Occluded Scatterers and the Urban Ground-to-ground Channel at Low UHF

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***Abstract*—Ground-to-ground radio links in urban environments rarely enjoy direct line-of-sight between terminals, and therefore in-canyon, over-rooftop, and scattering from distant structures become primary propagation modes. Because both rooftop diffraction and canyon propagation losses can be severe, and because the walls of deep urban canyons often occlude distant scatterers, the relative importance of these three propagation modes to a given urban channel is unclear. We present results of channel sounding measurements at 437 MHz for ground-to-ground links in Boston, Massachusetts, USA to quantify the importance of each propagation mode. Occupancy curves derived from our measured channels suggest that while canyon-mode propagation is dominant for short range urban links, the importance of the distant scatterer propagation mode increases with terminal separation distance, even when those scatterers are occluded from transmitter and/or receiver view. We present an urban channel model which evaluates the vertical profile of incident power on distant scatterers, even those that are occluded, and find that reasonable agreement can be obtained between measured and modeled channels only when occluded buildings are considered.**

I. INTRODUCTION

The low UHF band is widely used for military and first-responder communication systems. For ground-based operations in an urban scenario, radio links are often non-line-of-sight (NLOS) and therefore the three most important propagation modes are in-canyon (IC), over-rooftop (OR) and distant scatterers (DS), as described in [1]. In [1], the authors argued that the IC mode was dominant for essentially all of their measurements, conducted at a 2154 MHz frequency. In this work, we use results from urban ground-to-ground channel sounding at a lower frequency (437 MHz) and comparisons with site-specific channel models to show that DS propagation becomes dominant over longer distances and/or more complex urban geometries. Our findings support the notion that diffuse scattering from built structures [2] is critically important to the urban ground-to-ground channel, especially at low UHF.

II. METHODS

We performed wideband channel sounding measurements at a center frequency 437 MHz using the 25 MHz bandwidth system presented in [3]. The antennas were vertically polarized sleeve dipoles at 2.5 m above ground level for both transmitter (fixed, blue point on Fig. 1) and receiver (mobile, black points on Fig. 1). Measurements were conducted in the Back Bay neighborhood of Boston, Massachusetts, USA, where the mean building height is about 15 m, though a few very tall buildings (200+ m in height) exist along the "high spine" to the south of and adjacent to the study area. The measurements, conducted on sidewalks and in narrow alleys, were close to surrounding buildings such that only buildings along the same street were visible; the taller buildings of the "high spine" were not directly visible by either the transmitter or receiver.

Fig. 1. Channel sounding regions in Back Bay, Boston, MA.

Grouping these measurements into the three regions R1, R2 and R3 shown in Fig. 1, we summarized the resulting power delay profiles using path occupancy curves, discussed in [4]. In this analysis, we ignored paths greater than 15 dB down from the maximum arrival power, and the occupancy curves thus produced (Fig. 2) therefore only capture paths important to the channel. Typical transmitter-receiver separation distances are 150, 500, and 900 m for regions R1, R2 and R3 respectively. Because the location of both transmitter and receiver were known from each measurement, both the minimum distance path and bistatic delay contours can be overlaid on a map of the city. Certain propagation modes and delays can therefore be associated with specific locations within the city.

III. RESULTS

The occupancy curves of Fig. 2 show the probability of paths occurring within a given excess delay time bin, and summarizes a number of different power delay profile measurements for a given region. For region R1, the occupancy curve shows a dominant peak at $0.5\,\mu s$ excess delay time, consistent with IC propagation modes. A secondary peak at

3 µs coincides with buildings along the high spine, specifically the Prudential Tower, the second tallest building in Boston.

In region R2, a range of equally probable paths were observed between 0 and 3 µs excess delay time, with the most probable paths clustered around the peak at 2 µs. In this case, IC propagation would be expected to fall at 0.4 µs and DS propagation, again, associated with buildings along the high spine, are expected at about 2 µs.

For region R3, IC propagation is expected around 0.5 µs, while DS contributions from high spine buildings should arrive around 1.5 µs excess delay time. The measured occupancy curve for this region is similar to that of R2, with a wide band of equally probable paths between 0 and 3 µs.

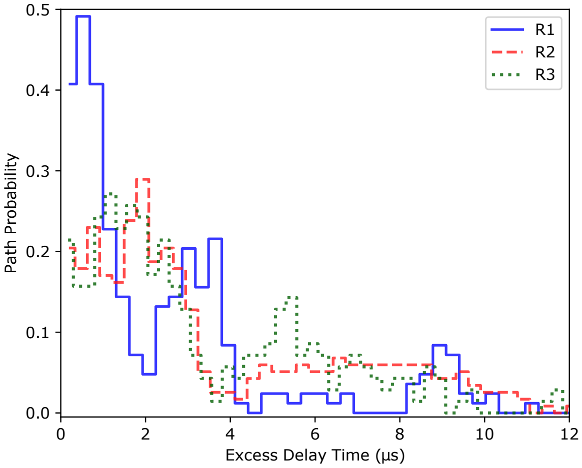

Fig. 2. Occupancy curves for regions R1, R2, and R3 within the Back Bay neighborhood, listed in order of increasing transmitter-to-receiver separation. Delay time bin width is 0.26 µs for all curves.

IV. DISCUSSION

The dominant, short delay peak in the R1 occupancy curve demonstrates that IC (and possibly OR propagation) dominates the short range urban channel at this frequency. The secondary peak centered at 3 µs for R1 shows that DS paths are still present in the short range channel.

In regions R2 and R3, the occupancy curve shows relatively equal probabilities for paths falling between 0 and 3 µs of excess delay time, with peaks approaching 2 µs, indicating that IC propagation becomes less likely and long-delayed DS contributions become more likely as transmitter-receiver separation increases beyond some critical distance.

In our geometry, the buildings giving rise to the DS paths are not in direct view of either the transmitter or receiver, and are therefore *occluded scatterers*. The power incident upon these scatterers depends on the diffraction geometry presented by the local urban canyon containing transmitter, and thus the incident power on a given scatterer must vary with elevation.

In an effort to interpret our measurement results, we have developed the Building Raster Urban Channel Estimator (BRUCE) to explicitly determine and sum the vertical incident power profile on both directly visible and occluded building faces. BRUCE takes as input an elevation raster of the area of interest (including both terrain and built structures) and the locations of both the transmitter and receiver within that terrain. This model generates azimuthal elevation profiles extracted from the input raster and analyzes them to locate and evaluate the vertical profile of incident power for transmitter-facing building surfaces. The output is two geo-located rasters: one raster of vertically and incoherently summed incident power on detected building faces, and a second raster of calculated bistatic delay times. BRUCE then processes the raster through a finite-bandwidth receiver to produce an estimated power delay profile, as shown in Fig. 3.

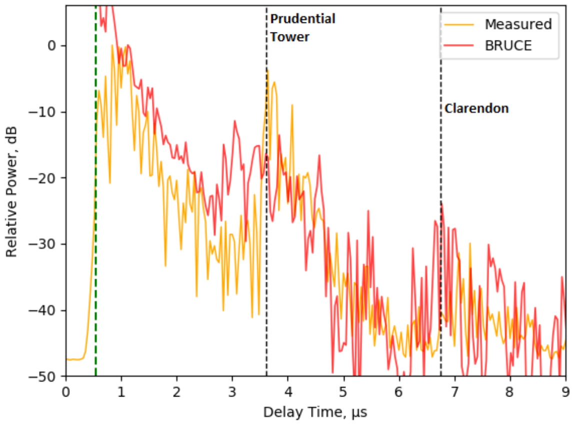

Fig. 3. Measured and modeled power delay profile for a point in R1.

V. CONCLUSIONS

Comparing channel sounding measurements and model results, we have shown that occluded scatterers are important for understanding and estimating the ground-to-ground urban channel in the low UHF band. We have also described a model which accounts for power incident on occluded buildings and shown good agreement between model and measurement only when occluded scatterers are included.

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