Evaluating the Accuracy of DKED and Fresnel Diffraction Models for Human Body Blockage in Indoor 5G Band Communications

Ahmed Alabish
dept. Computer Science
Libyan Academy
Tripoli, Libya
ahmed.cs@academy.edu.ly

Wjdan mohammed
dept. Computer Science
zawia University
Zawia, Libya
wjdan1997mohammed@gmail.com

Manal ghoumah
dept. Computer Science
Libyan Academy
Mislata, Libya
manalgoma90@gmail.com

Ali S Dowa
dept. Computer Science
zawia University
Zawia, Libya
ali.dowa@zu.edu.ly

***Abstract*— This paper investigates human-induced signal attenuation in indoor mm-wave communications at 32.5 GHz, a critical concern for 5G systems. Two distinct diffraction-based models are applied to the same indoor scenario to assess human blockage effects: one employs the Double Knife-Edge Diffraction (DKED) approach, and the other uses Fresnel diffraction principles with complex Fresnel integrals. Controlled experiments with a human subject moving between a transmitter (TX) and a receiver (RX) reveal that the DKED model consistently underestimates the received power by 2–6 dB, while the Fresnel diffraction approach underestimates it by 2–5 dB Based on the comparative results, the DKED model demonstrates higher accuracy in predicting signal attenuation, offering valuable insights for improving indoor 5G network performance.**

Keywords— Wireless Communication, 5G, Signal Attenuation, diffraction, human shadowing, DKED, Fresnel-diffraction.

I. INTRODUCTION

The rapid evolution of wireless communication and the growing demand for high data rates have propelled the adoption of millimeter-wave (mmWave) frequencies in 5G networks [1, 2] . However, the short wavelengths and high attenuation characteristics of mmWave signals make them particularly susceptible to environmental obstacles. Indoor environments compound these challenges, as common obstructions such as furniture and human bodies cause significant signal degradation through mechanisms like diffraction, scattering, and shadowing [2, 3]. Human bodies, in particular, not only block the line-of-sight but also act as reflectors and scatterers, thereby complicating signal propagation.

To address these challenges, several studies have explored diffraction-based models to characterize human blockage in mmWave frequencies [4, 5]. Among these, the Double Knife-Edge Diffraction (DKED) model is valued for its simplicity and relative ease of implementation, whereas Fresnel diffraction principles offer an alternative framework by leveraging complex Fresnel integrals to capture subtle effects of both human blockage and nearby scattering objects. However, direct comparisons between these two models in the 32.5 GHz band have been limited.

In this study, we apply both the DKED and Fresnel diffraction models to the same controlled indoor scenario and validate their predictions against experimental measurements. Our results indicate that while both models tend to underestimate the received power with the DKED model showing a deviation of 2–6 dB and the Fresnel diffraction approach 2–5 dB the DKED model provides a more accurate prediction of signal attenuation. These findings not only enhance our understanding of human-induced propagation effects at mmWave frequencies but also offer practical guidance for optimizing indoor 5G network performance in real-world environments.

II. RELATED WORK

Several research studies have investigated the effects of human body blockage on indoor communication links at various frequencies. For example, in 2021 [6] , a study was presented on the impact of human blockage on indoor communication links at a frequency of 32 GHz using the Double Knife-Edge Diffraction (DKED) model. Extensive measurements were conducted to analyze the influence of scattering objects in proximity to the communication link while it was entirely obstructed by a human body. The study employed diffraction modeling to accurately predict the attenuation caused by these obstructions, and the results indicated that the simplified models used were effective in capturing the complexities of signal degradation due to human blockage, thereby providing valuable insights for enhancing indoor 5G network performance.

In 2019, a research paper [4] proposed a simplified model for characterizing the effects of scattering objects and human body blockage in indoor links at 28 GHz. They conducted measurements to study the effects of scattering objects near the indoor link, while the link was fully blocked by a human body, utilizing reflection and diffraction modeling to predict the attenuation caused by these objects.

In 2016, a study [7] presented human blockage measurements at 73 GHz. The work utilized a simple model based on the double knife-edge diffraction (DKED) approach to characterize human blockage. In 2018, an experimental study [5] into the effects of human body movements on indoor wave propagation at frequencies between 18 and 22 GHz. Using realistic movement scenarios, the paper showed that

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even minor human motion can cause significant changes in received signal strength. The findings highlighted how crucial it is to include dynamic human effects in channel models, particularly for high-frequency indoor systems.

In 2019 [8], a study presented a detailed model for human blockage at 73 GHz, a key frequency in 5G mmWave communications. Their measurements in indoor environments led to the development of a double knife-edge diffraction (DKED) model to estimate human-induced shadowing. The model accurately predicted signal loss due to human obstruction, which was found to exceed 30 dB in some scenarios.

These studies contribute to our understanding of the effects of human body shadowing and provide insights into modeling and predicting signal attenuation in indoor millimeter-wave communication systems.

III. Overview of Propagation Models

The study of wave propagation is fundamental to the design and optimization of wireless communication systems, especially as technology advances toward the use of high-frequency bands, such as millimeter-wave (mmWave). This section provides a detailed overview of two important analytical models, used to predict human body effects on signal propagation: Fresnel diffraction model (FDM) and the Double Knife-Edge Diffraction (DKED) model.

A. *Fresnel diffraction model (FDM)*

The FDM is based on the principle of diffraction, which describes how waves bend around obstacles. This model simplifies the interaction between radio waves, and physical obstructions by approximating the obstruction as an edge. This simplification allows for easier calculations, while still capturing the essential diffraction effects [9].

The FDM utilizes mathematical expressions derived from Huygens' principle, which posits that every point on a wavefront can be considered a source of secondary wavelets. The key formula used in the FDM calculates the diffraction loss as a function of the geometry of the obstacle and the angle of incidence of the incoming wave. The formula takes into account the height of the obstacle relative to the line of sight (LoS) between the transmitter (Tx) and receiver (Rx) [9, 10].

The Fresnel diffraction integral is expressed by the following general equation:

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

Where v is the Fresnel-Kirchhoff diffraction parameter:

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

Where λ is wavelength, h is the height of the obstruction relative to the line-of-sight path and d_T & d_R are transmitter, receiver the distances to obstruction.

B. *Double Knife-Edge Diffraction Model (DKED)*

The DKED model enhances the Fresnel Diffraction Model (FDM) approach by treating the human body as a double knife-edge obstruction. This model recognizes that the human body affects signal propagation not only through blockage but also through scattering phenomena around its edges [7]. By accounting for the body's contours, the DKED model provides a more nuanced analysis of signal behavior in real-world environments.

In the DKED model, diffraction loss is calculated using a more complex set of equations that account for the two knife-edge obstructions representing the human body. The model incorporates parameters such as the width and position of the body, as well as the distances to the transmitter (Tx) and receiver (Rx). This enables more precise predictions of how signals are affected when interacting with the human body [4, 5]. The general equation for the DKED model is expressed as follows:

$$\mathrm{SL} = -20\log_{10}\left|\begin{array}{l}\left(\frac{1}{2}-\mathrm{F_{w1}}\right)\times\sqrt{\mathrm{G_{Txw1}(\theta)}}\times\sqrt{\mathrm{G_{Txw2}(\theta)}}+\\ \left(\frac{1}{2}-\mathrm{F_{w2}}\right)\times\sqrt{\mathrm{G_{Rxw1}(\theta)}}\times\sqrt{\mathrm{G_{Rxw2}(\theta)}}\end{array}\right| \qquad (3)$$

where θ is the projected angle from the transmitter (Tx) to one of the edge ($w1$ or $w2$) and from the edge ($w1$ or $w2$) to receiver (Rx), $G_{Txw1|Txw2|Rxw1|Rxw2}(\theta)$ (the subscript symbol "∗ | ⋅" denotes "∗ or ⋅") represents the normalized antenna gains as a function ofθ relative to boresight gain.

In summary, a thorough understanding of these propagation models is essential for optimizing wireless communication systems, particularly as high-frequency bands become increasingly prevalent. Accurately modeling wave propagation and the effects of human bodies will ultimately inform better design and deployment strategies for future wireless networks, ensuring robust and reliable communication capabilities in an ever-connected world.

IV. Measurement Environment and Settings

Both models were tested in controlled indoor environment at 32.5 GHz, utilizing a consistent measurement system to ensure comparability. The setup involved:

A. *Equipment Setup*

- *Antenna Setup:* The transmitting antenna (Tx) and receiving antenna (Rx) are positioned 2 meters apart, both mounted on stands at a height of 1 meter. Two identical horn antennas (PE9850/2F-20) are utilized, each featuring an 18.3° horizontal and a 16.7° vertical half-power beam width (HPBW) with a gain of 20 dBi.
- *Equipment Connections*: 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.
- *Environment Layout:* The measurement link is

positioned between a wall and a desk, both located at distances of L1=L2=2.4 m from the link, with the desk height set at 0.75 meters. Behind the Tx, steel cabinets measuring 2.2 meters in height are situated L3=13.5 m away. A plasterboard wall is located behind the Rx at a distance of L4= 3 m. The laboratory ceiling height is 2.9 meters as shown in fig.1.

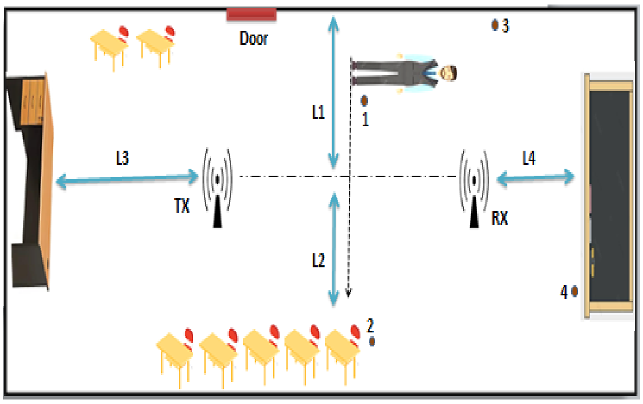

Fig. 1. Measurement environment.

B. *Human Blockage Scenario*

In a controlled indoor environment designed to simulate a typical 5G communication scenario, a transmitter (Tx) and a receiver (Rx) were positioned at a fixed distance of 2 meters from each other, aligned along a straight line, forming a line of sight (LOS) between them. The system operated at a frequency of 32.5 GHz; representative of millimetre-wave (mmWave) bands used in 5G networks. To analyze human-induced shadowing effects, a human subject with an average width of 0.47 meters to walk between Tx and Rx, simulating natural body movement in indoor settings such as offices or smart homes. The movement occurs along a path extending from −1 meter to +1 meter, centered on the midpoint between the transmitter (Tx) and receiver (Rx). The motion starts from one side, moves toward the line-of-sight (LoS) between the Tx and Rx, and crosses to the opposite side of the LoS. As the person moves, they progressively block the direct line-of-sight between the Tx and Rx, causing signal attenuation due to diffraction effects.

During this movement, the received power is meticulously recorded in 10 cm increments, yielding 21 measurement positions. This process offers insights into how the human body, particularly its width, affects signal propagation in high-frequency mmWave systems operating at 32.5 GHz. The setup enables systematic analysis of diffraction effects as the subject incrementally obstructs the line-of-sight (LoS) path at varying lateral positions, as illustrated in Fig. 2.

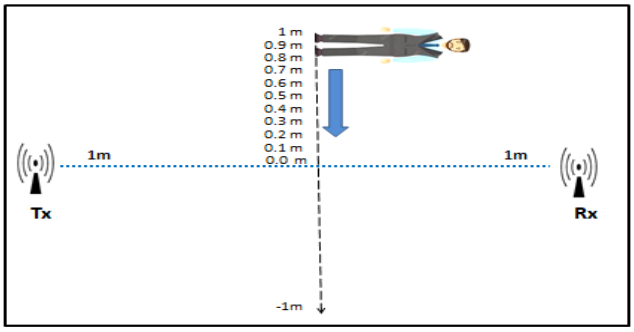

Fig. 2. Illustration of measurement scenario

V. Result and Discussion

The results of our study provide critical insights into the effects of human-induced attenuation on indoor mmWave communications at 32.5 GHz, highlighting the significance of diffraction modeling in accurately predicting signal degradation.

Our controlled experiments demonstrated that both the Double Knife-Edge Diffraction (DKED) model and the Fresnel diffraction approach consistently underestimated the received power during the blockage caused by a human subject. Specifically, the DKED model exhibited an underestimation range of 2–6 dB, while the Fresnel model ranged from 2–5 dB, as show in fig.3. This discrepancy emphasizes the challenges inherent in modeling complex indoor environments where human bodies act not only as obstructions but also as scatterers and reflectors.

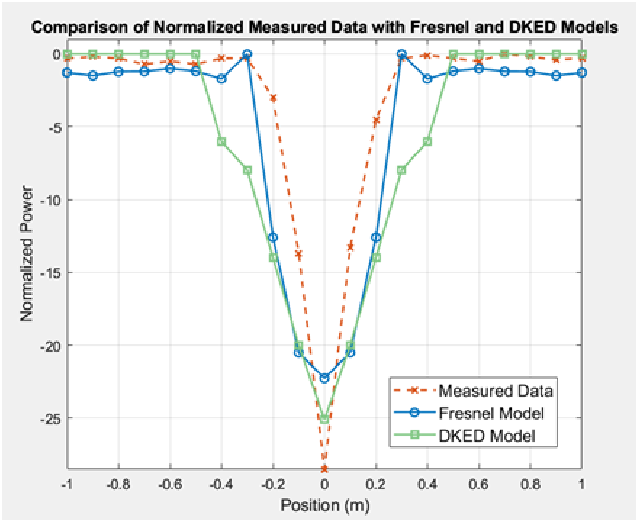

Fig. 3. Comparison of Normalized Measured Data with Fresnel and DKED Models.

The accuracy evaluation demonstrated that the DKED model, owing to its simplicity and geometry-based approach, yielded attenuation predictions that aligned more closely with measured values in the tested scenario. This finding is significant as it suggests that the DKED model can effectively capture the primary effects of human blockage. However, the Fresnel model remains a powerful tool, as it incorporates more detailed physical interactions, such as diffraction and wave curvature. While it slightly underestimated the attenuation in this specific case, its ability

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to model complex propagation effects makes it a valuable option, especially in environments where these effects are more noticeable. This highlights that both models offer distinct strengths, and their suitability may vary depending on the characteristics of the propagation scenario.

Moreover, our results underscore the importance of accounting for human presence in the design and implementation of indoor 5G networks. As users increasingly demand high data rates and reliable connectivity, understanding propagation characteristics in real-world environments becomes paramount.

This research contributes to the growing body of knowledge on mmWave propagation and offers practical insights for enhancing the design and deployment of 5G networks in environments, where human presence is frequent. By prioritizing accurate modeling of signal degradation caused by human blockage, network operators can better anticipate performance challenges and implement mitigation strategies, ultimately ensuring a more reliable user experience.

VI. Conclusion

This study presents a comprehensive evaluation of the Fresnel Diffraction Model (FDM) and the Double Knife-Edge Diffraction (DKED) model to assess the impact of human body shadowing on millimeter-wave (mmWave) indoor communication systems operating at 32.5 GHz. The investigation combines theoretical modeling with empirical measurements, in which the accuracy of each model is assessed by comparing simulated signal attenuation with actual power levels under controlled conditions. The results demonstrate both models' ability to predict signal attenuation. The findings highlight that diffraction is a key mechanism through which mmWave signals propagate around obstructions, and that attenuation patterns are strongly frequency-dependent and influenced by the dynamic positioning of the human body. These insights underscore the importance of selecting the appropriate model for accurate performance prediction and network planning in 5G systems, particularly in environments with high human activity and dense deployments.

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