b satellite downlink signal in a rainfall location where the intensity of the rain affects the satellite link. The frequency band used are 2.6 GHz, 28 GHz, and 60 GHz to satisfy all the Ka-band used for mmwave satellite links. The elevation angle is the simulation parameter that the atmospheric attenuations — such as rain and cloud — are calculated. It determines the effective path length of the signal through the atmosphere, which directly impacts the attenuation levels. At the end of the simulation, the BER and throughput of the link are also calculated. For starting the simulation, it is clear that the signal attenuation comes from three main types of the atmospheric effect which are the rain effect, the cloud effect, and the gas effect. Each of them depends on the satellite type and the geographic area that the simulation performs on. The most attenuation effect comes from the first type which is the rain attenuation. It depends on the rainfall rate intensity which is the amount of rain that can befall on a specific area and the total propagation length of the traveling wave, the received O3b signal suffers from the type of losses which mainly here the system loss and the atmospheric loss. The system loss comes from the equipment used in the satellite itself and also the free space loss that comes from the satellite height. The received power of the satellite link can be considered as:

Figure 2: Proposed scenario method

The simulation scenario assumes a ground station located near the equatorial region, specifically around 3° to 6° north latitude (e.g., Malaysia or northern Indonesia), which aligns with the operational footprint of the O3b satellite constellation. O3b satellites orbit in an equatorial Medium Earth Orbit (MEO) at approximately 8,000 km altitude with a low inclination, designed to serve regions between approximately ±45° latitude. This geographic alignment supports the use of high-frequency mmWave bands such as 28 GHz due to lower atmospheric attenuation and favorable elevation angles in equatorial regions.

$$Pr = EIRP + +Gr - FSL - La - Ls \quad (1)$$

where *EIRP* is the Effective Isotropic Radiated Power, *Gr* are the gain of the transmit and receive antennas, FSL is the Free Space Loss, *La* is the atmospheric loss, and finally, the *Ls* which is the system loss. The atmospheric loss can be considered as:

$$La = ra + ca + ga \quad (2)$$

where *ra* is the rain attenuation, *ca* is the cloud attenuation, and *ga* is the gas attenuation. In most research, gas attenuation can be neglected because of the small effect on the signal quality compared to rain and cloud attenuations. The simulation starts from determining the simulation parameters like the rain intensity rate, the frequency bands used, the elevation angle, the polarization, the pressure, temperature, and humidity. These parameters affect the signal quality according to the high-frequency band used.

The distance of the O3b satellite also plays an important role in the signal quality because of the FSL effect on the signal. The simulation asks about the frequency band which are 2.6 GHz, 28 GHz, and the 60 GHz which are the three most common bands used in the terrestrial networks and you know that the O3b satellite network comes to use to overcome the challenges of using terrestrial networks in the difficult terrain environments. The elevation angle is the simulation metric because of its effect on the signal quality on how the ground station sees the satellite in the sky. If the elevation angle increases the atmospheric attenuation decreases. When the simulation calculates all the frequency bands and repeats the simulation for different elevation angles from 5 degrees to 90 degrees, the simulation calculates the power received and calculates the Bit Error Rate (BER) of the system.

The simulation parameters are shown in Table 1. The polarization of the satellite link is circular which is widely used in O3b networks. The rain intensity is 0.3 which is in the range of 0.25 to 1 mm/h that indicates the light rain area with 0.0027 Kg/m2 liquid water contents to indicates a cloudy condition. The gain of the receiver antenna is 20 dB to meet the antenna gain requirements for the ground station, which is situated at an elevation of 400 meters above sea level. It is important to note that the actual distance between the satellite and the ground station in the O3B system typically falls within the range of 36,000 kilometers, allowing for the use of suitable frequencies in communications. The temperature is 238 in Kelvin to satisfy the status of the cloud type temperature which is in general equals -35 Celsius. The EIRP of the transmit antenna is 50 dBW which is in general the EIRP of the O3b satellite transmit antenna.

TABLE 1: Simulation parameters

Simulation parameter	Values
Type of Satellite	O3b
Carrier frequency (GHz)	2.6, 28, 60
Attenuation type	Cloud, Rain
Polarization	Circular
Rain rate (mm/h)	0.3
Temperature (K)	238
liquid water contents	0.0027 (Kg/m2)
Pressure (inhg)	30
Humidity	20%
EIRP (dBW)	50
Receiver Gain (dB)	20
Station Hight (m)	400

The simulation metrics for this work are:

Bit Error Rate (BER)

There are a probabilities of mistakes being brought into the system because of mismatch impedance, ICI, attenuation, and bit synchronization error. The receiver operation is expected to coordinate unique baseband information to locate the absolute number of errors. This can be calculated into a straightforward equation as:

$$BER = (total\ number\ of\ error) / (total\ number\ of\ received\ data) \quad (3)$$

i. Rain Attenuation

It is the degradation of the signal quality due to the effect of the rain intensity. It depends on the vertical height L of the satellite above the earth service, the elevation angle θ, and the rainfall rate intensity. It is calculated by [20]:

$$A\,[dB] = \gamma R * Leff * La \quad (4)$$

Where γ is a constant and Leff equal:

$$Leff = \frac{L}{Sin(\theta)} \quad (5)$$

ii. Cloud Attenuation

It is the attenuation that is caused by the availability of the cloud in the sky. It depends on L which is the total columnar content of liquid water, Kl which is the specific attenuation by water, and θwhich is the elevation angle. It can be calculated by [20]:

$$LC[dB] = L \cdot Kl \cdot sin(\theta) \quad (6)$$

iii. Throughput

The total amount of data per second at the receiver. The channel used effects in general the capacity of the system. So, determining the throughput of the system is considered important because of its relation to the spectrum available [21]. It can be calculated as:

$$Thr = \frac{8 .Nrx}{T_{Sim}} \quad (7)$$

Where *Thr* is the average throughput in bps, *Nrx* is the successfully received number of packets in bytes, and *Tsim* is simulation time in s.

iv. Signal to Noise ratio (SNR)

It is the performance metrics that gives an indication of the quality of the signal related on the noise in the system. It is calculated as

$$SNR = \frac{P_r}{P_n} \quad (8)$$

Where P_r is the transmuted power and P_n is the noise power.

3. Result and Discussion

Figure 3, shows clearly that the most effective atmospheric attenuation on the satellite link comes from the rain. As the frequency increases, the rain attenuation increases. This is logical and acceptable with the concept that the atmospheric conditions affect the short-wave and mmwave signals besides of the path loss comes from the far distance between earth station and satellite. Besides, the elevation angle affects the degree of the rain effect on the signal quality. It is considered as a highly effective parameter for the signal quality degradation. There is 10 dB degradation as the elevation angle increases from 5o to 90o for 60 GHz, 1 dB for the 28 GHz, and 0.001 dB for the 2.6 GHz. The less attenuation comes from the vertical sight between transmitter and receiver to eliminate the ground effect on the signal quality. 2.6 GHz gives the less rain attenuation compared to 28 GHz and 60 GHz. It gives near 10-5 dB at 50o elevation angle while the rain attenuation reaches near 0.1dB and 1 dB for the 28 GHz and 60 GHz respectively as shown in Figure 3.

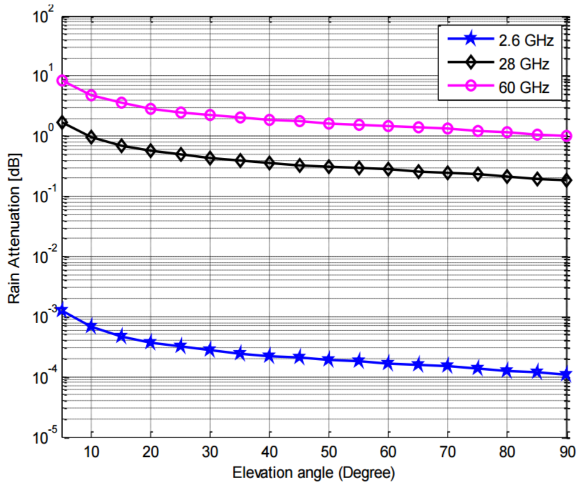

Figure 3: Rain attenuation of the O3b satellite vs. elevation angle

In Figure 4, shows the rain attenuation with respect to the rain exceedance time (the percentage time that the frequency exceeds the rain drop). It is clear that there is a direct proportional between increasing the frequency and rain attenuation, and an inverse proportional between the rain attenuation level and the exceedance time. Figure 4 was obtained when using 45^0 for the elevation angle because it is the angle that the rain attenuation has less effect after it as shown in Figure 3. It is important to show the effect of the exceedance time on the rain attenuation because it indicates the ability of the carrier frequency to exceed the rain drop. In heavy rain areas where the raindrops falling is continues, increasing the frequency band used in O3b satellite link means more rain attenuation level which affects the satellite link budget. Figure 4 illustrates the rain attenuation as a function of the percentage of time during which that level of attenuation is exceeded. This approach is based on ITU-R P.618 recommendations, which are widely used in satellite communication link design. It helps assess link availability and reliability under varying climatic conditions. For instance, a 3 dB rain attenuation exceeded for only 0.01% of the time implies that the link would be highly reliable for 99.99% of the time. As shown, higher frequencies suffer more severe attenuation over longer exceedance periods, which limits their suitability in regions with frequent heavy rainfall.

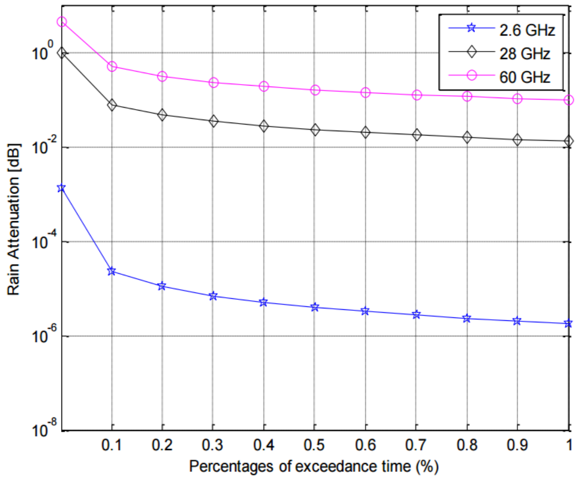

Figure 4: Rain attenuation of the O3b satellite vs. percentage of exceedance time

The same notice comes from Figure 3. The cloud effect is also an important effect to study to evaluate the atmospheric attenuations that affect the satellite signal quality. It is the second main effect behind the rain effect. It is the effect of the existence of the clouds between transmitter and receiver. In general, most studies omit gas attenuation simulations due to their minimal impact on satellite communication and get enough by simulating rain and cloud effects. For Figure 5, as shown, there is 0.1 dB difference attenuation as the elevation angle increases from 5o to 90o for the 60 GHz. Unlike rain, the cloud attenuation effect is less than the rain effect because that clouds are existence in all directions between ground segment and satellite not as rain where the rain drop volume, the rain direction of falling, and the rain intensity affect the signal quality. At 45o elevation angle, there is less than the 0.0001 dB cloud attenuation for the 2.6 GHz while it degraded to 0.01 for the 60 GHz.

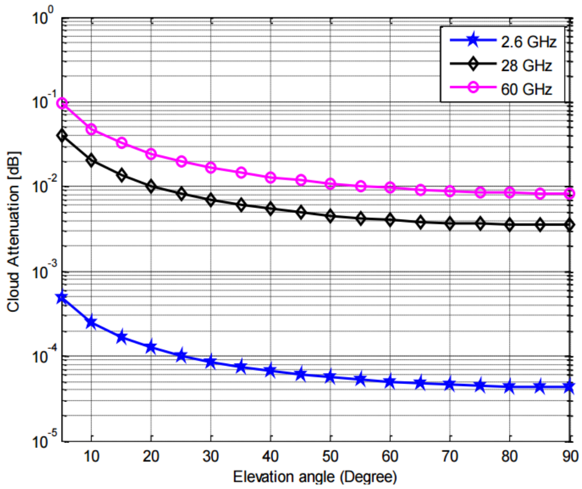

Figure 5: Cloud attenuation of the O3b satellite vs. elevation angle

As said before, there are three main atmospheric attenuations that affect the satellite link budget which are rain, cloud, and Gas attenuations. The Gas attenuation has the less effect compared to the other two attenuations, because of this it is neglected in this paper. The other two attenuations affect the link budget by increasing the losses that the satellite signal face. With additions to the system loss and free space loss, the atmospheric attenuation loss affects the satellite signal quality as shown in Figure 6 which indicates the Signal-to-Noise Ratio (SNR) with respect to the elevation angle. Figure. 6 shows that as the frequency increases, the noise increases. It is important also to say the simulation results show that incase of using 60 GHz, the elevation angle should be greater than 9o to have a SNR value greater than 0 dB. This is because of the ground effect of the small elevation angle. In Figure 6, shows that there is 60 dB difference when using 28 GHz and 60 GHz from 5o to 90o elevation angle while there is 20 dB difference only when using 2.6 GHz for the same range of angles. This is important to notice to see the ground effect on the O3b system because it is promised to be used instead of terrestrial networks in some difficult areas.

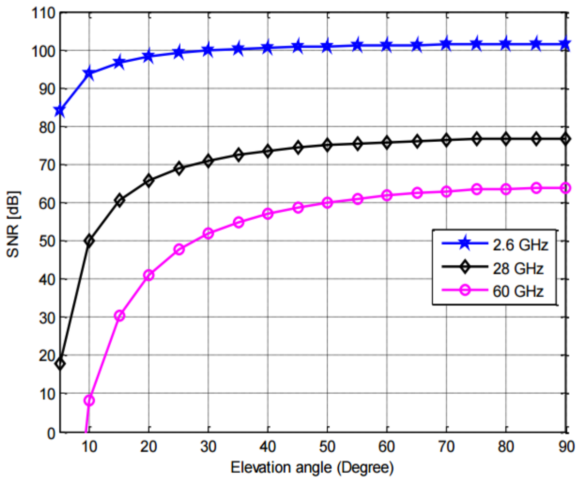

Figure 6: SNR vs. elevation angle

Figure 7, shows the throughput for the mmwave bands proposed in the scenario. It is clear that the throughput of the O3b can be considered as a promised network to be used instead the terrestrial networks because of its high throughput compared to terrestrial in spite of the large distance communication. It can also carry Gbits of data. Fig. 7 shows that although the 60 GHz is greater than 28 GHz and it is logical to carry more information, but in satellite communication, the distance of communication is very large, so the 60 GHz signal is degraded very fast, so the throughput reaches the ground segment using 60 GHz is less than that comes from 28 GHz. Figure. 7 also shows that the elevation angle affects the throughput of the mmwave signal because of the ground effect on the signal link. To avoid the ground effect, elevation angle should be greater than 25o in case of 60 GHz, and greater than 10o in case of 28 GHz. In general, the 60 GHz band does not used in O3b satellite links because of the high elevation angle effect and high free space losses. It is good to use 28 GHz to have high throughput whatever the elevation angle is above the 20o which means more flexibility to communicate between the ground segment and the satellite segment.

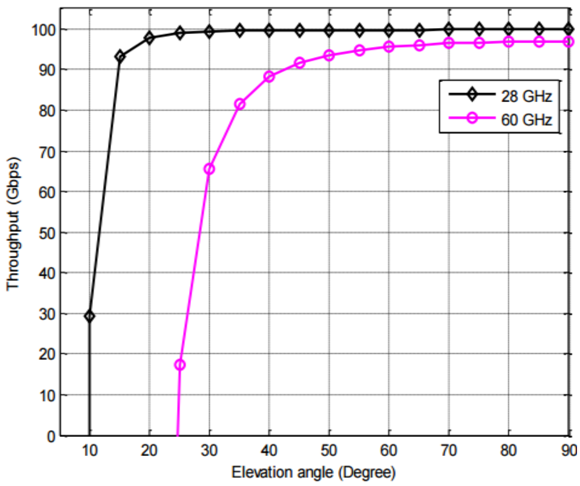

Figure 7: Throughput of the O3b satellite

Figure 8, confirms results come from Figure. 6 and Figure. 7. It shows that there are huge errors comes from using 60 GHz especially for small values of elevation angles. There is no a great advancement in BER above the 45o of the elevation angle which means that it is useless to use 60 GHz in O3b satellite without using a technique of regenerate the signal many times to overcome the high errors come from the free space loss.

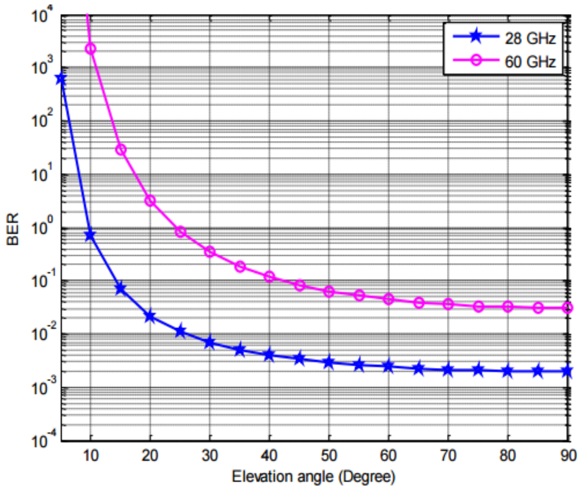

Figure 8: BER of the O3b satellite

4. Conclusion

This study demonstrates that while mmWave frequencies offer high throughput potential, their susceptibility to atmospheric attenuation, particularly rain, poses challenges for satellite links. Among the bands analyzed, the 28 GHz (Ka-band) provides a practical balance between capacity and resilience to weather effects, especially in equatorial regions with suitable elevation angles. In contrast, the 60 GHz band (V-band) suffers from excessive path loss and attenuation, making it less feasible for long-range O3b communications without additional technologies like signal regeneration. These findings support the selective deployment of frequency bands based on geographic and climatic conditions. Future work may focus on dynamic beamforming, satellite diversity, and the integration of O3b systems with terrestrial backhaul to enhance reliability and coverage.

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