

Explicit Formula for Path Loss Prediction in Urban Streets for Microcellular Communications

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ABSTRACT

This paper presents an explicit formula for propagation path loss prediction of microcellular communication in an urban street scene. The formula is derived based on geometrical optics and diffraction theory and it takes into account multiple reflections along main streets, side streets and diffractions around corners. Comparisons between our theoretical results with measurements and ray tracing model results in New York city and Tokyo show good agreement.

1. INTRODUCTION

The rapid growth of wireless communications has made the use of microcells indispensable. Efficient propagation prediction models are important for cells coverage determination for such microcellular communication systems, which are characterized by low transmitting power and low base station antennas at lampposts level.

There are a number of prediction models for the received signal level based on ray tracing technique and uniform theory of diffraction (UTD) [1]-[3]. However, the computation time and memory requirement is a major problem for such models. There are some other models based on statistical methods [4]. Such statistical models may not be applicable to other sites with different operating frequencies. Analytical prediction models for cellular communications with base antennas above, near and below rooftop level has been reported by Xia [5]. In his paper, path loss formulae are derived based on double diffracted signal around rooftops. Thus, reflections along streets and diffractions around street corners at street cross junction are not considered, but these components might be dominant for microcellular applications since base station antenna is at height well below surrounding buildings.

The purpose of this paper is to derive a closed-form expression for predicting path loss in urban microcellular communication environments as represented by fig. 1 [6]. The formula takes into account reflections along streets and diffraction around corners at street junctions. Comparison between theoretical results and measurements show good agreement.

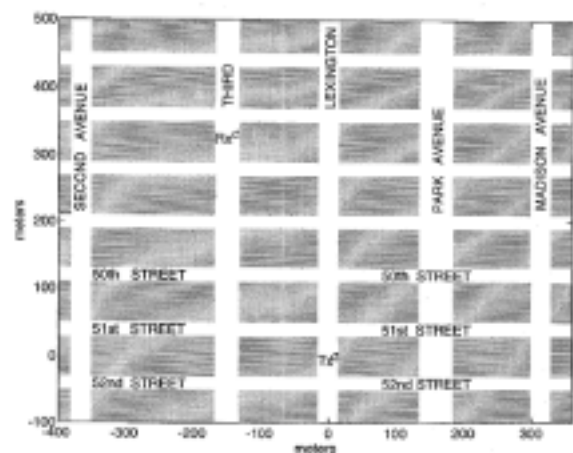


Fig. 1. Top view of street grid of New York city [6]

2. CLOSED-FORM EXPRESSION

For a receiver in a particular side street in urban environment, where it is in out-of-sight (OOS) region, the received signal from transmitter may arise from reflections along main street and side street with or without diffractions around street corners at street junction. We assume that all the buildings in the streets have infinite heights and smooth surfaces so that the diffracted signals over building rooftops are negligible. This assumption is justifiable according to microcells characteristics in urban environments. We will consider reflection component and diffraction component respectively.

Let r_m be the distance from transmitter T_x on a main street to a street junction J_m and r_s be the distance from receiver R_x on a side street to J_m as shown in fig. 2. Let W_m and W_s be the street width of main street and side street respectively.

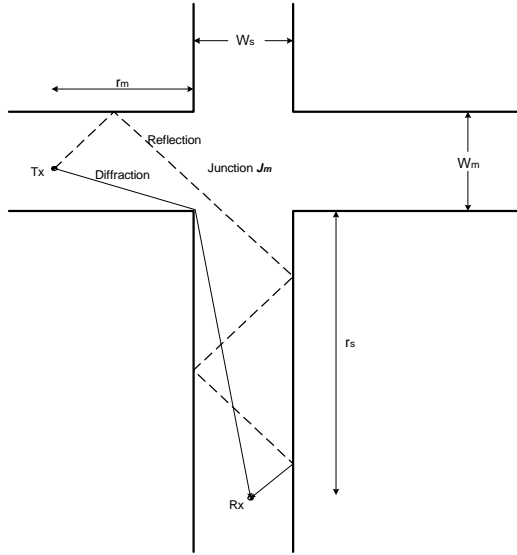


Fig. 2. Illustration of side street scene showing typical reflected path and diffracted path

To derive a closed form expression, reflection coefficients of main street and side street are assumed to be constant. Thus, the dominant reflected path is assumed to be the one going through the least number of reflections. The path loss for reflection component can be shown to be given by

$$PL_R = 10 \log \left(\frac{\lambda}{4\pi(r_m + r_s)} \right)^2 + 2L_w \sqrt{\frac{r_m r_s}{W_m W_s}} \quad (1)$$

where L_w is loss in -dB per reflection. The first term in the equation is free space loss and the second term is the loss due to reflections along street walls. From the equation, it can be seen that the narrower main street and side street are, the lower the reflected signal strength is.

The dominant path among diffracted paths is the direct diffracted path around corners without involving any reflection along main street and side street. Based on *Fresnel-Kirchhoff* diffraction theory [7], the direct diffracted field at receiver R_x is written as

$$E(R_x) = \frac{j}{2\lambda} A \iint_{\Omega} \frac{e^{-jk(r_m+r_s)}}{r_m r_s} (\cos(n, r) - \cos(n, s)) d\Omega \quad (2)$$

where A is the electric field amplitude at 1 meter from T_x , n is unit vector normal to side street entrance, and r , s are direction vectors of normal incident path and diffracted path respectively.

It is assumed that the diffracted signal is mainly contributed from a zone within which all diffracted paths have less than half wavelength difference with a reference diffracted path. In the derivation, we assume that

$$\begin{aligned} r_m &\gg W_m \\ r_s &\gg W_s \\ \cos(n, r) &\cong 0 \\ \cos(n, s) &\cong -1 \end{aligned} \quad (3)$$

It is found that path loss due to diffraction is written as

$$PL_D = 10 \log \left(\frac{\lambda}{4\pi r_m r_s} \right)^2 + 10 \log \left(\frac{\lambda r_m r_s}{4r_s^2} \right) \quad \begin{matrix} r_m < r_s \\ s & m \end{matrix} \quad (4)$$

The first term in equation (4) is actually the line-of-sight path loss at junction J_m and the second term is based on diffraction at street corners. From this formula, we can see that the diffracted signal strength is determined by distances from T_x and R_x to street junction.

The equation (4) can be further simplified as

$$PL_D = 10 \log \left(\frac{\lambda}{4\pi} \right)^2 + 10 \log \left(\frac{\lambda}{4r_m r_s} \right) \quad \begin{matrix} r_m < r_s \\ s & m \end{matrix} \quad (5)$$

Combining equation (1) and (5), path loss along a side street is given by

$$PL = 10 \log \left[\left(\frac{\lambda}{4\pi} \right)^2 \frac{\lambda}{4r_m r_s} + \left(\frac{\lambda}{4\pi(r_m + r_s)} \right)^2 10^{\frac{2L_w \sqrt{\frac{r_m r_s}{W_m W_s}}}{10}} \right] \quad \begin{matrix} r_m < r_s \\ s & m \end{matrix} \quad (6)$$

3. COMPARISON OF RESULTS

Using our formula, we have computed the signal path loss along side streets for several urban scenes and compared them with published measurements. Fig. 3 shows the computed path loss along the 51st street in Manhattan, New York City together with measurement done by Rustako et al. [8] and UTD model results by Tan and Tan [6]. The measurement is taken at 900MHz. The dark solid line is the theoretical result combining reflection component and diffraction component. It agrees well with the measurement in thin solid line.

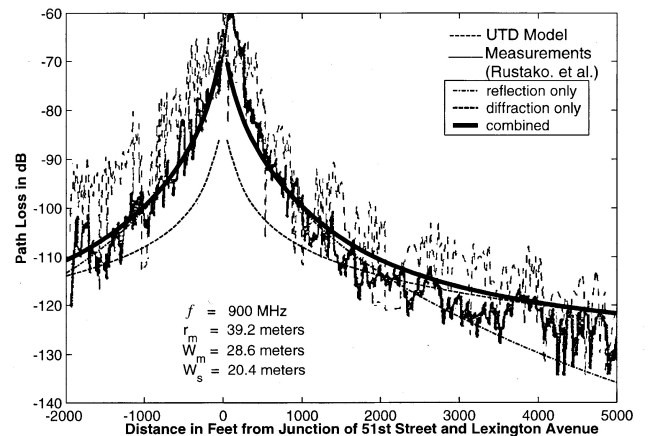


Fig. 3. Path loss along 51st street in Manhattan

From the figure, it can be seen that reflection component dominates the received signal when receiver is near to street cross-junction. However, reflection component drops fast as receiver moves far away from junction. Diffraction component contributed equally as reflection component when r_s is around 2000 feet. After that, the received signal is mainly contributed from diffraction component. It is also observed that there is sharp decrease in signal strength near to street junction of 51st street and Lexington Avenue, which is called corner attenuation in some papers.

Fig. 4 shows comparison of calculated results with measurement in Tokyo by Iwama et. al. [9] and UTD model results by Tan and Tan [6]. The measurement was made at 1.5GHz. It can be seen the results agrees well with measurement and UTD model results too. At round 150 meters from street junction, path losses due to reflection and diffraction are equal.

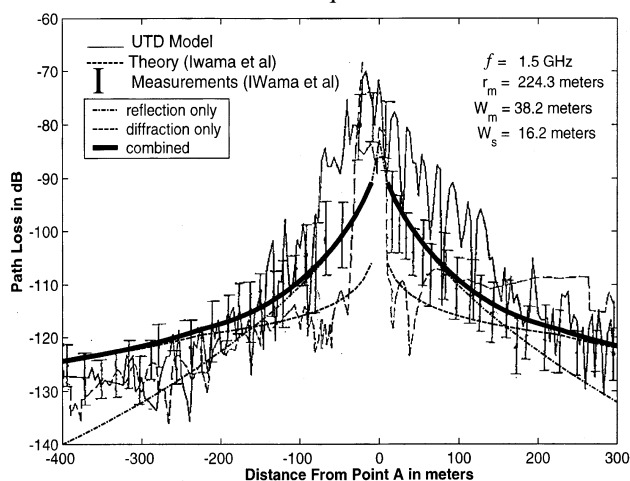


Fig. 4. Path loss along side street CAD in Tokyo

5. CONCLUSION

A closed-form expression is presented for the path loss prediction in urban street grid environments for microcellular communication systems. The formula is a function of street widths, distances from T_x and R_x to street cross-junction, and wavelength. Good agreement between predicted and measured results indicates that the applicability of our formulae and the formula can be used as a fast and rather accurate path loss prediction tool for microcellular communications. Our results also show that reflected signal dominates received signal when receiver is near to street cross junction and diffracted signal dominates as receiver moves far away from street cross junction.

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