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A REVIEW OF THE EFFECTS OF LOW ELEVATION ANGLES ON THE PROPAGATION FOR SATELLITE COMMUNICATION LINK

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ABSTRACT

The propagation phenomenon for satellite communication links is affected by the elevation angle of the satellite. Low elevation angles can cause signal attenuation due to increased atmospheric absorption, increased multipath fading, and rain attenuation. These effects can lead to decreased signal-to-noise ratio, reduced link availability, and degraded performance. This paper examines the effects of low elevation angle on the propagation phenomenon for satellite communication links. The paper begins by discussing the basics of satellite communication links, including the components of a link, the types of signals used, and the various propagation phenomena that can affect signal transmission. It then focuses on the effects of low elevation angle on signal propagation, including multipath fading, scintillation, and rain attenuation. The paper discusses how these effects can be mitigated through various techniques such as antenna design and signal processing. The results suggest that increasing the antenna gain and using higher frequency bands can help reduce the impact of low elevation angles on satellite communication links. Finally, it provides an overview of current research in this area and suggests potential future research directions.

Keywords: satellite communication, low elevation angle (LEA), multipath fading, tropospheric scintillation, rain attenuation

INTRODUCTION

The propagation of electromagnetic waves through the atmosphere is a complex phenomenon that is affected by many factors, including the elevation angle of the satellite. Low elevation angles have a significant impact on the performance of satellite communication links, as they can cause increased attenuation and signal fading due to atmospheric absorption and scattering. Satellite communication links are a type of communication system that uses satellites to transmit and receive data. These systems are used for a variety of applications, including television broadcasting, telephone services, internet access, and military communications. Satellite communication links use radio waves to send and receive signals from the satellite to the ground station (Roddy, 2001). The satellite acts as a relay station, sending signals from one point on the Earth to another, the signal is then received by the ground station and sent to its destination. Satellite communication links are used in many different industries, including telecommunications, broadcasting, navigation, and military operations. Satellite communication links are composed of several components, including a satellite, an antenna, a transmitter, a receiver, and a ground station. The satellite is the main component of the link and is responsible for relaying signals between two or more locations. The antenna is used to send and receive signals from the satellite. The transmitter converts the signal into radio waves that can be sent to the satellite. The receiver then converts the radio waves back into a signal that can be understood by the ground station. Finally, the ground station processes and distributes the signal to its intended destination (Pan et al., 2001). Satellite communication links use a variety of signals to transmit data. These signals can be analog or digital. Analog signals are continuous waveforms that represent sound, video, or other information. They are transmitted in the form of radio waves and can be used for long-distance communication. Digital signals are composed of discrete bits of information that represent text, images, or other data. They are transmitted in the form of pulses and can be used for short-distance communication. Digital signals are more efficient than analog signals because they require less bandwidth and can be compressed more easily (Morton et al., 2020). Most of the research focuses in their investigations onto how the weather actions like rain, gases, and other phenomenon, can increase their volume density as the elevation angle decreases, which result in longer distances established between earth and the satellite. The availability of Quality of Service (QoS) in any earth space system is crucially influenced by specific characteristics of signal propagation. Low elevation angles affect the behavior of the channel especially in Low Earth Orbit (LEO) (Huang et al., 2014). This paper discusses the effects of low elevation angles on satellite communication links, including their impact on signal strength, link budget calculations, and other performance metrics. The paper will also explore potential mitigation strategies for overcoming these effects, such as using higher gain antennas or employing frequency diversity techniques. Finally, the paper will discuss how advances in technology are helping to reduce the impact of low elevation angles on satellite communication links.

Satellite visibility

Satellite visibility is highly dependent on sky visibility which in turn affected by earth station elevation angle installation, hence three models are used to characterize the propagation effects of the transmitted signals causing fading to appear at different elevation angles (Vieira et al., 2022). First is Line of Sight (LOS) Clear sky, Shadowing by trees and blocking by mountain or buildings Figure (1) shows the environmental state probabilities of sky visibility for the mobile satellite communications tested in Japan.

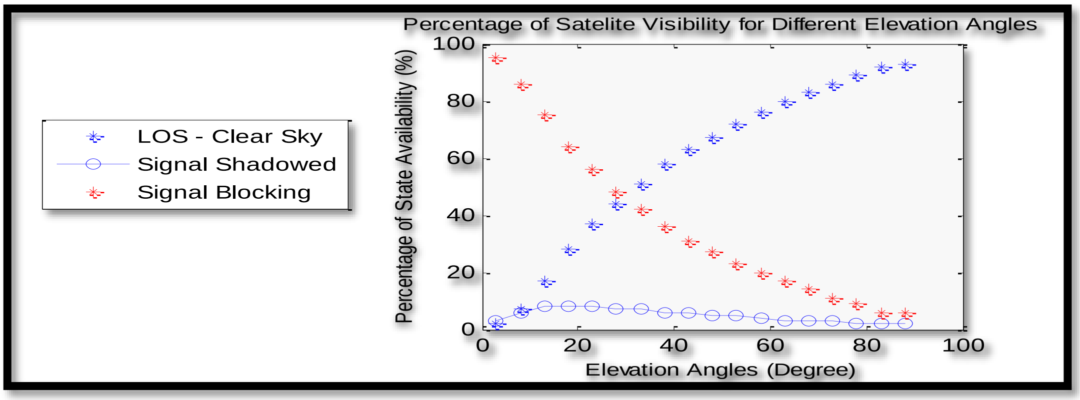


Figure 1: The environmental state probabilities for different elevation angles of Geostationary Orbit (GEO) orbit (Kitano et al., 2012).

From the figure, it can be observed that, at low elevation angles more than 75 % of sky vision is blocked which enables signals to be blocked too (Kitano et al., 2012). Looking to the spot in the LEO orbit, it can be seen that at low elevation angles more satellite are visible because at this distances LEO satellites move much faster than Mobile terminals and most of practical cases they are neglecting the motion of MT. Similar satellites are used to study two different states of Markov modeling, which is used to include the effect of elevation angle on the LEO satellite communication. The following formula shows the radius of the coverage area of the satellite which is highly dependent on the minimum elevation angle (Kitano et al., 2012).

$$R_s = R_E\left(\frac{\pi}{2} - \varepsilon_{\min} - \sin^{-1}\left(\frac{R_E}{R_E + h}\cdot\cos\varepsilon_{\min}\right)\right) \quad (1)$$

Where R_E is the radius of the earth; h is the altitude of the satellite, and ε_{min} is the minimum elevation angle required. The two satellites are GLOBALSTAR of constellation I with h = 1410 km; and another of constellation II with h = 1000 km. Figure (2) shows the average number of visible satellites.

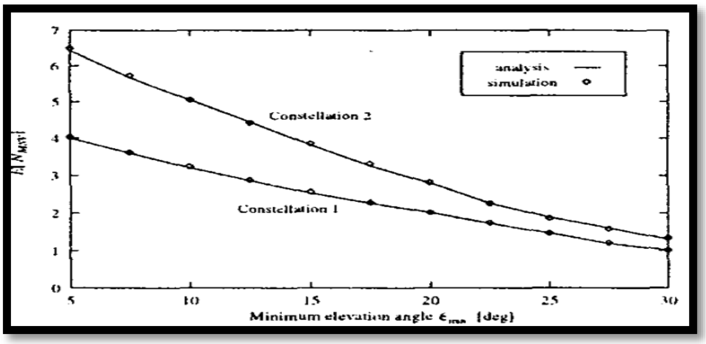


Figure 2: Number of satellites being visible as a function of elevation angle at latitude 35° (Kwon et al., 1999).

It can be seen that, more satellites are available at low elevation angles and this case is paramount especially in LEO orbit. Furthermore, additional satellites available for one ground terminal lead to have higher interference at downlink connection. Of course, when more satellite are visible the handoff can be performed accurately without connection drop as shown by figure (3) (Kwon et al., 1999).

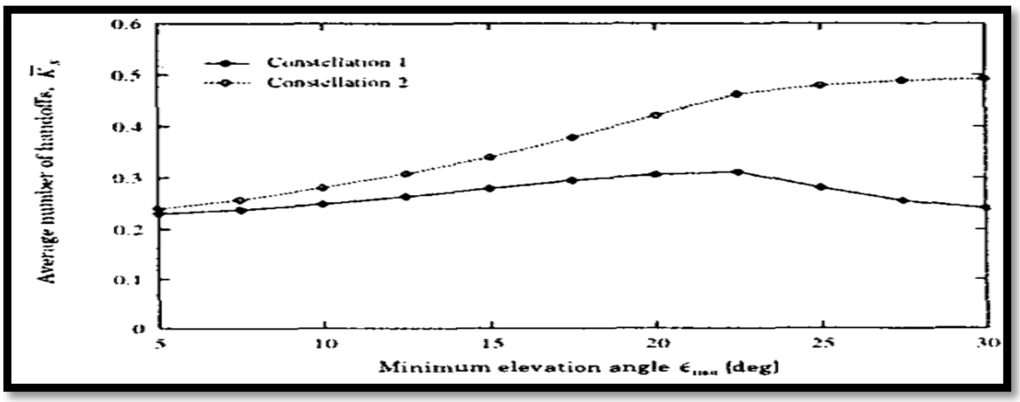


Figure 3: Handoff in terms of elevation angle (Kwon et al., 1999).

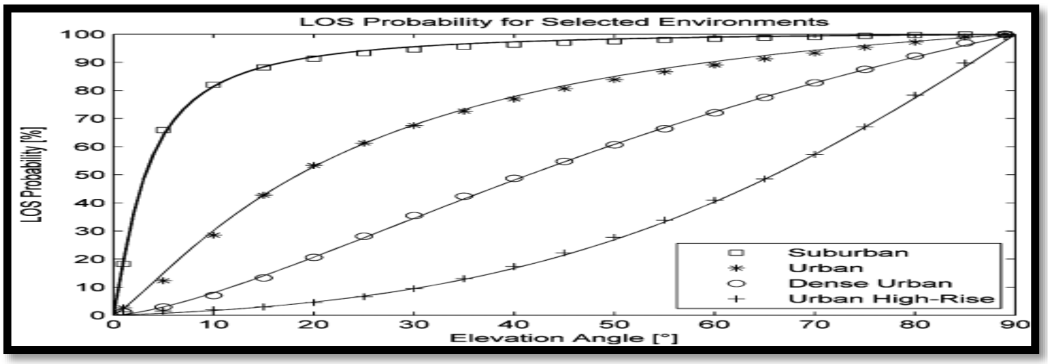


Figure 4: LOS as a function of different elevation angles (Holis & Pechae, 2008).

Figure 4 above, it shows more crowded mobiles lead which produce less LOS probability as indicated by Urban High-Rise whilst each one of them produces less line one site probability (Holis & Pechae, 2008).

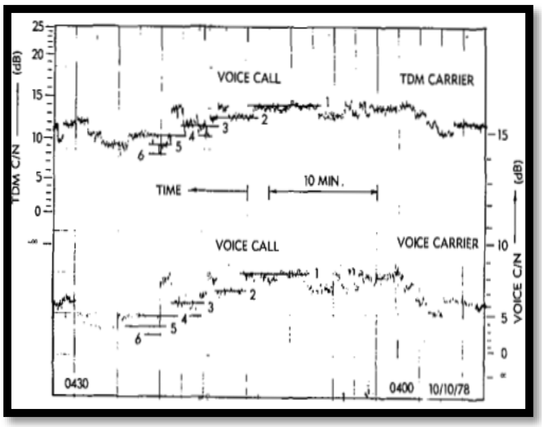
Atmospheric attenuation

The effects of low elevation angle on signal propagation can be significant, especially in the context of wireless communication. Low elevation angles can cause a decrease in signal strength, an increase in multipath fading, and a decrease in the coverage area of a wireless network (Al-Hajri et al., 2015). This is because signals traveling at lower angles have to travel further distances before they reach their destination, resulting in more attenuation and thus weaker signals. Additionally, low elevation angles can cause an increase in multipath fading due to the increased number of reflections that occur when signals travel at lower angles. This is because more reflections result in more interference and thus more fading (Basar, 2021)

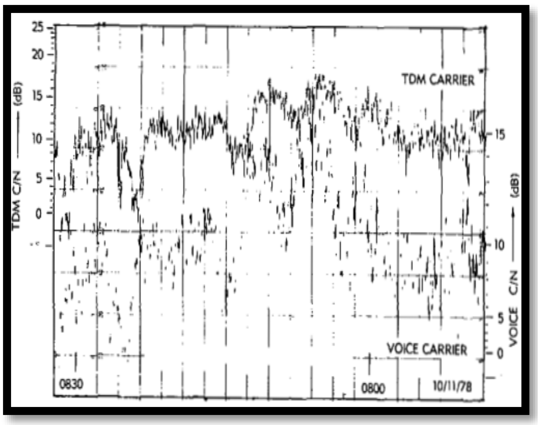
Multipath fading and scintillation

Satellite scintillation is a phenomenon that occurs when the signal from a satellite is affected by irregularities in the ionosphere. These irregularities cause the signal to fluctuate in strength, resulting in fading and distortion of the signal. Scintillation is among the contribution to attenuation that lead to reduction in the link performance. Three scintillation models was recommended by ITU-R P.618-10 in regards to percentage time and elevation angle in respect to the loss when it reached certain limits (Lee et al., 2011). The magnitude of the amplitude at minimum elevation angle reduce to minimum due to tropospheric scintillation and multipath effects, especially over-water and coastal links. This effect is very significant up to 25 dB and above. (Dairo et al., 2020) developed karasawa model to determine the effect of tropospheric scintillation using Eutelsat-36B and NigComsat-1R satellites. The result obtained shows that scintillation is maximum in Sahel and minimum in tropical region. Other satellite were not captured in the study. Peak to peak amplitude and scintillation intensity are important and are major factors to be consider to alleviate the effects of scintillation in communication link (Ashidi, 2020). Logarithmic and polynomial functions was proposed by the researcher in order to determine the best model in cushing the effect. Other models were not deployed in the research and logarithmic model was found to be the best performing one.

Multipath fading is a phenomenon that occurs when a signal from a satellite is reflected off of objects such as buildings or trees before it reaches its destination. This causes the signal to arrive at different times, resulting in interference and distortion of the signal (Yeh, & Lin, 2019). In mobile satellite communication service at L-band, this propagating signal is severely attenuated due to low elevation angles. Research was carried out in Mexico to test the signal degradation due to scintillation and Multipath fading at lower elevation angles (D. Fang et al., 1982). In his research, it has been observed that, mean strength of the signal attenuated severely at below 5 degree elevation angle. Other factors were not considered during the research. Figures (5) represent the voice and TDM carrier at 11° and 2° of elevation angles respectively. From the figures above, it can be observed that by decreasing the elevation angle from 11 to 2 degree the signals is almost disappeared



(a)



(b)

Figure 5: TDMA and Voice carrier at 2° and 11° elevation respectively (Fang et al.,1982).

Doppler effects at LEA

Satellite communication through Low Earth Orbit Mobile terminals or earth stations experienced significant Doppler, because the time of this orbit is little, this makes the satellite to approach and to split from the receiving earth station (Singh & Kumar, 2011). The Doppler effect is a phenomenon that occurs when the frequency of a wave changes due to the relative motion between the source and the observer. It has a significant impact on satellite communication particularly at low elevation angles. As the satellite moves away from the receiver, the frequency of the signal decreases, resulting in a decrease in signal strength. This can cause problems with communication, as the signal may become too weak to be received (Wang & Zhang,2018). Additionally, as the satellite moves closer to the receiver, the frequency of the signal increases, resulting in an increase in signal strength. This can cause interference with other signals and can lead to data loss or corruption. Figure (6) shows the effects of the Doppler at different elevation angles (Ali et al., 1998).

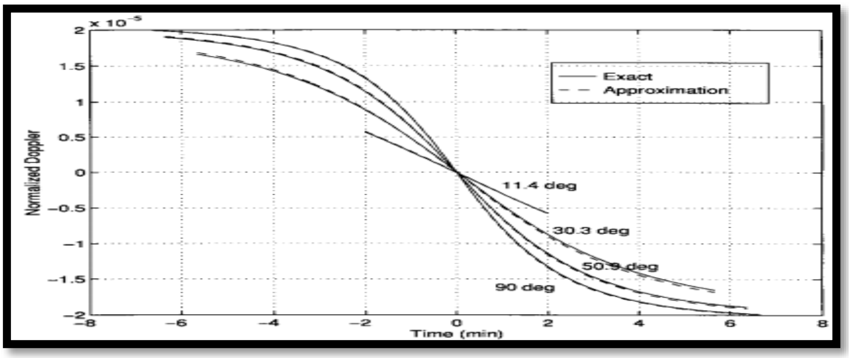


Figure 6: The Doppler effects at different elevation angles (Ali et al., 1998).

Rain, cloud, and water attenuation at Low Elevation Angles

Rain droplets absorb and scatter the signal energy and cause its power level to attenuate to a value depending on the size and shape of the droplets that the signal passes through as well as the rain rate. Referring to the ITUR P.618 the modeling formulas proved that it is also dependent on the elevation angle installed at earth station. Figure 16 shows the effects of elevation angles on the rain attenuation (Al-saegh al., 2014). In (Tomaz et al., 2023), proposed an algorithm model to track rain attenuation across satellite to earth pathway. Essential elements were presented in establishing series attenuation for LEO satellite based applications.

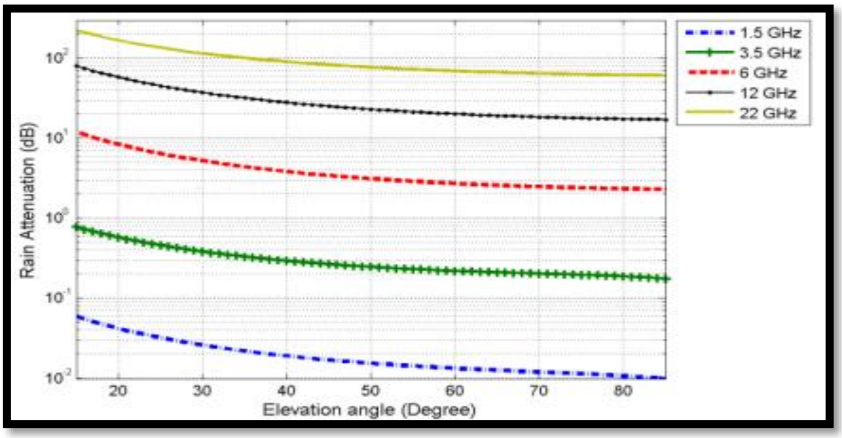


Figure 7: Deferent elevation angles produce deferent rain attenuation (Titus & Arnold, 1982).

Cloud content of liquid water also causes absorption and scattering of electromagnetic energy especially for frequencies above 10 GHz, but with less intensity than that of (Titus & Arnold, 1982).

Cloud attenuation, in addition to the transmission parameters such as the signal frequency and the elevation angle θ, depends on the cloud parameters such as average height, thickness, as well as the total columnar content of liquid water in Kg/m2 (liquid water contents LWC) and temperature.

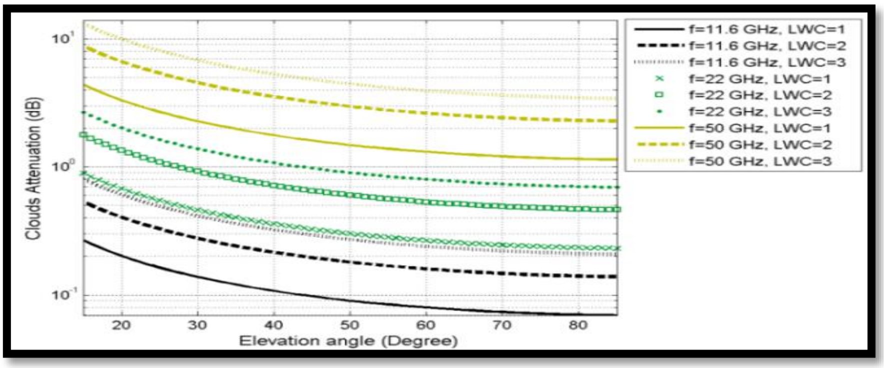


Figure 8: Elevation angle vs. cloud attenuation (Al-saegh et al., 2014).

Figure 8 present attenuation in respect to low elevation angle produced by the clouds. For the water based attenuation; the signal propagating through the atmosphere undergoes degradation in signal level owing to the water vapor and dry air components in the transmission medium. Water particles absorb and scatter the wave energy more than oxygen (Al-saegh et al., 2014).

Effects of Lea on Modulation and Bit Error Rate (BER)

The effect of low elevation angle on a satellite communication link depends on the type of modulation used. Generally, lower elevation angles result in higher levels of signal attenuation, which can lead to increased bit error rates (BER). This is because the signal is weaker and more susceptible to interference and noise (Rytir, 2022) For digital modulation schemes such as QPSK or 8PSK, the BER increases significantly as the elevation angle decreases. This is because these modulation schemes are more sensitive to signal attenuation than analog modulation schemes such as FM or AM. As a result, the signal-to-noise ratio (SNR) decreases and the BER increases. Effect of low elevation angle on satellite communication links on modulation and bit error rate has been studied in several journals. In a study published in the IEEE Transactions on Aerospace and Electronics by (Kim & Lee, 2003), it was found that the bit error rate (BER) of a satellite communication link increases significantly when the elevation angle is reduced. The authors concluded that this is due to increased signal attenuation caused by the increased path loss at lower elevation angles. Furthermore, they found that the modulation scheme used in the link also affects the BER performance, with higher order modulation schemes providing better performance than lower order schemes. Another study published in IEEE Transactions on Vehicular Technology (Chen & Lin, 2008) found similar results, with an increase in BER as the elevation angle decreased. The authors also noted that higher order modulation schemes provided better performance than lower order schemes.

DISCUSSION

Rain attenuation, scintillation remains the major challenges in satellite microwaves communications particularly at higher frequencies above 10 GHz, which eventually reduced the signal strength. In (Ezeh & et al., 2014) the author present three models to predict rain attenuation. However, only three years data was used, there is need to look for long time data, so as to estimate the effect of rain attenuation in satellite link. (Ahmad & Aamir,2016) investigate the impact of rain attenuation on elevation angle. In his research, the author recommends using higher-level Elevation angle for optimum satellite links usage. Effect of scintillation was discussed in (Morton et al., 2020). The author present how the effect can be mitigated in high and low altitude by designing an antenna with minimal multipath and reject maximum reflections. The author placed more emphasis on ionosphere conditions only, further atmospheric layers were not considered in his research. Increasing the antenna height and use of multiple antenna increase the signal strength and reduce the effects of low drastically (Al-Hijri et al., 2018). Additionally, by using Vacuum Tube Amplifier or class AB amplifier also reduced the effect of low elevation angle and strength of satellite communication signals (El-Sayed et al., 2016).

CONCLUSION

This work reviewed literature on the impacts of low elevation angles on the propagation phenomenon for satellite communication link. The paper highlights major effects and most popular researches that discussed more about low elevation angles (LEA) in respect to earth-space link. The report will helps the satellite link designer to put in consideration the presence of signal impairments caused by troposphere fading due to atmospheric gases, clouds, rain, fog, precipitation and turbulence at low elevation angles of earth station. In addition, it helps the designer in the choice of suitable modulation, Bit rate, and other phenomena’s like Doppler effects, scintillation which have an effect when low elevation angles being installed at earth stations. These effects can be mitigated by using higher gain antennas, increasing the antenna size, and using frequency diversity techniques. Additionally, careful link budgeting and antenna pointing optimization should be employed to ensure optimal performance of the link.

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