Improving Millimeter-Wave Channel Models for Suburban Environments with Site-Specific Geometric Features

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Abstract **─** This paper proposes simple procedures to improve traditional statistical millimeter-wave channel models for suburban environments with site-specific geometric features. Blockages by buildings and vegetation were considered and existing models were verified with measurement data for an emulated microcell deployment. The results indicate that a holistic, network-level approach for channel modeling will help deal with the high dependence of millimeter waves on site-specific features.

Index Terms **─** Channel modeling, millimeter wave, site-specific geometric features, suburban environments.

I. INTRODUCTION

Millimeter wave (mm-wave) bands have become the most promising candidate for enlarging the usable radio spectrum in future wireless networks such as 5G [1]. Since frequent and location-specific blockages are expected at mm-waves, the challenge is understanding the propagation characteristics of mm-wave signals and accordingly predicting the channel state information as needed, so that the high mobility requirements of these wireless networks can be addressed in real-time.

The majority of current research has focused on urban areas with high population densities [1]–[3]. Very few measurement campaigns have been performed in suburban and rural environments. Moreover, statistical models for point-to-point links have received significant attention, but this approach ignores all or most of site-specific geometric features, which mm-waves are sensitive to due to blockages. In this paper, we explore this research gap by focusing on suburban environments and improving standard 5G channel models with site-specific geometric features.

II. MM-WAVE PROPAGATION MEASUREMENTS FOR SUBURBAN ENVIRONMENTS

An outdoor propagation measurement campaign was carried out at the United States Naval Academy (USNA) in Annapolis, Maryland. The transmitter (TX) was temporarily installed on the Mahan Hall clock tower to emulate a typical 5G suburban microcell deployment. A custom-designed broadband sliding correlator channel sounder was used as the receiver (RX) and moved around the campus to obtain path loss measurements. More details for the measurement setup can be found in [4].

III. BUILDING BLOCKAGE ANALYSIS

One approximately 200-m-long straight track was chosen for a continuous signal recording, to investigate the shadowing effect of buildings on a moving user. The resulting basic transmission losses are shown in Fig. 1 (a). The dotted lines illustrate the boundaries between the line-of-sight (LoS) area and the non-line-of-sight (NLoS) area due to blockages. As we can see, the most significant blockage was from Michelson Hall, which obstructed the southern half of the track. Rickover Hall partially blocked the track at the north end.

To estimate the path loss caused by building blockages, the knife-edge diffraction (KDE) model [3] was utilized. In our case, the Universal Transverse Mercator (UTM) coordinate system was extended with height to form a 3-dimensional (3D) space for computing

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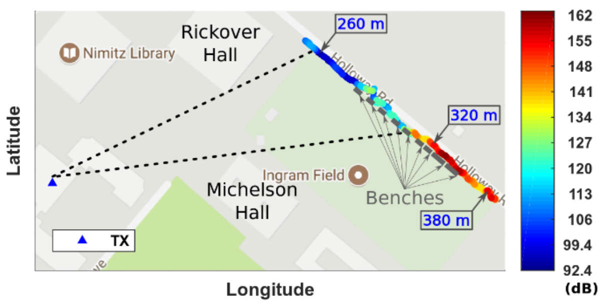
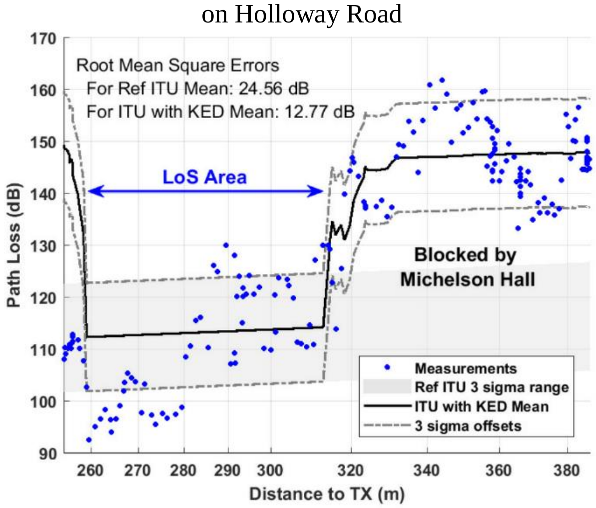
the effective height of the obstructing screen, as well as the distances between the TX, the RX, and the screen. Note that the path obstruction may occur either on a horizontal roof edge or a vertical side edge of the building. Finally, the screen height was computed as the distance between the obstruction point and the direct Euclidean path between the TX and the RX. The resulting diffraction losses were used to shift the large-scale path loss predictions from the International Telecommunication Union (ITU) site-general model for propagations over rooftops [5]:

$$PL(d,f) = 10 \cdot \alpha \cdot \log_{10}(d) + \beta + 10 \cdot \gamma \cdot \log_{10}(f) + N(0,\sigma),$$

where d is the 3D direct distance between the TX and the RX in meters and f is the operating frequency in GHz. In our case, f = 28 GHz. The parameter values α = 2.29, β = 28.6, γ = 1.96, and σ = 3.48, were chosen for the LoS propagation in a suburban environment [5], which are recommended by ITU for distances from 55 m to 1200 m at 2.2–73 GHz frequency.



(a) Track with Basic Transmission Losses on Holloway Road



(b) Path Loss for the Modified ITU Model

Fig. 1. Considering building blockages to improve a statistical channel model. (a) Path losses on Holloway road illustrate the shadowing effect of buildings. The numbers in the boxes are distances to the TX. (b) After being shifted by diffraction losses, the ITU model closely follows the measurement results.

Figure 1 (b) shows the final results. The ITU model provides path loss predictions in the form of Gaussian variables. Accordingly, 3-sigma ranges for both the original and shifted ITU models are shown and root mean square errors (RMSEs) are computed separately according to the mean of each model. As we can see, the modified ITU predictions follow the measurement data much better than the original ones, providing a RMSE improvement of 11.79 dB. Another observation is, for distances below 280 m, the original ITU model overestimated the path loss by around 20 dB. This may be caused by some strong reflection path(s). Also, the KED model overestimated the attenuation caused by Rickover Hall. This was probably because the blockage happened at the southern vertical edge of the building, which corresponds to a very short obstructing screen, whereas the KED model applies for a screen with infinite height. Still, the KED model helped identify the path loss peak below 260 m.

IV. FOLIAGE ANALYSIS

The effect of foliage for modeling mm-wave channel is a vital consideration for suburban environments as scattering and absorption at these frequencies can significantly attenuate 0 2 4 6 8 10 12 14 16 18 Vegetation Depth (m) -20 -10 0 10 20 30 40 50 Attenuation (dB) Specific Attenuation: Slope of Fitted line = 0.0662 dB/m Measurements Fitted Weissberger ITU-R FITU-R COST235 Fig. 2. Comparison of computed and measured path loss at 28 GHz. the signal. In our measurement campaign, eleven sites had partial or total obstruction of the LoS signal from foliage, ranging from a single tree to a small grove of trees. Our measurement results were compared against four well known empirical models [6] that are valid in this frequency range: COST235, Weissberger, ITU-R and FITU-R models.

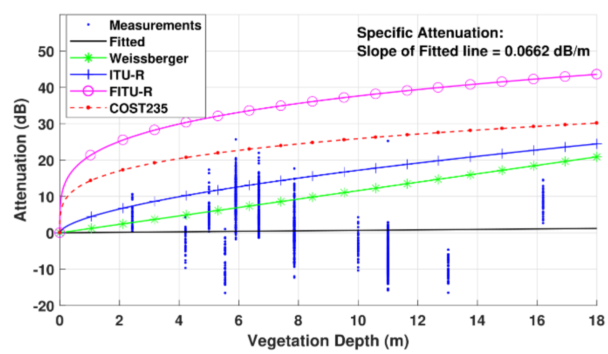


Fig. 2. Comparison of computed and measured path loss at 28 GHz.

Figure 2 illustrates our measured excess vegetation attenuation versus vegetation depth as well as existing model predictions. We can see that the mean measured value of foliage attenuation (0.07 dB/m) is significantly less than those of model-predicted values. In fact, our measurements demonstrate a significant amount of multipath energy arriving at the receiver, likely being scattered from other objects in the environment. As a result, we recorded a greater signal strength than what would be predicted by these simple single-path attenuation models.

V. CONCLUSION

In this paper, we illustrate two measurement- and geometry-based techniques for improving existing statistical mm-wave channel models. Our approach is suitable for a holistic, network-level model that utilizes side information and the results could be updated in real-time. Our techniques demonstrate a modest, but significant, overall improvement in propagation modeling accuracy.

ACKNOWLEDGMENT

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