PROPAGATION IMPAIRMENTS IN 6G COMMUNICATION DUE TO NON-LINE OF SIGHT EFFECTS

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Abstract

The emerging sixth-generation (6G) mobile network provides a higher spectrum to users. It uses frequencies between 7 GHz and 3 THz. In such frequencies the effects of propagation impairments on the signal are significant. The present work is focused on analyzing the effects of the environmental factors lying in the Non Line of Sight (NLOS) path between the transmitter and the receiver. At frequencies above 7 GHz, the link operates under dense urban areas having high-rise buildings, rural areas or mountainous terrain having tall trees, etc. Hence in an NLOS link, the effects of shadowing, vegetation, and multipath fading are significant. A system undergoes multipath propagation when multiple reflections of the transmitting signal arrive at the receiver at different times. The empirical models are used for this analysis, to estimate the losses due to diffraction, vegetation, and shadowing. This study is useful in the design of a 6G system taking into consideration the signal impairments.

Key Words - 6G, Multipath Propagation, Diffraction, Vegetation, Shadowing.

1. Introduction

The 6G technology is expected to provide a more extensive spectrum, cost-effectiveness, and a high level of security, in addition, to increased coverage and lower power consumption. For addressing these requirements in a 6G network several technological advances, including waveform design, multiple access, channel coding methods, different antenna technologies, network slicing, and cloud edge computing, are used [1]. However, the wireless signal is susceptible to propagation impairments along its path. The time variation of received signal power caused by changes in the transmission medium or path is termed as fading. The system design of a mobile environment experiencing fading is the most challenging technical problem. Fading is affected by changes in atmospheric conditions, such as rainfall in a fixed environment. The relative location of various obstacles changes over time, creating complex transmission effects in a mobile environment, where one of the two antennas is moving relative to the other.

The work in [2] shows the frequency dependency of key propagation phenomena such as the characteristics of path loss in an urban environment, human blockage, and scattering from a rough building surface up to 150 GHz.

The remainder of the paper is organized such that the multipath propagation is illustrated in section 2. The effects of diffraction fading are demonstrated in section 3. The losses experienced due to vegetation attenuation are manifested in section 4. Shadowing loss is illustrated in section 5. Finally, the conclusion is drawn in section 6.

2. Multipath Propagation

Reflection, Diffraction, and Scattering are three propagation mechanisms that play a role in multipath propagation. The multipath propagation mechanism is illustrated in Fig. 1.

2.1 Reflection

Reflection occurs when an electromagnetic signal encounters a surface that is large relative to the wavelength of the signal. For example, a ground-reflected wave received near a mobile unit. Since there is a 180° phase shift for ground-reflected wave after reflection, the ground wave and the Line of Sight (LOS) wave may tend to cancel, resulting in high signal loss. The reflected signal has a longer path compared to the unreflected signal which creates a phase shift due to delay. Further, multipath interference occurs because the mobile antenna is lower than most human-made structures in the area. At the receiver, these reflected waves may interfere constructively or destructively.

2.2 Scattering

Scattering occurs if the size of an obstacle is on the order of the wavelength of the signal or less. The outgoing signals are formed from several scattered weaker incoming signals. Numerous objects such as lamp posts and traffic signs can cause scattering at typical cellular microwave frequencies. It is difficult to predict the effects of scattering.

Depending on local conditions and as the mobile unit moves within a cell, the above propagation effects influence system performance in various ways. Diffraction and scattering are generally minor effects, if a mobile unit has a clear LOS to the transmitter, although reflection may have a significant impact. If there is no clear LOS, such as in an urban area at street level, diffraction and scattering are the primary means of signal reception [3]. As the frequency increases, human blockage loss increases and the scattering is more diffused [4].

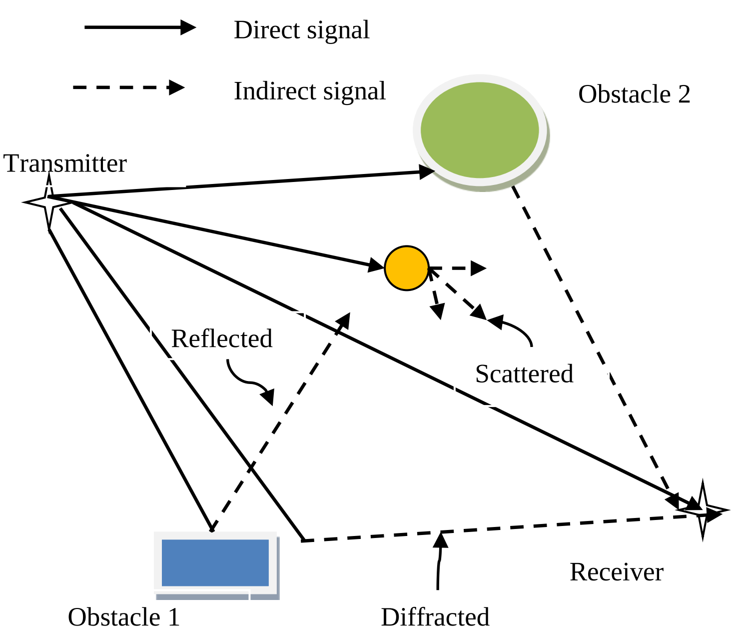

Fig. 1. Multipath Propagation

3. Effects of Diffraction Fading

If there is an opaque object on the path of the signal, diffraction occurs at the edge of that object which is large compared to the wavelength of the radio wave. When radio wave encounters such an edge, waves propagate in different directions with the edge of the source. The signals can be received even if there is no unobstructed LOS from the transmitter. The diffraction loss is suffered by millimeter wave signals when they are hit by one or two obscuring points located over the rooftops of the buildings is analyzed.

For various distances between the transmitter and the receiver, the objects have different heights. The results obtained illustrate that the loss due to diffraction is inversely proportional to the distance between the obscuring object and the transmitter, the wavelength, and the distance between the transmitter and the receiver.

Huygen's principle states that all points on a wave front can be considered as point sources for the production of secondary wavelets that can combine to produce a new wave front in the direction of propagation of the signal [5]. Diffraction is based on Huygen's principle. When the radio path between the transmitter and receiver is obstructed by an object that has sharp edges there is an occurrence of diffraction. The structure of the object, the amplitude, phase, and polarization of the incident wave contribute to the extent of diffraction [6].

When the LOS path is usually blocked by buildings in urban area environments, diffraction models are significant for predicting NLOS wireless channels.

3.1 Diffraction loss dependence on path clearance

The diffraction loss varies by the type of terrain and vegetation. For a given path ray clearance, the loss will vary from a minimum value for a single knife-edge obstruction to a maximum for smooth spherical earth [7].

3.2 Diffraction loss due to irregular terrain

Many propagation paths encounter one obstacle or several obstacles. It is useful to estimate the losses produced by such obstacles. It is useful to idealize the form of the obstacles to make such calculations, by either assuming a knife-edge of negligible thickness or a thick smooth obstacle with a well-defined radius of curvature at the top. The indications provided in the ITU-R P.526-15 should be regarded only as an approximation since real obstacles have more complex forms [8].

The radius of curvature of the obstacle corresponds to the radius of curvature at the apex of a parabola to the obstacle profile in the vicinity of the top. The maximum vertical distance from the apex that is used in the procedure should be in the order of the first Fresnel zone radius where the obstacle is located when fitting the parabola. The median radius of curvature *'r'* of the obstacle is calculated using *'N'* samples as:

$$r=\frac{1}{N}\sum_{1}^{N}\frac{x_i^2}{2y_i} \quad (1)$$

where 'x_i' and 'y_i' represent the x-coordinate and ycoordinate value for sample 'i'.

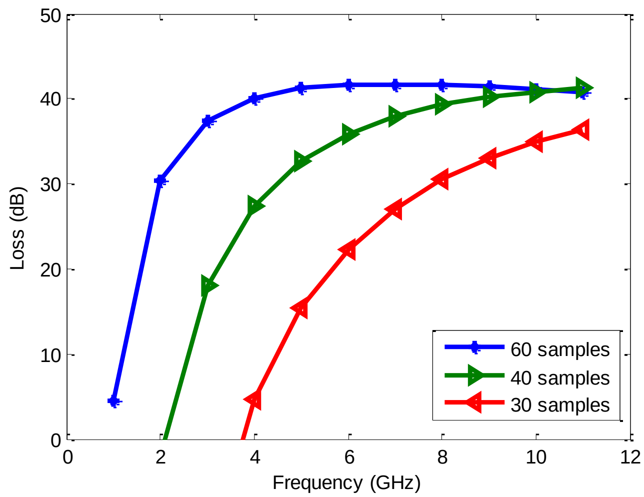

Fig. 2. Diffraction loss due to single-rounded obstacle

The diffraction loss due to a single rounded obstacle (radius of curvature = 3 m) is shown in Fig. 2 for the 2-11 GHz range. The diffraction loss increases with increasing frequency along with an increase in sample size. At 60 samples, the diffraction loss saturates above 5 GHz frequency, which corresponds to the maximum vertical distance from the apex of the rounded obstacle that is located in the first Fresnel zone radius.

3.3 Diffraction loss due to average terrain

The diffraction loss over average terrain can be approximated from ITU-R P.530-18. This loss is mainly dependent on the height of the obstacle from the path of the trajectory of the signal. The diffraction loss over average terrain can be approximated for losses greater than about 15 dB using the formula:

$$A_d = -20\,h/F_1 + 10 \qquad \text{dB} \qquad (2)$$

where 'h' is the height difference (m) between the most significant path blockage and the path trajectory, and 'F_1' is the radius of the first Fresnel ellipsoid.

$$F_1 = 17.3\sqrt{\frac{d_1 d_2}{fd}} \qquad \text{m} \qquad (3)$$

where 'f' is the frequency in GHz, 'd' is the path length in km; 'd_1' and 'd_2' are distances in km from terminals to the path obstruction.

At frequencies above about 2 GHz, diffraction fading of this type has been alleviated by installing sufficiently high antennas. Therefore, the most severe ray bending would not place the receiver in the diffraction region when the effective earth radius (5280 miles) is reduced below its normal value.

The effective earth radius is the real earth radius (3690 miles) multiplied by the k-factor (4/3) which is dependent on the refractivity gradient [9] [10]. The direct path between the transmitter and receiver needs a clearance above ground of at least 60% of the radius of the Fresnel zone to achieve free-space propagation conditions as indicated in the diffraction theory [7].

4. Vegetation Attenuation

The vegetation attenuation is a significant factor that has to be taken into consideration while designing an NLOS link. The network planners have to increase system capacity by locating transmission antennas at heights lower than surrounding trees and buildings due to the larger number of users, especially mobile users [11] [12]. In the radio path of a point-to-point link, the effects of trees singly or as a group influence the received signal level, which have been studied by analytical methods based on experimental measurements [13] which have shown to:

- Directly provide an additional attenuation (excess) to that of free space
- Contribute to scattering which indirectly results in lateral contributions to the received signal and affects
- Depolarise the incident wave [14] [15] [16].

The ITU-R P.833-10 model is used for a single vegetation obstruction for above 1 GHz frequency. The diffracted, ground-reflected, and through-vegetation scattering components are first calculated to estimate the total field and then combined.

The diffracted components are formed by the diffraction that occurs over the top of the vegetation and around the sides of the vegetation. The ITU-R recommendations are used to calculate these components and the ground-reflected component. This model is based on the theory of Radiative Energy Transfer (RET) that is used for calculating the through or scattered component [17].

The total loss experienced due to vegetation as given by ITU-R [18] is:

$$L_{total} = -10\log_{10}\left\{10^{\left(\frac{-L_{sidea}}{10}\right)} + 10^{\left(\frac{-L_{sideb}}{10}\right)} + 10^{\left(\frac{-L_{top}}{10}\right)} + 10^{\left(\frac{-L_{ground}}{10}\right)} + 10^{\left(\frac{-L_{scat}}{10}\right)}\right\} \qquad (4)$$

where 'L_{sidea}' and 'L_{sideb}' are the diffraction loss from the sides of the obstacle, 'L_{top}' is the diffraction loss at the top, 'L_{ground}' is the loss from the ground reflected wave, and 'L_{scat}' is the attenuation due to scattering.

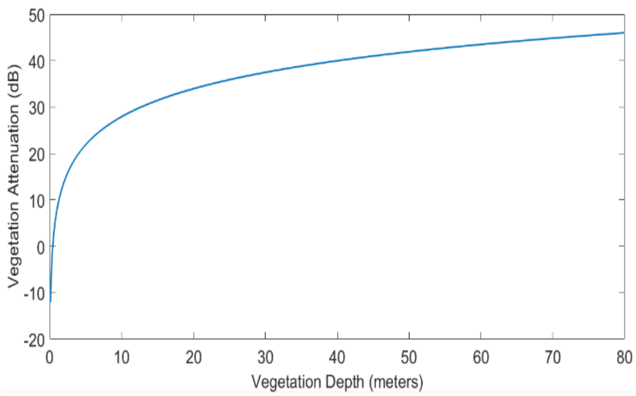

Fig. 3. Loss due to vegetation using ITU-R model at 11 GHz

Fig. 3 illustrates the loss experienced due to vegetation at 11 GHz frequency. The loss increases with the increase in the vegetation depth. At a vegetation depth of 80 m, an attenuation of 47 dB is experienced.

Previous works illustrate that with leaves, the diffraction around the edge or top of the trees is the dominant mode of propagation. In comparison with the scattered components the diffracted components are less attenuated. Generally, in without leaf condition, the ground reflection acts as the dominant component [19].

The signal received with a small number of trees obstructing the signal path decayed at a considerably faster rate, relative to the signal when more trees obstruct the path [14]. The increase in foliage attenuation for about the first 30 m as a function of foliage depth was found to be nearly linear. It increases at a rate of 2.1 dB/m with leaves and 1.74 dB/m without leaves. The attenuation increases in greater foliage depth at much-reduced rates of 0.41 dB/m with leaves and 0.19 dB/m without leaves. This is because propagation between the transmitter and the receiver is primarily by a strongly attenuated LOS component at small foliage depth, while multiple scattering of radio waves by the various parts of trees becomes a major contributor to loss to the received signal.

5. Shadowing Loss

The macro-cellular path loss models illustrate that the predicted path loss will be constant for a system operating in the base station to mobile environment. This occurs because path loss is a function only of antenna heights, environment, and distance. However, for a given distance in practice, the clutter due to buildings and trees will be different for every path. This causes variations concerning the nominal value. So some paths will be less obstructed having increased signal strength, while the others will suffer increased loss. This phenomenon is termed shadowing or slow fading [20].

Shadowing causes the received Signal-to-Interference-Plus-Noise Ratio (SINR) to vary dramatically over long time scales and is considered an important effect in wireless networks. Reliable high-rate communication may be nearly impossible in some locations in a given cell. The path loss due to shadowing is considered to be random and follows a log-normal distribution [19]. If the transmission experiences *'N'* random attenuations β_i, $i = 1, 2, \ldots N$ between the transmitter and receiver, the received power *'P_r'* can be modeled as:

$$P_r(dB) = P_t(dB) + 10\sum_{i=1}^{N}\log_{10}\beta_i \tag{5}$$

where 'P_t' is the transmitting power.

Using the Central Limit Theorem, the sum terms will become Gaussian as *'N'* becomes large, hence the shadowing is log-normal. The log-normal shadowing should be taken into account during system design. The base station deployment through micro diversity using variable transmit power should be carried out. There is a need to consider that some users will experience poor performance at a certain percentage of locations.

For smaller cells, the Walfish-Ikegami (W-I) model is recommended for modeling microcellular environments. An urban environment with a series of buildings is the assumption in the model. The limitation of this model is that its use is restricted to frequencies from 800 MHz to 2 GHz. Using the W-I model total path loss is calculated as [21] follows:

$$\text{Shadowing Loss} = -65.9 + 38\log_{10} d + \left(24.5 + \frac{1.5f}{92.5}\right)\log_{10} f \tag{6}$$

where, 'd' is the distance in km between Base Station (BS) and receiver, and 'f' is the frequency in MHz.

Fig. 4 shows that as the distance between the BS and the receiver increases, the path loss due to shadowing increases significantly.

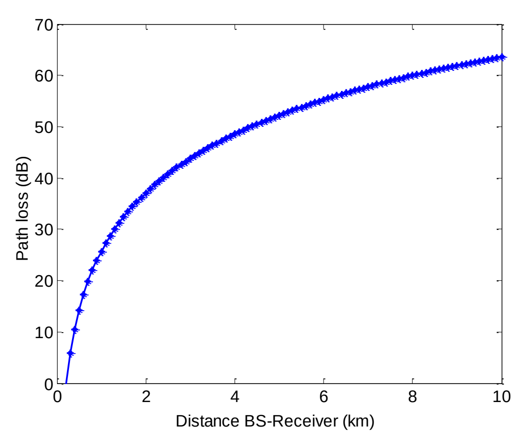

Fig. 4. Path loss due to log-normal shadowing using Walfish-Ikegami model

6. Conclusion

In the NLOS 6G link, diffraction, vegetation, and shadowing are the major factors that contribute to signal impairments. The existing empirical methods are used to demonstrate the overall losses experienced in the presence of these effects. With all the factors an increase in frequency and path length produces increased signal attenuation. As 6G networks use high frequencies this attenuation is quite significant. Based on the estimation of the losses, suitable fade mitigation techniques such as OFDMA, and MIMO have to be employed to achieve the required link margin.

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