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Double Knife-Edge Diffraction Model for Analyzing Human Body Shadowing Effects in Fifth-Generation Wireless Systems

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Abstract. This paper addresses the critical challenge of human-induced signal attenuation in millimeter-wave (mmWave) communications, a key concern for fifth-generation (5G) network reliability in indoor environments. Our study introduces a simplified model to quantify the impact of human body blockage on indoor communication links at a frequency of 32.5 GHz., a frequency relevant to 5G systems. The influence of nearby scattering objects is investigated through experimental measurements involving a human body. Key wave propagation phenomena, including diffraction, are considered for each scattering object. The Double Knife-Edge Diffraction (DKED) model is used to estimate the attenuation caused by the human body (to estimate blockage losses). Through controlled experiments with human subjects, we systematically analyze how scattering objects and body positioning influence signal propagation. The model's performance is validated by comparing simulation results with experimental data. The findings show that the proposed model effectively predicts signal attenuation in indoor environments, providing valuable insights for future studies on human presence effects in fifth-generation (5G) communication systems.

Keywords: 5G, DKED, diffraction, human shadowing, millimeter-wave, blockage.

I. Introduction

In recent years, the demand for high data rates from end-users has significantly increased, driven by technological advancements. The fifth generation (5G) wireless systems, which will utilize millimeter-wave (mm Wave) frequencies, are expected to meet these growing demands [1]-[2]. However, the performance of mm Wave systems is highly susceptible to environmental obstacles due to the shorter wavelengths of mm Wave signals. Therefore, assessing environmental conditions is crucial for evaluating the performance of 5G communication systems. This is particularly important in indoor environments, where obstacles like human bodies and furniture can cause signal blockage. As a result, several studies have explored the effects and characterization of human body blockage in mm Wave frequency bands [3]–[4]. These studies have employed various models to estimate the attenuation caused by human blockage. Among these, the Double Knife-Edge Diffraction (DKED) model presented in [5] is widely used because it is simple, accurately simulates human blockage effects, and is easy to implement. However, only a few studies have focused on measurements to assess the impact of human blockage at 32.5 GHz, a frequency band allocated for 5G [6]–[7]. It is clear that both people and nearby scattering objects can significantly affect indoor communication links [8]-[9]. Nonetheless, no research has yet considered the effects of human body blockages near the propagation link at this frequency band. To the best of our knowledge, this article presents the first estimation to accurately characterize the effects of nearby objects on indoor links at 32.5 GHz, specifically when the human body fully obstructs the link. In this study, simple propagation models, such as diffraction, were employed to predict signal attenuation. The Double Knife-Edge Diffraction (DKED) model was specifically used to estimate the attenuation caused by human blockage[10]. The accuracy of the models was evaluated by comparing simulation results with measured received power. The findings show that even this basic model performs effectively for simplified indoor links. In particular, the diffraction model for human body scattering yielded acceptable results. As a result, the outcomes of this study may encourage further

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research into modeling the effects of people blocking and moving around communication links in future 5G wireless systems.

II. MESUREMENT SYSTEM AND ENVIORMENT

The measurement setup, shown in Fig. 1, comprises a transmitting antenna (Tx), a receiving antenna (Rx), a signal generator, and a spectrum analyzer. For both transmission and reception, two identical horn antennas (PE9850/2F-20) were used, each with a gain of 20 dBi and half-power beam widths (HPBW) of 18.3° horizontally and 16.7° vertically. The antennas were positioned 2 meters apart on a stand at a height of 1 meter. The Tx was connected to an Agilent E8244A signal generator, while the Rx was linked to an Agilent E4448A spectrum analyzer. Low-loss cables were used to interconnect all components [3].

Before conducting the measurements, several adjustments were made to ensure ideal conditions. An indoor propagation link was set up to ensure the noise floor remained within an acceptable range. To accurately align the link with the position of a human body, a laser beam was used. Additionally, losses from connectors and cables were measured, and the system was calibrated through preliminary testing [3][10]. All measurements were carried out in the RF and Antenna laboratory at Atilim University, Ankara, Turkey [3][4][7][8][10]. The floor plan of the laboratory is shown in Fig. 2. On one side of the link, there was a tiled wall parallel to the link, and on the other side, there was a desk (0.75 m high) positioned parallel to the link. The distances from the wall and the desk to the link were both L1 = L2 = 2.4 m. Behind the Tx, there were steel cabinets (2.2 m high) placed in front of the tiled wall, and these cabinets were located L3 = 13.5 m away from the Tx. Behind the Rx, a plasterboard was mounted on a tiled wall, at a distance of L4 = 3 m from the Rx. The ceiling height of the laboratory room was 2.9 m.

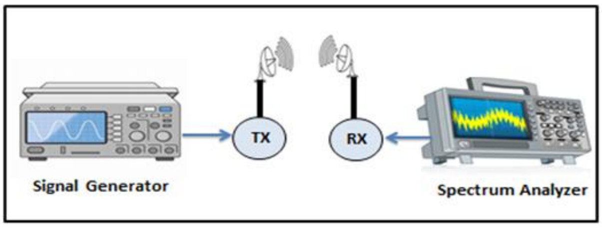

Figure 1. Measurement system.

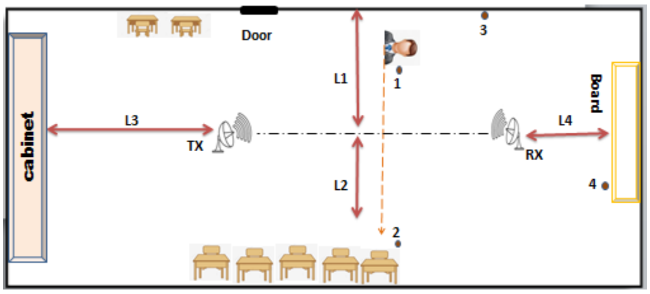

Figure 2. Measurement environment

III. Methodology

In this scenario, a human body crossing through the propagation link at equal distances from both sides. In this instance, a person with a width of 0.47 meters is utilized to simulate realistic conditions. The measurements are designed to track the impact of the human presence on the signal as he moves towards the link and crossing it. Specifically, the individual is positioned starting from a distance of 1 meter away from the link, gradually advancing until they completely cross it and reach a distance of -1 meter on the opposite side. During this movement, the received power is meticulously recorded at every 10 cm increment, resulting in a total of 21 measurement positions. This detailed approach allows for a comprehensive analysis of how the presence of the human body affects signal strength at various stages

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of the crossing, as illustrated in Fig .3 .

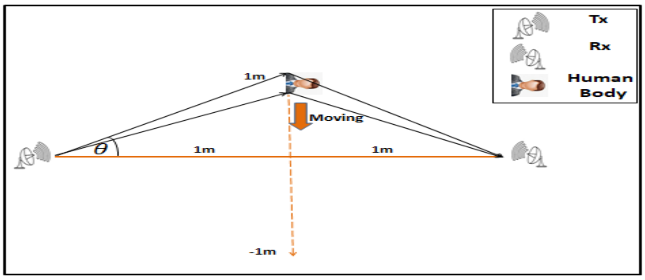

Figure 3. Illustration of measurement scenario

IV. Modeling The Shadowing While Human Body Blocking The Link

This section provides the details of the model used for the measurement scenario. However, before diving into the specifics, a brief explanation of the Double Knife-Edge Diffraction (DKED) model [7][10] is necessary to predict the attenuation caused by human blockage. While several precise methods were discussed in the introduction, the DKED model is regarded as one of the simplest approaches for simulating human blockage. It also provides an efficient means of reducing complexity when modeling a human blocker. For these reasons, the DKED model was selected for this study. In the DKED model, human blockage is approximated as a rectangular screen with infinite vertical height, where only the side edges of the screen are considered for diffraction. Typically, the top-down projection of the blockage is shown in Fig. 4. The resulting shadowing loss due to the blockage is then calculated in decibels as follows:

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

Here is the projected angle from the Tx to the edge ($w1$ or $w2$) and from the edge ($w1$ or $w2$) to Rx, $GTxw1|Txw2|Rxw1|Rxw2\ (\theta)$ are the normalized gains of the antennas based on θ relative to boresight gain.

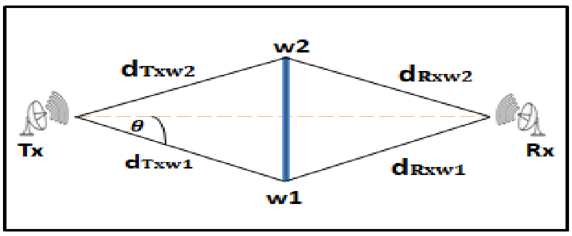

Figure 4. Plan view of the blockage.

for reducing the difficulty as well as its efficiency of modeling human blocker. There has been an overall agreement in using this model in this study for this purpose [10]. DKED modeling approximates Human blockage by a rectangular screen. Only the screen side edges are considered for diffraction. Fig. 5 shows the plane view of the blockage in such cases. The blockage loss due to shadowing is mathematically described by:

$$\boldsymbol{F}_{\boldsymbol{w1,w2}} = \frac{\boldsymbol{tan^{-1}}\left(\mp\sqrt{\frac{\pi}{\lambda}}\left((\boldsymbol{D}_{\boldsymbol{2w1,w2}}+\boldsymbol{D}_{\boldsymbol{1w1,w2}})-\boldsymbol{r}\right)\right)}{\boldsymbol{\pi}} \qquad (2)$$

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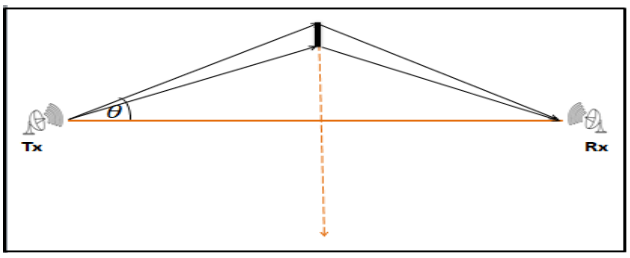

Figure 5. Propagation model (top-view)

The received power can be defined as [11].

$$Pr = Pt + GT(\phi) + GRxP(\phi) - PL \qquad (3)$$

Where Pr is the Rx power, Tx power is Pt , the angle of incidence from the Tx to the edge of person and from the edge to the Rx is ϕ .The antennas normalized gains in relation to the gain of boresight are $GTx|Rx(\phi)$ and PL is the over-all loss. Hence, the path loss expressed in decibels is [12]:

$$PL = PL0 + SL \qquad (4)$$

In (4), PL is the product of two components:

1) free-space path loss $\quad PL0 = 20 \log_{10} \left(\frac{4\pi d}{\lambda}\right) \qquad (5)$

Where PL**0** is the free-space path loss measured in decibels (dB). d is the distance between the TX and RX (in meters). λ is the wavelength of the signal.

2) SL is the shadowing loss caused by the human body approaching towards the link, and can be calculated by using (1) and (2) .

V. MEASUREMENT RESULTS

To systematically evaluate the accuracy of the Double Knife-Edge Diffraction (DKED) model in predicting human-induced attenuation at 32.5 GHz, we compared simulated results with empirical measurements for the scenario depicted, results for the scenario as shown in Fig.6. To systematically evaluate the accuracy of the Double Knife-Edge Diffraction (DKED) model in predicting human-induced attenuation at 32.5 GHz, we compared simulated results with empirical measurements for the scenario depicted, results for the scenario as shown in Fig.6. The experiments involved a human subject traversing the midpoint of a 2-meter indoor propagation link (1 m from both TX and Rx), with received power recorded at 10 cm increments. The DKED simulations predicted a peak attenuation of −66.1 dB during full line-of-sight (LOS) blockage, while measurements revealed a more severe power drop to −68.2 dB at the same position. a 2.1 dB discrepancy. Across all 21 measurement points, the model consistently underestimated received power by 2–6 dB, this discrepancy may result from the uncertainty in the antenna gains, which vary between 2 and 10 dB

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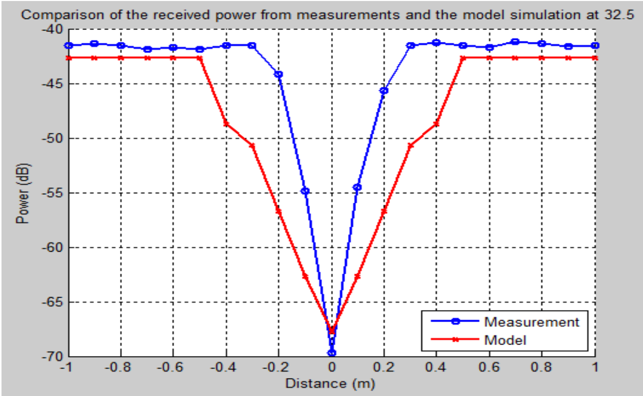

Figure 6. Comparison between measured and simulated received power

VI. Conclusion

This paper presents measurements conducted to study the effects of scattering objects, specifically the human body, near indoor links at 32.5 GHz, until the link was fully blocked by the human body. To predict the attenuation caused by this obstacle, diffraction modeling was employed. The accuracy of the model's predictions was evaluated by comparing the simulation results with the measured received powers. The results indicate that the DKED model performs well. Therefore, the promising findings from this study provide valuable insights for modeling the effects of people blocking and moving near communication links, including multiple human body modeling, in future 5G systems.

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