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Impact of Human Body on Knife-Edge Diffraction in Wireless Communication

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Abstarct -This paper examines the effect of human body blockage on signal propagation (millimeter-wave (mmWave) signal propagation) in indoor environments links at 32.5 GHz (a critical frequency for fifth-generation (5G) network), with a particular focus on the diffraction effects caused by the human body, where diffraction is one of the important wave propagation mechanisms. In this study, measurements were taken to assess the effect of the human body as it moves between the transmitter and the receiver. To predict the signal attenuation, the principles of Fresnel diffraction were utilized, particularly emphasizing complex Fresnel integrals. Our results show that the received power varies significantly based on the person's position, as diffraction loss highly depends on the body's location. This study enhances our understanding of how human-induced diffraction, is critical for designing more reliable wireless networks. As the findings demonstrate that the proposed model effectively predicts signal attenuation in indoor environments and emphasizes the importance of accounting for human interference when optimizing communication systems, thus supporting the effective deployment of 5G technology.

Keywords—diffraction, Wireless communication, Fresnel- diffraction, human blockage, 5g.

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I. Introduction

Wireless communication systems are increasingly demanding the use of higher frequencies (millimeter-wave), and to do this, it is important to understand and address the obstacles that may interfere with the signal [1]. In millimeter-wave (mmWave) frequencies, such as those utilized in 5G networks, the effects of physical obstructions become increasingly pronounced due to the short wavelengths and high attenuation characteristics at these frequencies[2-4]. One of the important phenomena is diffraction, which describes the bending and spreading of radio waves around obstacles. This becomes critical when the obstacles are themselves human bodies, a common enough feature indoors, and will result in shadowing, diffraction, and other complicated interference patterns which may pose many challenges in signal transmission reliably.
Several studies have explored the effects and characterization of human body blockage in mm Wave frequency bands. These studies have employed different models to estimate the attenuation caused by human blockage[5-8]. However, there is still a need to understand the impact of human blockage and shadowing particularly in indoor environments where a significant portion of wireless communication occurs. Provide this study to a simple approach to characterize the effects of diffraction by human bodies in an indoor link operating at 32.5 GHz, it is a continuation of previous studies that were published and evaluated [5][6][10]. To our knowledge, so far there are no measurements or modeling work reported in the open literature on human blockage at 32.5 GHz.

In this study, the attenuations caused by the human body are estimated under a controlled scenario, involving a person moving between a transmitter (TX) and a receiver (RX). By modeling the effects of human body shadowing on indoor links within 5G systems, and validation of this model was performed using measurements data. This study aims to understand how these effects can be mitigated and how they

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will impact the performance of 5G communication systems in real-world environments.

Finally, the results show the model's ability to predict attenuation caused by human blockage and shadowing. These results will provide valuable insights for designing and deploying efficient and reliable 5G networks in indoor environments.

II. Measurement Environment and Settings

This section outlines the specifics of the measurement environment, where the transmitting antenna (Tx) and receiving antenna (Rx) are positioned 2 meters apart, each mounted on a stand 1 meter high. The Tx is connected to an Agilent E8244A signal generator, while the Rx is linked to an Agilent E4448A spectrum analyzer. Low-loss cables are utilized to minimize signal degradation during connections. Two identical horn antennas (PE9850/2F-20) are employed, featuring an 18.3° horizontal and 16.7° vertical half-power beamwidth (HPBW) and a gain of 20 dBi for both transmission and reception. To ensure optimal measurement conditions, a laser beam is used for indoor propagation link alignment with the human body. Additionally, connector and cable losses are measured, and preliminary calibration measurements are conducted to fine-tune the system.

The setup consists of a link positioned between a wall and a desk, both set at a distance of $L1 = L2 = 2.4$ m from the link, with the desk height at 0.75 meters. Behind the transmitter (Tx), there are steel cabinets that stand 2.2 meters tall, located $L3 = 13.5$ m away. Additionally, a plasterboard wall is situated behind the receiver (Rx) at a distance of $L4 = 3$ m. The height of the laboratory ceiling is 2.9 meters.

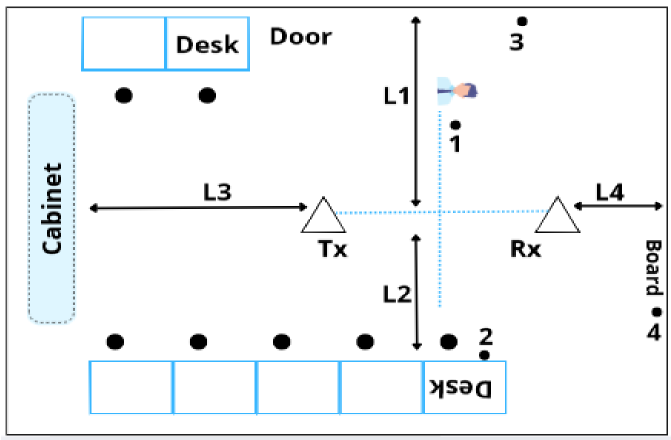

Fig. 1. Measurement environment.

Then, we conducted measurements of the received power based on the scenario described in the following sections.

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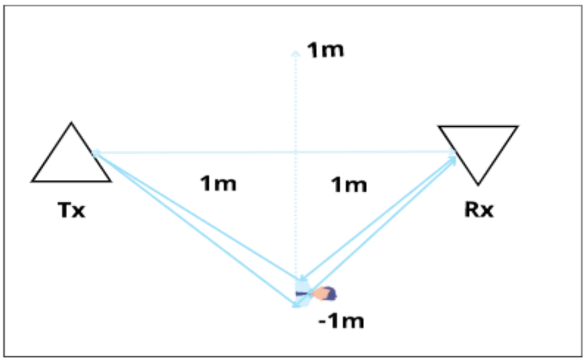

Fig. 2. Measurement scenario.

III. MODEL FOUNDATIONAL PREREQUISITES

In this section, the prerequisites for the proposed propagation model for the measurement scenario are presented.

A. Path Loss

Path loss is intimately linked to the environment where the transmitter and receiver are located. It defines signal strength variance during propagation, considering factors like distance, frequency, and antenna characteristics[9-11]. One important component of path loss is free-space loss, which represents the signal attenuation when there is a clear line-of-sight (LOS) path between the transmitter and the receiver. The basic formula for free-space path loss (FSPL) is given by[11]:

$$FSPL(dB) = 20\, log_{10}\,(\frac{4\pi d}{\lambda})$$

Where FSPL is the free-space path loss, d is the distance between the TX and RX, λ is the wavelength of the signal.

In general, propagation path loss increases with frequency as well as distance. The more the distance increases or the frequency of the signal increases, the greater the loss in the strength of the signal, thereby affecting the received power[9].

B. Fresnel Zone Radius

The Fresnel zones refer to the elliptical regions around the line-of-sight between a wireless transmitter and receiver. These zones are concentric but have a different impact on signal propagation. An important consideration is the existence of obstructs within what is called the First Fresnel Zone(FFZ) [9, 11]. The radius of the first Fresnel zone $R1$ is given by:

$$R_1 = \sqrt{\lambda \frac{d_T d_R}{d_T + d_R}}$$

Where R1 indicates the radius of the first Fresnel zone, λ is the wavelength of the signal, d_T and d_R are the distances to the obstruction from the TX and RX respectively .

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C. Diffraction Attenuation Models

The diffraction is one significant propagation mechanism, which allows radio signals to propagate around obstructions when an obstacle blocks the signal path. The phenomenon can be modeled using the Fresnel-Kirchhoff diffraction theory, which builds upon the Huygen's principle[11, 12]. The diffraction attenuation F(v) can be determined using complex Fresnel integrals given by

$$\mathrm{F}(v) = \frac{E}{E_0} = \frac{1+j}{2}\int_{v}^{\infty} exp^{\left(\frac{-j\pi t^2}{2}\right)} dt$$

Where v is Fresnel-Kirchhoff diffraction parameter[9]:

$$v = h\sqrt{\frac{2(d_T + d_R)}{\lambda d_T d_R}}$$

Where h is the height of the obstruction relative to the line-of-sight path. d_T is the distance from the TX to the obstruction. d_R is the distance from the obstruction to the RX.

The diffracted wave resulting in dB can be expressed as:

$$l_{db=20\log_{10}\mathrm{F}(v)}$$

IV. Modeling The Shadowing While Human Body Blocking The Link

In this section, we discuss the influence of a moving person on received signal strength. The focus is on the diffraction that occurs at the shoulders as the person traverses between the transmitter (TX) and receiver (RX).

A. Scenario Description

In this scenario, the transmitter (TX) and receiver (RX) are positioned on a 2-meter horizontal line, forming a line of sight (LOS) between them. A person moves on a path that is halfway between the TX and RX, we denote the width of the person as 0.47 meters, which will be critical in our calculations for diffraction effects. When the person at 1 meter away moves towards to the middle of the link (LOS) and cross it to the opposite side. The shoulders are critical points for analyzing the effect of diffraction on the signal, as each movement of the person affects the angle of incidence of the signal on the shoulders, and the interference and diffraction level.

B. Geometric Model

Fig.3. shows the geometric model, where the human body is represented as a barrier with two identical vertical edges, and the diffraction effects at these edges are analyzed. It is assumed that the rest of the body between the edges causes shadowing or blocking, because high frequencies tend to diffract around the edges only[13-16]. The diffraction effect caused by the shoulders is calculated using Fresnel-Kirchhoff diffraction theory. The Fresnel integral is applied to each edge to calculate the diffraction effects more accurately. The model allows each shoulder to be treated as a diffraction source independently, thereby making possible more details in analyzing just how the electromagnetic waves interact with the body at these key points.

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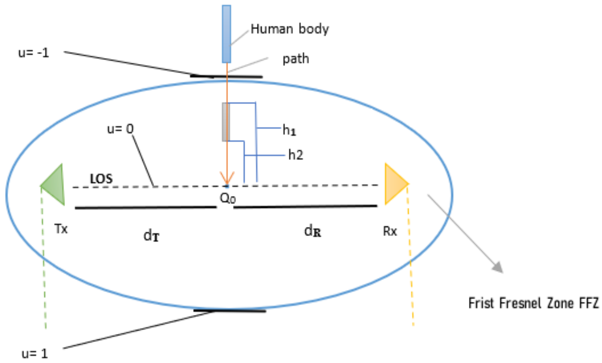

Fig. 3. Simplified diffraction geometry

C. Modeling Scenario

We analyze how the signal changes when a person moves towards LOS, especially when crossing the FFZ. The focus is on the diffraction at the person's shoulders [13-23]. This model can calculate the total effect of wave diffraction by complex Fresnel integral, so Fresnel integral for edge 1 is given as

$$\mathrm{F}(v_{edge\_1}) = \frac{E}{E_0} = \frac{1+j}{2}\int_{v_{edge\_1}}^{\infty} exp^{\left(\frac{-j\pi t^2}{2}\right)} dt$$

Similarly, the Fresnel integral for edge 2 is given as

$$\mathrm{F}(v_{edge\_2}) = \frac{E}{E_0} = \frac{1+j}{2}\int_{-\infty}^{v_{edge\_2}} exp^{\left(\frac{-j\pi t^2}{2}\right)} dt$$

Where v is given as

$$v_{edge\_i} = h_{edge\_i}\sqrt{\frac{2(d_T + d_R)}{\lambda d_T d_R}}$$

Where j is the imaginary unit, λ is the wavelength, h is the vector distance from LOS to the edge

The overall diffraction loss due to the presence of the moving obstruction is computed as:

$$l_{db} = 20\log_{10}\left|\mathrm{F}(v_{edge\_1}) + \mathrm{F}(v_{edge\_2})\right|$$

To assess the overall impact on received signal strength we calculate the total path loss, which is the summation of free-space path loss and the diffraction loss. This provides a comprehensive view of how the moving person influences the wireless communication between the TX and RX.

V. MEASUREMENT RESULTS

The accuracy of the proposed model is confirmed by comparing the simulation results with actual measurement data. Fig. 4. illustrates the comparison between the model's simulated received power and the measured values. It can be observed that the model tends to underestimate the received power by 3–7 dB. This discrepancy may be due to uncertainties in the antenna gain values. The results reveal a consistent underestimation of received power by the model, with discrepancies ranging from 3 to 7 dB across all blockage positions. For instance, at full LOS obstruction (0 m position), the model predicted a received power of −62.2 dB, whereas measurements recorded a deeper attenuation of −68.1 dB with a 6 dB gap. Similarly, during partial blockage phases (e.g., ±0.5 m positions), deviations averaged 3.5 dB, highlighting the model's sensitivity to dynamic human positioning.

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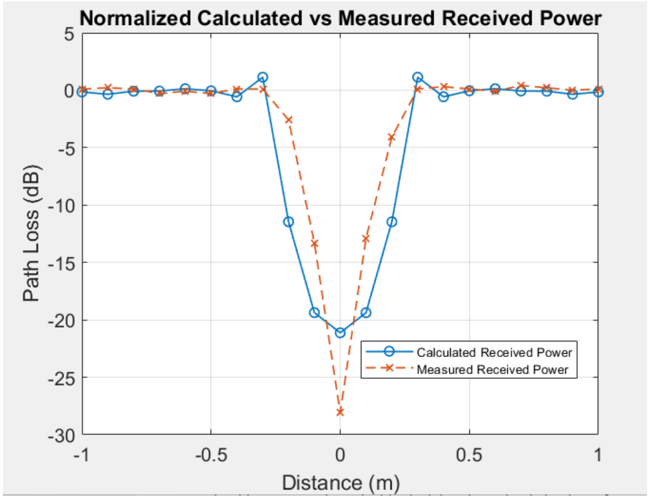

Fig. 4. Normalized for comparison of measurements and the model simulation.

VI. Conclusion

Millimeter waves (mmWaves) have received significant attention due to their potential to meet the ever-increasing demands for data rates. However, researchers face a major challenge due to their sensitivity to the blockage. This study focuses on examining the effects of human shadowing blocking on mmWaves in indoor links at 32.5 GHz for 5G systems. The diffraction modeling uses the Fresnel diffraction model is verified by comparing the simulation results of the proposed model with the measurement results. The model has been demonstrated to be capable of predicting the attenuation of wireless signals in indoor environments and these results can be used to improve wireless communications.

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