Accurate Urban Path Loss Models Including Diffuse Scatter

Dmitry Chizhik[1], Jinfeng Du[1], Manav Kohli[2], Abhishek Adhikari[2]
Rodolfo Feick [3], Reinaldo. A. Valenzuela[1], Gil Zussman[2]
[1] Nokia-Bell Labs, Holmdel, NJ, USA, dmitry.chizhik@nokia.com
[2]Electical Engineering Department, Columbia University, New York, NY, USA
[3] Department of Electronics, Universidad Técnica Federico Santa Maria, Valparaíso, Chile

***Abstract*— Standard ray tracing predictions are found to overpredict signal strength in "down the street" scenarios when compared against over 800 urban street measurements on 12 Manhattan streets, nominally Line of Sight (LOS) scenarios, by over 20 dB at 300 m. Use of Uniform Theory of Diffraction (UTD) formulas for around corner cases is found to underpredict signal strength in comparison to observations, with 7.8 dB RMS error. It is found that including effects of scatter from street clutter, such as vegetation and street poles results in simple path loss expressions with RMSE of 7.8 dB for down-street cases and 2.3 dB for around corner.**

***Index Terms*—propagation, measurement.**

I. INTRODUCTION

Performance of wireless communications is critically dependent on achieving adequate coverage, particularly challenging at mm wave bands [1]. This paper concentrates on modeling path gain, the most basic aspect of propagation, key in determining coverage. Path gain is defined as the ratio of average receive and transmit powers for omnidirectional, co-polarized transmit/receive antennas. Models are needed both to estimate system performance and requirements in generic circumstances, such as determining inter-site distance required for adequate coverage at a given frequency and transmit power as well as planning and placement of base stations in a particular area.

Prominent approaches to propagation modeling in communications include empirical models derived through fit to measurements and ray tracing. Empirical models [3][4][5][6][7][8][9][10] are simple to use and require little to no environmental information but are found to fail to reproduce site-specific effects, especially in mm wave bands.

Ray tracing [11][12]can handle very general environments to predict the full impulse response of the channel but requires detailed environmental information, Vegetation and urban street clutter play a critical role in attenuating signal, especially at mm wave bands, with attenuation through a 10 m crown of a single tree on the order of 20 dB at 28 GHz. Such detailed information is often difficult to obtain.

In this work we find through comparison to 28 GHz path loss measurements in Manhattan streets that using standard ray tracing techniques overpredicts signal strength in down the street cases and underpredicts it in around the corner scenario. We find that simple models that include absorption and scatter from collections of small objects, such as vegetation and street poles leads to much improved accuracy, particularly for around the corner case, with scattering model providing 2.3 dB RMS error, as compared to 7.8 dB RMS error for UTD.

II. PATH LOSS IN "LOS" STREET CANYONS

Path loss was measured at 28 GHz in Manhattan (details on equipment and procedure are in [13] and [14]). In all cases, a street level omnidirectional transmitter, mounted on a tripod 1.5 m above ground, emitting a 28 GHz CW tone was placed at multiple locations along the street, emulating a mobile terminal. A spinning 10° horn receiver, emulating a base station, was placed on a rooftop or a high balcony, recording receiver power as a function of azimuth angle. The data discussed here consisted of two scenarios. One, "down-street" data set consisted of 800 links measured on 12 streets at ranges reaching 800 m, with both transmitter and receiver in the same street. Another, "around corner" data set, had 75 links measured around the corner at ranges up to 250 m, in true Non-Line of Sight (NLOS) conditions. In the around the corner case, intervening buildings were always higher than the 15 m "base station" height, thus favoring around the corner paths as opposed to over the top. A typical street scene, viewed from the "base station" is shown in Fig. 1. The measured "down street" path loss results for all 12 street canyons are shown in Fig. 2. The data falls between LOS and NLOS 3GPP UMa models, with RMS errors exceeding 14 dB. Notably, the data is below free space prediction by some 10 dB at 200 m. It may also be observed that conventional ray tracing predicts even higher power. This prediction includes reflections from the buildings lining the canyon as well as the ground, added in power to represent average power, without the small-scale fading effects. Note that higher average power predicted using this model is unavoidable whatever the material and geometric properties of the walls are.

Fig. 1. Typical street view from a balcony above a Manhattan street.

It may be hypothesized that the substantial additional loss observed here is due to scattering and absorption from street clutter, including vegetation, street furniture, vehicles, etc. seen in Fig. 1. It was found in [15] that coarse information on location, thickness and height of the region with foliage can be used to construct a simple yet accurate path loss model, reproducing observed street-street variation, resulting in 4.9 dB RMS error, much better than 14 dB errors obtain from 3GPP recommendations. Here we consider an even simpler model [16][17][18]based on even coarser information, such as average absorption/meter (effective absorption κ):

$$P=\left(\frac{\lambda}{4\pi r}\right)^{2}e^{-\kappa r} \tag{1}$$

Where range r is the distance between the base station and street level terminal, and λ is the wavelength. The effective absorption κ= 0.009 Np/m, corresponding to 0.04 dB/m is the sole parameter adjusted to fit data, leads to 7.8 dB RMSE. This is comparable to the 7.9 dB RMSE found through conventional 2 parameter (slope-intercept) fit to the entire 12 street data set. Unlike the slope-intercept mode, (1) naturally approaches free space predictions at short ranges, reproducing expected behavior as the expected number of obstacles intervening between transmitter and receiver approaches zero at short range. The model (1) may be used to represent for propagation down a street canyon in generic system simulations where street-specific information, leading to more accurate predictions as in [15] is either unavailable or too particular.

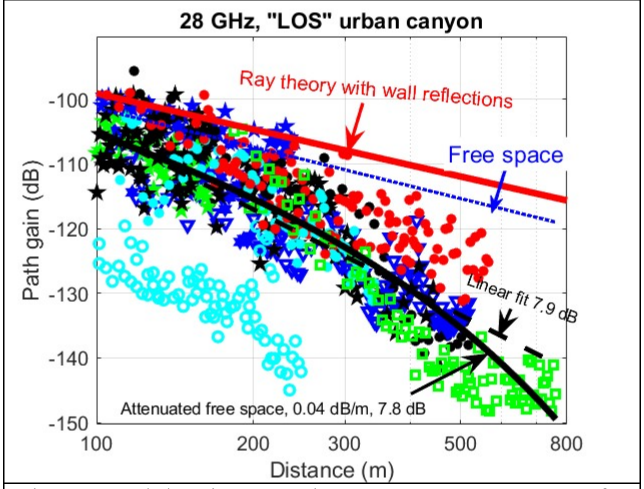

Figure 2. Path loss in 12 Manhattan streets, "LOS" except for foliage, clutter, each of 12 street data sets distinguished by different marker

III. PATH LOSS AROUND URBAN CORNERS

The observed data is shown in Fig. 3, where both around the corner data set as well as "down street" data for the street containing the "base" are shown. As in previous section, the down the street data (triangles at top) is below Free space and ray theory predictions. Formula (1), labeled in Fig. 3 as "attenuated free space" is found to have 4.2 dB RMSE, only slightly worse than 3.4 dB RMSE obtained through linear fit. The effective absorption κ= 0.009 Np/m was used, as in the general data set shown in Fig. 1, without adjustment.

The around the corner data (circles at bottom) is 7.8 dB above the 4-corner Uniform theory of Diffraction predictions, a standard mechanism in ray tracing for such environments. This can be explained through considering additional mechanisms such as scatter from poles and rough building walls[19]. An empirical model to represent such data using an empirical diffraction coefficient, adjusted to match the data was described in [13].

Here we consider an even simpler heuristic model, representing the street intersection as a cylindrical scatterer with an effective scattering width σ_{scat} $=N_{\text{poles}}\times\sigma_{\text{pole}}$, setting N_{poles} =4 and σ_{pole}= 0.24 m for 4 poles with a typical width of 0.24 m, typical of New York City. The resulting path gain for around the corner case may be derived using physical optics [20] as:

$$P_{\text{corner}}=\frac{\lambda^{2}\sigma_{\text{scat}}}{(4\pi)^{3}r_{1}r_{2}\left(r_{1}+r_{2}\right)}e^{-\kappa\left(r_{1}+r_{2}\right)} \tag{2}$$

Where r_1, r_2 are distances from base to corner and corner to mobile terminal, respectively. As in down the street formula (1), effective absorption loss for going through street clutter is accounted for, with κ= 0.009 Np/m.

The predictions, labeled as "4 0.24 m pole scatter" result in 2.3 dB dB RMSE, much better than 7.8 dB RMSE from UTD formulas. The model suggests that scatter from objects, such as poles, is a much stronger mechanism than building corner diffraction for around the corner cases.

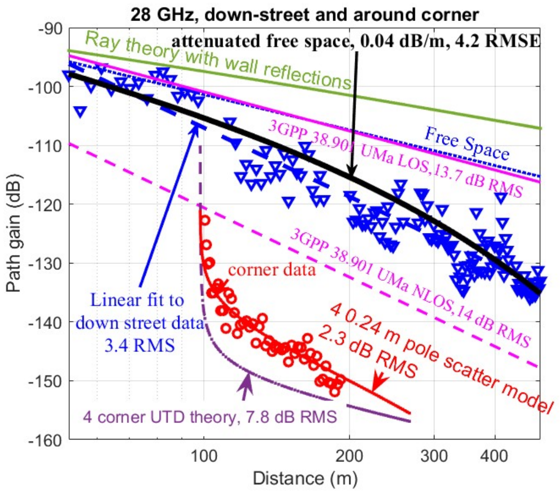

Fig. 3. Path gain down the street and around corner in Manhattan.

IV. CONCLUSIONS

It is found that use of standard ray tracing methods overpredicts signal strength in down-street scenarios and underpredict signal strength in around the corner links. Both effects may be attributed to the impact of clutter, usually ignored in ray tracing, such as lampposts, rough building walls and crucially, vegetation. Information on the presence of such clutter is often difficult to get and difficult to use with traditional ray tracing formalism. It is found that adjustment of appropriate theoretical formulas to include absorption (in down the street portions) and scatter (in around the corner paths) provides for generic formulas for such scenarios that are within 7.8 RMSE for down street "LOS" case, and 2.3 dB RMSE for around the corner case, even without street-specific environmental details. More extensive data collection for further comparisons and refinements is underway.

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