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A Simplified Model for Characterizing the Effects of Scattering Objects and Human Body Blocking Indoor Links at 28 GHz

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ABSTRACT This paper presents a simple approach to characterize the effects of scattering objects around indoor links at 28 GHz while the link is fully blocked by a human body. The effects of scattering objects nearby the link were studied by conducting measurements with a metallic reflector and the human body. Here, the basic mechanisms of wave propagation, such as reflection and diffraction, were accounted for each scattering object. To predict the attenuation caused by the metallic reflector, a specular reflection model was employed in reflection modeling. In diffraction modeling, on the other hand, the double knife-edge diffraction (DKED) model was exploited to predict the attenuation by the human body. Simulations were then compared with measurements to evaluate the prediction accuracy of the models. Results indicate that the presented simple models work well for indoor links. Therefore, the results of this paper could be extended to model multiple human bodies near the indoor links of fifth generation (5G) systems.

INDEX TERMS 5G, double knife-edge diffraction, environmental blockage, human blockage, millimeter-wave.

I. INTRODUCTION

In recent years, demands from end-users on high data rate have been substantially increased with the growing technology. As a new generation of communication, the fifth generation (5G) wireless systems which will use millimeter-wave (mmWave) frequencies is believed to meet these demands [1]. However, the efficiency of mmWave systems is sensitive to obstacles in the environment due to shorter wavelengths of mmWave signals. In this context, evaluating the environmental conditions becomes important to assess the performance of 5G communication systems. Especially in indoor environments, the obstacles such as human body along with furniture cause blockage problem in the links. For this reason, the effects and characterization of human body blockage on such links at mmWave bands have been investigated by several studies [2]–[7]. By most of these studies, different models have been used to estimate the attenuation due to human blockage. Among these models, double knife-edge diffraction (DKED) model provided in [4] is mathematically simple, accurately simulates the human blockage effects, and allows straightforward implementation.

On the other hand, only limited works have considered measurements to evaluate the effects of human blockage at 28 GHz where candidate frequency bands have been allocated for 5G [5]–[7]. It is also evident that people and scattering objects in the vicinity of the link highly affect the indoor links [8], [9]. However, at this frequency band, no study has taken into account the effects of multiple blockages near the propagation link. In this context, to the best of our knowledge, the study presented in this article is the first report to provide a simple but accurate approach to characterize the effects of nearby objects around indoor links at 28 GHz while human body fully blocking the link. In the study, two scattering objects, a metallic reflector and human body, were considered. To do this, simple propagation models such as reflection and diffraction were incorporated. In diffraction modeling, DKED model was employed to predict the attenuation caused by human blockage(s) for the sake of simplicity. In reflection modeling, specular reflection model was used to predict the attenuation due to metallic reflector. The accuracy of the models were then evaluated by comparing the simulations

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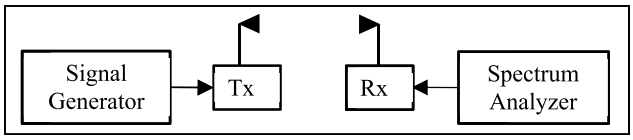


FIGURE 1. Measurement system.

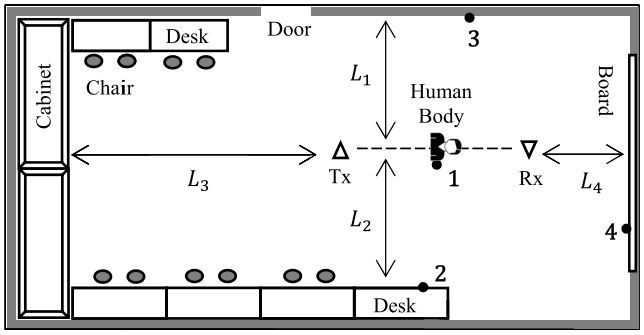


FIGURE 2. Floor plan of the laboratory environment.

with the measured received powers. The results show that even these simple models may work well for simplistic indoor links. Especially, the diffraction model of human body scattering provides acceptable results. Thus, the results obtained in this study may encourage the researchers to study modeling of people blocking and moving nearby the links in future 5G wireless systems.

II. MEASUREMENT SYSTEM

The measurement system consists of a transmitting antenna (Tx), a receiving antenna (Rx), a spectrum analyzer, and a signal generator as shown in Fig. 1. In the system, two identical horn antennas (PE9850/2F-20) with 18.3° horizontal and 16.7° vertical half-power beamwidth (HPBW) and 20 dBi of gain were used for transmitting and receiving purposes. Both antennas were placed on a stand with 1 m high. The distance between these antennas was 2 m. The Tx was connected to Agilent E8244A signal generator whereas the Rx was connected to Agilent E4448A spectrum analyzer. These connections were made by low loss cables.

Before performing the measurements, some adjustments were made to achieve ideal measurement conditions. In this manner, an indoor propagation link was constructed to control the noise floor level in a reasonable range. The link was aligned to paunch of a human body by using a laser beam. Furthermore, the loss caused by connectors and cables was measured, and the system calibration was then made by conducting preliminary measurements. The measurements were carried out at RF and Antenna laboratory of Atilim University, Ankara, Turkey. Floor plan of the laboratory environment is shown in Fig. 2. At one side of the link, there was a tiled wall parallel to the link. At the other side, there was a desk with 0.75 m high parallel to the link. The distance from both the wall and the desk to the link was $L_1 = L_2 = 2.4$ m. Behind the Tx, there were steel cabinets with 2.2 m high in front of the tiled wall. These steel cabinets were $L_3 = 13.5$ m away from the Tx. Behind the Rx, there was a plaster board hanging on a tiled wall. This was $L_4 = 3$ m away from the Rx. The ceiling height of the laboratory room was 2.9 m. Moreover, the effects of multipath from the fixed scatterers were examined. To do this, firstly, a human body with 0.5 m body width was assumed to be blocking the link. It was considered that signals radiated from Tx were diffracted from point 1 (shoulder of the human body). Then, the positions of the scatterers that are most likely contributing to the received power were identified (2, 3, and 4). These scatterers were also considered to be perfect conductor as worst case scenario. Next, the received signal power due to these scatterers and due to human body were calculated separately. Furthermore, the difference (isolation) between the received power of the human body and multipath components was found. From the results, a minimum of 14 dB isolation was obtained. This proves that multipath powers from the fixed scatterers can be ignored.

During the measurements, the received powers were measured with the blocker(s) moving step-by-step. The reason is due to the limitation of measurement system. To ensure the stability of measurement system, measurements were performed three times at each position of the blocker, and the mean value was then calculated. It should be also noted that recordings of the received signal power were made on perpendicular polarization. Measurement scenarios carried out in this study are described in the following.

A. SCENARIO I – HUMAN BODY BLOCKING THE LINK WHILE A REFLECTOR APPROACHING TOWARDS THE LINK

In this scenario, the propagation link was laterally blocked by a person. Meanwhile, a metallic reflector frontally approaching towards the link as shown in Fig. 3 (a). The metallic reflector assumed to be perfect electrical conductor was placed on a stand with 1 m high. The size of the reflector is 1 m (width) × 1 m (length) × 1 mm (thickness). The body width of the person blocking the link is 0.5 m. During the measurements, the reflector was moved from − 1 m to − 0.3 m. Here, movement is limited to − 0.3 m owing to body width of the person in order to avoid overlapping of the blockers. At every 10 cm step, the received power was measured from 8 positions.

B. SCENARIO II – HUMAN BODY BLOCKING THE LINK ANOTHER HUMAN BODY APPROACHING TOWARDS THE LINK

This scenario was the one that considers a situation when a person laterally blocks the link together with another person laterally approaching to the link as shown in Fig. 3 (b). The body width of the person blocking the link and the person approaching to the link was 0.5 m and 0.47 m, respectively. During the measurements, the person approaching towards the link was moved from −1 m to −0.6 m to avoid overlapping of the blockers as in previous scenario. The received power was then measured at every 10 cm step from 5 positions.

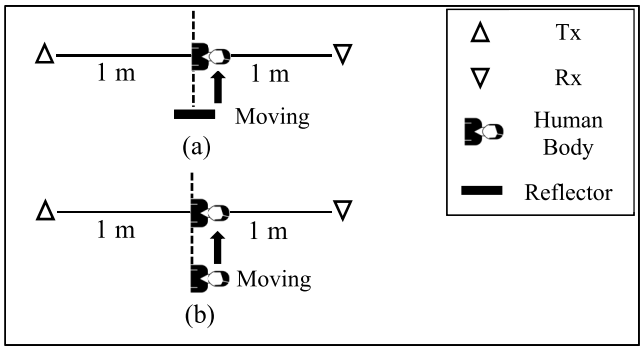


FIGURE 3. Illustration of measurement scenarios. a) Scenario I. b) Scenario II.

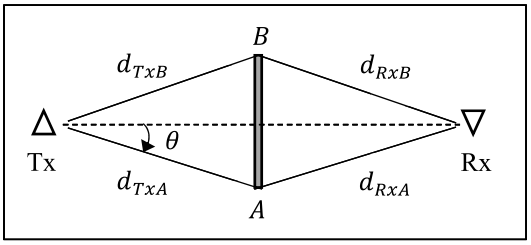


FIGURE 4. Top-down projection of the blockage.

III. MODELLING OF SCATTERING OBJECTS WHILE HUMAN BODY BLOCKING THE LINK

This section presents the details of the models considered for each of measurement scenario. But before that, it is necessary to give brief explanation on DKED model [4] for the purpose of predicting the attenuation caused by human blockage.

Although several accurate methods have been proposed in the literature, using DKED appears to be simplest model to simulate the human blockage. It may also be an efficient approach to reduce the complexity in modeling of multiple human blockers. For this reason, it has been decided to use in this study. In DKED modeling, human blockage is approximated by rectangular screen with infinite vertical height. 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 shadowing loss of the blockage is then given in decibels by

$$SL = -20\log_{10}\left|\left(\frac{1}{2}-F_A\right)\times\sqrt{G_{TxA}(\theta)}\times\sqrt{G_{TxB}(\theta)} + \left(\frac{1}{2}-F_B\right)\times\sqrt{G_{RxA}(\theta)}\times\sqrt{G_{RxB}(\theta)}\right| \quad (1)$$

where θ is the projected angle from the Tx to the edge (A or B) and from the edge (A or B) to Rx, $G_{TxA|TxB|RxA|RxB}(\theta)$ (the subscript symbol "$*|\cdot$" denotes "$*$ or $\cdot$") are the normalized gains of the antennas based on θ relative to boresight gain, $F_{A|B}$ are the shadowing caused by the edges:

$$F_{A|B} = \frac{tan^{-1}\left(\pm\frac{\pi}{2}\sqrt{\frac{\pi}{\lambda}\left(d_{TxA|TxB}+d_{RxA|RxB}-r\right)}\right)}{\pi} \quad (2)$$

where $d_{TxA|TxB|RxA|RxB}$ are the projected distances between the Tx and the edge (A or B) and from the edge (A or B) to Rx, λ is the carrier wavelength, r is the distance between the Tx and Rx.

Therefore, to ensure the applicability of the DKED model, the received power was measured with a person laterally crossing the propagation link between the Tx and the Rx by following the procedure in [6]. It was observed that the attenuation caused by the human blockage agrees with DKED model.

On the other hand, in scenario I, there is also a metallic reflector causing specular reflections in addition to a human blockage. An illustration that shows the propagation model considered in this scenario is given in Fig. 5 (a). By using a specular reflection model together with the DKED model, the received power is simply calculated as [10]

$$P_r = P_t + G_{TxP}(\phi) + G_{RxP}(\phi) - PL \quad (3)$$

where P_r is the received power, P_t is the transmitted power, ϕ is the projected angle from the Tx to the center of the metallic reflector (C) and from C to the Rx, $G_{Tx|Rx}(\phi)$ are the normalized gains of the antennas relative to boresight gain, and PL is the total loss. To study the total loss characteristics, propagation mechanisms such as reflection and diffraction should be accounted. Evidently, propagation from the Tx to the Rx is viewed as reflection occurring at the center of metallic reflector along with the diffraction taking place over the sides of the blocker on the link. With this viewpoint, the PL is the product of: 1) the reduction in the field due to diffraction of the human body blocking the link (PL_1), and 2) the reduction in the field due to reflection from the reflector approaching towards the link (PL_2). Hence, the path loss expressed in decibels is [11]:

$$PL = PL_1 + PL_2. \quad (4)$$

In (4), PL_1 is the product of two components: 1) free-space path loss $PL_0 = 20\log_{10}\left[\left(\lambda/4\pi r\right)\right]$ where λ is the carrier wavelength, and 2) SL that was found in (1). Similarly, PL_2 is the product of two components: 1) PL_0, and 2) the loss due to reflection ($|\Gamma|$) [12]. For this case, r in PL_0 is the total distance between Tx to C and C to Rx.

An illustrative example of the propagation model of scenario II is shown in Fig. 5 (b). In this propagation model, only diffraction mechanism is considered. It is worth noting that reflection from human body could also be utilized. Obviously, this is burdensome and detracts from the primary focus of this study. Thus, both human bodies are modeled by using DKED model as it allows simple and adequately accurate prediction of human body attenuation. However, reflection could still be studied for scattering from human body. To calculate the received power, it is necessary to treat PL by means of revising PL_2 in (4). In this case, PL_2 is the product of PL_0 and SL_m where SL_m is the shadowing loss caused by the human body approaching towards the link, and can be calculated by using (1) and (2).

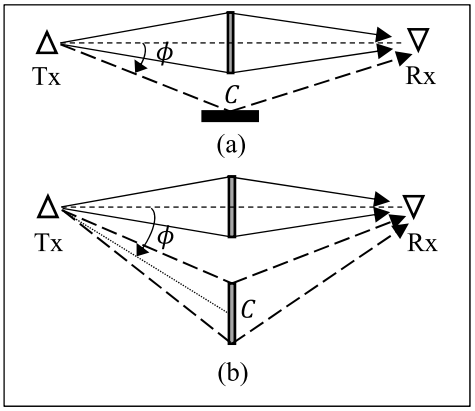


FIGURE 5. Propagation model (top-view). a) Scenario I. b) Scenario II.

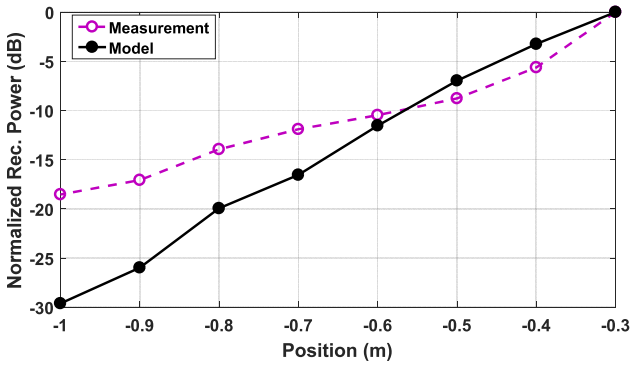


FIGURE 6. Comparison of the received power from measurements and the model simulation (scenario I).

IV. MEASUREMENT RESULTS

In order to evaluate the applicability of the models, model simulations and the measurement results were compared for both scenarios.

A. SCENARIO I

Fig. 6 shows the comparison of the received power from measurements and the model simulation. At some positions where the metallic reflector is close to the propagation link (between − 0.3 m and − 0.5 m), the model overestimates the measured received powers by approximately 2 dB. At other positions, where the reflector is relatively away from the link, the model underestimates the measurements. It is important to note that normalized gains of antennas significantly affect the blockage attenuation. Before conducting the measurements, antenna gains ($G_{Tx|Rx}$ (ϕ)) at each position of the reflector were measured. These were then compared with radiation pattern provided in the antenna datasheet. Measured antenna gains were validated within 2–10 dB error margin. It should be noted that there is still an ambiguity in gains of antennas.

B. SCENARIO II

The model simulation and the received power from measurements are compared as shown in Fig. 7. It can be observed that the model underestimates the measured received powers by 3–5 dB; again, this may be attributed to the ambiguity in

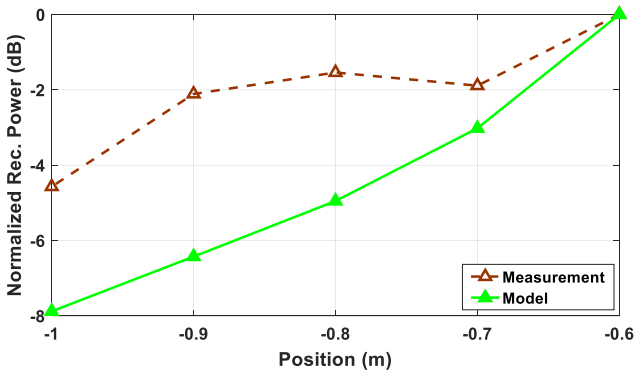


FIGURE 7. Comparison of the received power from measurements and the model simulation (scenario II).

gains of antennas (2–10 dB). The prediction accuracy of this model outperforms the specular reflection model of metallic reflector.

V. CONCLUSION

In this paper, measurements were conducted to study the effects of scattering objects (a metallic reflector and human body) near the indoor link at 28 GHz while the link was fully blocked by a human body. To predict the attenuation caused by these objects, reflection and diffraction modeling were exploited. The prediction accuracy of the models was evaluated by comparing the model simulations with the measured received powers. The results show that the attenuation due to metallic reflector simulated by specular reflection model may be inaccurately predicted when the object is away from the link. This may stem from the antenna pattern gain that has significant impact on the received power. More precisely, by performing measurement of pattern gain, it has obtained that the gain becomes significantly lower after 0.8 m away from the link (between 3 dBi and − 1 dBi). For this reason, contribution of the scattering object to the received power might be ignorable when it is away from the link. On the other hand, DKED model of the attenuation caused by human body scattering can work well. Therefore, the promising results achieved in this study could offer useful insights for modeling of people blocking and moving nearby the links (multiple human body modeling) in future 5G systems.

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