A Survey on the Effects of Human Blockage on the Performance of mmWave Communication Systems

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***Abstract*—Human blockage is one of the key challenges that limit the ability of mmWave communications to provide ultra-high data rate and ultra-low latency links, thus severely reducing the quality-of-service (QoS) experienced by the users. In this paper, we present the most common human body blockage models, which are used in blockage analysis to predict the level of attenuation caused by the human body to mmWave signals. Moreover, the main parameters of human blockage which affect the received signal are discussed, while the effect of blockage on the received signal and network coverage is analyzed. Finally, we provide insights to potential solutions that overcome human blockage, in order to further improve the overall performance of mmWave communications.**

Keywords—Human blockage, mmWave, 5G.

I. INTRODUCTION

During recent years, 5G wireless systems have exhibited promising advantages to meet the growing demand of user needs in terms of throughput, sum rate, and latency [1], [2]. Essentially, the mmWave spectrum offers a multitude of positive prospects for efficient network communications [3]. However, its short wavelengths render it vulnerable to a blockage of the line-of-sight (LoS) path. These blockages are among the primary reasons that deteriorate the performance of mmWave systems in diverse propagation environments [2]. Contrarily to microwave systems, the human body tends to be a major hindrance for mmWave communication systems that can, indeed, decrease the efficiency of mmWave links [4]. In this context, several works have been conducted to investigate the assessment of human blockage (HB) models at different propagation bands [4]-[14]. Fig.1 presents how the human body can interact with a set of obstacles in the case of a typical mmWave communication scenario. It should be stressed that the type of transmission environment, e.g. indoor, outdoor, or urban outdoor, may contribute on the blockage effect and determine its extent.

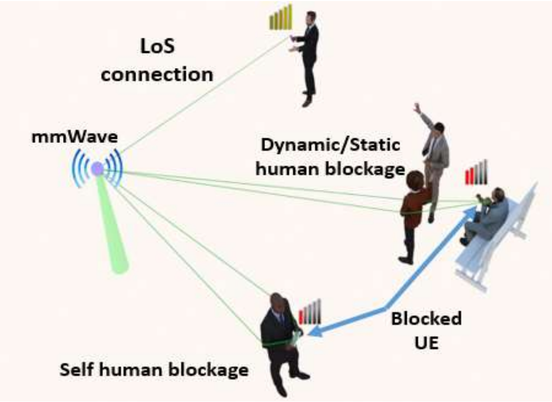
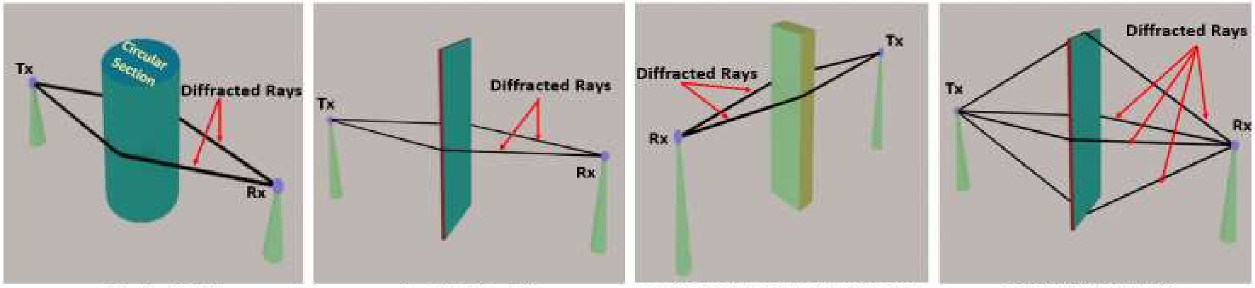
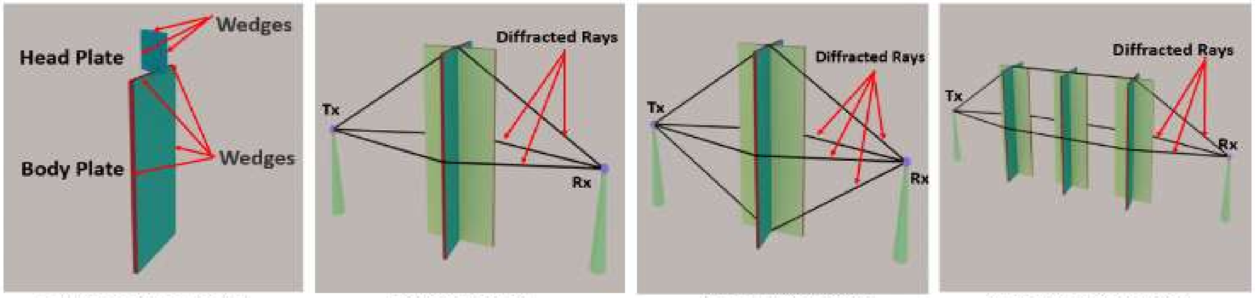


Fig 1: A regular human blockage scenario.

The dielectric properties of the human body play a vital role in the study of the mmWave propagation characteristics. Thus, mmWave signals are prone to high attenuation caused



a : Cylinder Model b : DKED Model c : Geometrical-Empirical Model d : METIS KED Model



e : Wedged Plates Model f : MKED Model g : DT-MKED Model h : Vogler's MKED Model

Fig 2. A collection of different human blockage models.

by human body shadowing. This entails the need to develop accurate HB models to assess the human body characteristics on indoor or outdoor propagation environments. It is noteworthy to mention that these models can comprehensively estimate the real-time blockage loss of signals using mathematical schemes related to the analysis of diffraction of the radiowaves. In this paper, we investigate the main up-to-date methods for human body shadowing, based on theoretical studies and the principles of electromagnetic propagation.

The paper is structured as follows: Section II presents the most popular human blockage models, while Section III discusses the primary parameters that affect human body shadowing. Section IV elaborates on how the human blockage affects the channel condition, and Section V summarizes the most common algorithms for human blockage mitigation. Finally, Section VI concludes the work.

II. HUMAN BLOCKAGE MODELING

A. *Human Blockage*

The human body is the usual obstacle in mmWave links, where the majority of cases in mobile communications require interaction between the two communication ends, i.e. the transmitter (Tx) and receiver (Rx). As Fig. 1 illustrates, there are two kinds of HB. The first is the self-human blockage, where the LoS connection between the base station (BS) and receiving device is blocked by the user's own body or hand, while the other type of HB is the dynamic or static human body blockage, where the LoS between the BS and the Rx is blocked by a frequently moving or standing obstacle near the user. The latter is more likely encountered in dense human areas, which are common scenarios in urban environments, shopping malls, stadiums, museums and airports.

B. *Blockage Models*

Fig. 2 depicts the basic blockage models that have been proposed in the relevant literature. Herein, we describe eight different models (the most common ones) in order to predict the level of attenuation caused by the human body to radio signals. This sub-section briefly highlights these models, extensively employed in blockage analysis.

Specifically, Fig. 2(a) shows the *Cylinder model*; a type of model that uses cylinders having a circular or elliptical cross section [5]. These cylnders describe the human body as a perfect conducting structure (or a water-filled cylinder) for the diffraction ray modeling. The uniform theory of diffraction (UTD) and the geometrical theory of diffraction (GTD) models are mostly used to describe the diffraction around this cylinder. On the other hand, the *Double Knife-Edge Diffraction (DKED) model*, shown in Fig. 2(b), was proposed in [6] to represent human body shadowing. The human body is assumed as a screen with perfectly absorbing properties, and has infinite extent vertically. Furthermore, Fig. 2(c) demonstrates the *Geometrical-Empirical model* to characterize human body shadowing. It suggests a modified version of the DKED model during the blockage period. It predicts blockage fading through the original DKED model in terms of a diffraction correction factor, which is empirically estimated from exhaustive measurement results [7]. Also, Fig. 2(d) presents the *METIS KED model* [8], which attains better estimations by considering a finite height screen and including two more diffracted rays. The human body is simulated as a rectangular absorbing screen. It uses the four edges of the screen to calculate the losses caused by the human body shadowing. Its major advantage is that it can compute losses at scenarios, where multiple blockers are invlolved.

Subsequently, Fig. 2(e) shows the *Wedged Plates Model*; the assumption made, herein, considers the human body as two flat lossy dielectric plates. The upper plate represents the head and neck and the lower plate the human body part below the shoulders. Each edge of these plates is deemed as a wedge with a zero-wedge angle [9]. In this model, the UTD is used to calculate the diffraction coefficients around the plates, and the rays between the transmitter and reciever, diffract on the wedges which are illustrated in Fig. 2(e). Next, shown in Fig. 2(f), the *Multiple Knife-Edge Diffraction (MKED) model*, represents the human body via two crossed double knife edges for the diffraction around the human torso and two crossed single knife edges for the diffraction over the head [10] or over the head and shoulders [11]. In addition, the *Double-Truncated Multiple Knife-Edge Diffraction (DT-MKED) model*, in Fig. 2(g), simulates the human body as a 3D screen, based on the MKED model, yet it adds an extra path of diffraction between the legs of the human body, described by the bottom of the screen [12]. Finally, *Vogler's Multiple Knife-Edge Diffraction (Vogler's MKED) model* [13], shown in Fig. 2(h) , offers better HB attenuation estimates when more separated persons, block the LoS path between the transmitter and the receiver. Note that human bodies are modeled as perfectly absorbing screens via a MKED model.

III. KEY PARAMETERS OF HUMAN BLOCKAGE

There are various ways that human body shadowing can affect the received signal. The following constitute the basic HB parameters, mostly related to obstacle density in the surrounding environment.

A. Distance between Rx and Tx

In contrast to lower band frequencies, the signal strength in the mmWave spectrum decreases significantly with the distance between Tx and Rx. Nonetheless, once the distance increases, the probability of HB emergence, also, increases, as the LoS path could be blocked by more than one blockers. But with appropriate Tx antenna height, only the blockers located at the last 1/10 of the ray path can influence the received signal and place the Rx under the blockage effect [14]. Note that the maximum harsh blockage effects (losses up to 40 dB) appear when the blocker distance is less than one meter from the Tx or Rx antenna, namely the cellular network case [15].

B. Heights of Rx and Tx

The mmWave networks work in smaller distance ranges and the height of the Tx antennas is quite smaller than that in the base stations (BSs) of 4G networks. Actually, an increased Tx height reduces the HB. For large Tx antenna heights, any additional increase has a linear effect on the blockage probability, while for small Tx heights, this effect becomes exponential [16]. So, the increase of the Tx antenna height improves the reliability of services in mmWave systems.

C. Base Station Density

The BS density is defined as the number of BSs in a given transmission region. Hence, increasing the BS number would reduce the HB probability. However, it is necessary to observe the optimal BS number to avoid inter-cell interference, due to the high density deployment of the BSs. Moreover, high BS numbers result in more complicated initial access and radio resource management processes. The required BS density is, mainly, dependent on the blockers density and the minimum application requirements (latency, reliability, data rate etc.). Also, there is a tradeoff between BS density and BS heights for different blocker densities [17], where the optimal setup for the BS heights reduces the density requirement of BS deployment, which, in turn, reduces the overall cost and the interference owing to the high deployment of BSs.

D. Human Movement/Velocity

The dynamic movement of a person has less effects on the received signal power than the standing/static case. Note that people usually have a walking speed between 0.5 to 2 m/s, and the human walking speed leads to received signal fluctuations. Furthermore, increasing the density of the blockers, who move around the receiver, increases the fluctuations. walking speed has still the most significant influence on signal inconstency [18], taking into consideration the human body size and the signal propagation environment. Lastly, the velocity of the human body affects the blockage period. So, a high-speed user has a shorter blockage period.

IV. HB EFFECTS ON CHANNEL PARAMETERS

The blockage of transmitted signals by the human body has a lot of consequences. It affects diverse parameters needed for an effective communication, especially in 5G. Next, we discuss some of the HB effects on the channel parameters.

A. Coverage

The coverage of a Tx antenna can be negatively affected by HB. During transmission, the larger the number of human blockers, the less the effective coverage of the users due to the multiple diffractions and absorption of the transmitted signals. Thus, the optimal coverage requirement is of key importance for an enhanced QoE. In the mmWave regime, the height of antennas, the BS density, and the blockers density affect the coverage probability [17]. Also the design of mobile networks improves the coverage probability with the minimum BS density and mitigates the blockage more efficiently than a random deployment of the BSs [17].

B. Received Power and Path Loss

The received power and pathloss are highly affected by human body shadowing, where the high penetration of the human body leads to high affetcs on the pathloss. Every human body can add a signal loss around 20 dB to the transmitted power in the mmWave spectrum [4]. So, it degrades the efficiency of the channel, where the throughput and sum-rate are also greatly affected. Different blocking environments entail separate pathloss models. Knowing the pathloss model for a given environment will help to analyze the expected channel quality of the network. Indeed, it is critical for estimating the degree of the transmitted signal attenuation for different blockage densities.

V. ANTI-BLOCKAGE ALGORITHMS AND SOLUTIONS

There are various techniques suggested to overcome the HB effects during LoS transmission, thus guaranteeing the

QoS for users in mmWave systems. Some of the most contemporary algorithms are highlighted below.

A. Diversity Techniques

Several diversity techniques have been reported to treat HB shadowing. The most common one is the BS diversity or macro diversity and coordinated multipoint. It is a method of signal coordination between uncorrelated propagation paths existing among BS, BS diversity, and coordinated multipoints. They are attractive technologies in mmWave communication systems. Explicitly, in the macro diversity, the user attempts to simultaneously connect to more than one BS in order to increase the probability of achieving LoS connectivity. Moreover, via the coordinated multipoint, the BSs have to nullify their beams that add interference to the user. In this way, the user is served with one BS and experiences the minimum interference from other BSs [20].

B. Handover

The handover (HO) technique is another method used to move the connection of a user from a given cell to another one that has better connection conditions or has a smaller blockage probability. Both soft and hard HO have been suggested to enable the efficient connection of a user to a better cell with an acceptable signal-to-interference-plus-noise ratio (SINR) condition. Furthermore, several works have studied the use of proactive HO schemes for solving the blockage problem. For example, the use of a proactive traffic control system helps in estimating the mobility of human blockers in addition to knowing the distance between users and potential blockers [21]. The controller is used to HO a user to another BS before the effect of human blockers becomes eminent. Recently, machine/reinforcement learning has, also, been employed for BS selection, based on the system throughput and the number of successful HOs, as a metric for ensuring a seamless connection in mmWave [22].

C. Reconfigurable Intelligent Surfaces

A reconfigurable intelligent surface (RIS) comprises passive and reconfigurable scatterers. These scatterers have the ability of modifying the transmitted radio waves with a major intention of improving the signal strength at a given location. The RIS has the main advantage of adjusting the electromagnetic wave from a transmitter in a programmable manner by ensuring that the phase shifts of the reflecting elements are regulated. This technique improves the spectral efficiency and coverage probability of the network in highly dense human environments. The mmWave RIS have appeared as a solution for mobile operators, since they ensure high system reliability and user connectivity in a dense user scenario (wheremany potential blockers exist). The use of RIS is anticipated to alleviate the high-power consumption and complexity problems in 5G networks and reduce the interference resulting from network densification [23].

D. Unmanned Aerial Vehicles

5G technology has facilitated the development of other devices that can enhance transmission of data. Unmanned aerial vehicles (UAVs) are promising candidates for efficient data transmission, since they can serve as BSs. The UAV has, also, the advantage of unconstrained mobility. This renders it a much better option for mobile operators in an area with high and immediate service demands, where the deployment of a static network architecture is not feasible [24], [25]. Efficient coverage can be provided by a UAV in crowded locations or temporary events, such as sporting activities, carnivals, fairs, etc. For example, to handle high data rates in mmWave, traditional infrastructure requires a large number of cellular BSs, which lead to severe interference, whereas only one mmWave-BS UAV can achieve the same average data rate as ten conventional static BSs [25].

VI. CONCLUSIONS

This paper presented a review of several techniques in the area of mmWave HB. Several models used for the HB analysis have also been presented, whereas the key parameters in HB and the blockage effect on the received signal and the network coverage were described. Finally, some solutions were described to enhance mmWave communication performance and suppress the HB effects.

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