FAST PATH LOSS PREDICTION BY USING VIRTUAL SOURCE TECHNIQUE FOR URBAN MICROCELLS

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Abstract - This work proposes a new principle for fast path loss prediction and cell coverage calculations for urban microcells in high rise building environment. The technique is based on finding a virtual source located in line of sight with the mobile station (MS). This technique maps the out-of-sight propagation prediction problem to a line-of-sight propagation prediction problem. The received power at MS is given in a closed form expression. Based on comparison performed with experimental results, it seems that breakpoint is valid in side-street propagation. The proposed virtual source principle opens a door for a new fast computation technique for path loss modeling in the microcellular environment.

I. Introduction

Currently, the concept of microcells is used to increase the capacity of radio networks and overcome the crowding of the radio spectrum [1]. Microcell generally refers to small cell (< 1 km) with the antennas that are below the surrounding buildings' rooftop. This placement of antennas results in a different propagation mechanism from that of cellular communication systems. The street orientation and individual blocks of buildings make a difference in signal reception. With the increasing demand for cheaper and better wireless services, it is becoming very important to optimal design the cell geometries and deploy the minimum number of base stations to provide the maximum possible coverage. Therefore, to calculate the coverage, a fast path loss prediction tool is of primary importance. This tool is essential for efficient planning of current and future radio networks.

II. Background

It is important to develop reliable planning tools for future broadband communication systems in urban microcells. In network planning different empirical propagation models have been used to calculate the coverage area of the base station [2]. These models give good predictions when the transmitter is above the rooftops and give poor results when applied for microcells. However, these models do not take into account the exact geometry of the surrounding buildings and the actual wave propagation phenomena. In urban microcells, the usual approach to study channel properties is to model the propagation by using the ray-optical approximations. These models usually use the ray tracing algorithms to compute the rays from the transmitter to the receiver via different propagation mechanisms, which usually are reflections, diffractions and some combinations of them. The ray tracing technique has some drawbacks. Firstly, the technique is very tedious to implement. Therefore, we have to take another approach in our prediction, which will be described in this paper. Secondly, the ray tracing requires large database of the propagation environment, which may not exist or is expensive to get, although only part of it is essential in the propagation prediction. Thirdly, the lengthy time spent in ray tracing computation is a major problem with mobile radio propagation prediction for urban microcellular environments. Fourthly, the use of different values of permittivity and conductivity in the calculation of Fresnel reflection coefficients makes large difference in the prediction of multiple reflections. Different ray tracing techniques have been introduced to overcome the lengthy computation time but they are still not fast enough.

In this work, a new principle for fast path loss and cell coverage prediction of urban microcellular environment is proposed. This new model predicts propagation for mobile station (MS) traveling in out-of-sight side streets. The proposed technique is based on using virtual source principle. The previous work [3],[4] proposed a virtual source technique for parallel street propagation prediction problem and mapping it to side street propagation prediction problem. This work simplifies the problem more by placing the proposed virtual source in line-of-sight with the mobile station.

III. Proposed Technique

This new model predicts propagation for mobile station (MS) traveling in out-of-sight side street. The proposed new technique is based on using virtual source concept. The virtual source is located in a position having line-of-sight with the MS. Thus, this new technique maps the out-of-sight propagation prediction problem into line-of-sight propagation prediction problem. The technique provides the received power at the MS along the side street in closed form expression taking into account the information about the BS and the MS positions in microcellular environment.

Side-Street Propagation Prediction

The position of the base station with respect to the surrounding building has influence on the dominant propagation mechanism. Two possibilities of base station location can be considered with respect to the distance between sidewall and the base station. In the first case, the base station is on (or close to) the sidewall, the second case, the position is at some distance from the side-wall. In the first case, it is expected that the dominant propagation mechanism is the forward multiple diffraction. Therefore, the side street corner, on the side where the base station is located, may work as a source (virtual source), VS_I in Fig. 1, for radio wave propagation in the out-of-sight side street. When the base station is close to or on the sidewall, the propagation mechanism is dominated with low grazing incidence rays, thus, the forward multiple-diffraction is expected to be significant for wave propagation in to the side street. Utilizing the results presented in [5] and making them applicable for microcellular environment, a closed form formulation could be found for the received power at the mobile station due to this virtual source.

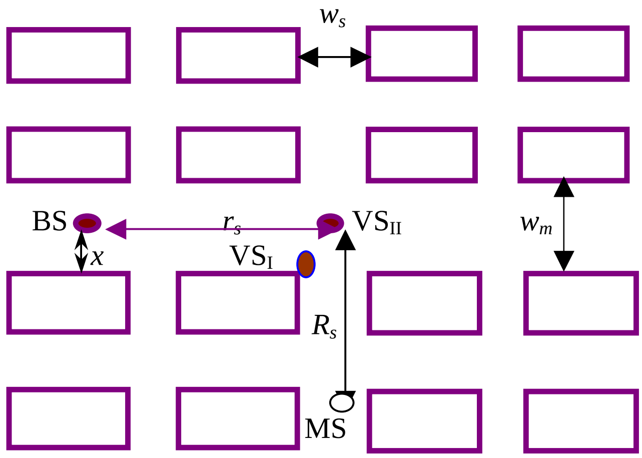

Fig. 1. A microcellular environment plan view

When the base station is located at some distance from the side-wall, the dominant propagation mechanism for the signal received at the mobile station in the side-street depends on the distance of the mobile and base stations to the intersection [2],[6]. When the mobile is in the out-of-sight region and close to the junction the reflection mechanism dominates [6]. When the mobile is further away from the junction, the diffraction mechanism dominates [2],[6]. The distance at which the diffraction becomes dominant over the reflection depends also on the distance from the transmitting antenna to the turning corner, but also depends on the frequency, street widths, and the position of the transmitting and receiving antenna with respect to the sidewall.

The formulation presented in this work is based on the principle that the power leakage in to the side street is regarded as a virtual source for the propagation of waves in to the side street. There could be different approaches for the derivation of this power leakage. For simplicity, the following assumptions are made in derivation of the leakage power: First, neglecting entering power due to diffraction and reflection in the main street (i.e., where the base station is located). Second, the virtual source is placed in the center of the side street. Third, it is assumed that it has the same offset distance x from the sidewall in the main street. Fourth, it is also assumed that it has the same height as the base station antenna height. Thus, the aim is to find the total direct radiated power that enters the side street. Considering this total power entering the side street as the transmit power of a virtual source (VS_{II}), the virtual source is located in line of sight with the mobile station (see Fig. 1). Since the virtual source represents the power entering the side street, thus, it transmits only in the dedicated side street. For the opposite part of the side street, different virtual source with different transmitting power is needed. The virtual source power is derived utilizing angular information of direct waves that propagate in to the side street from the base station. This model is valid for the case when the base station is located at some distance from the sidewall. The received power at the mobile station due to the virtual source can be given in a closed form expression as

$$P_r = \begin{cases} \alpha\left(\sqrt{\dfrac{xw_s}{2\pi}}\dfrac{\lambda}{4\pi r_s R_s}\right)^2 P_t, & R_s \le r_b \\ \alpha\left(\sqrt{\dfrac{xw_s}{2\pi}}\dfrac{\lambda r_b}{4\pi r_s R_s^2}\right)^2 P_t, & R_s > r_b \end{cases}, \quad (1)$$

where P_r is the received power by isotropic antenna at MS, P_t is the transmitted power by isotropic antenna at the base station (BS), λ is the wavelength, x is the distance between the BS and the sidewall, for the opposite part of the side street x is replaced with w_m-w_s, where w_m is the main street width, w_s is the side-street width, r_s is the distance between the BS and the center of the side-street where the MS is traveling, R_s is the traveling distance in the side street from the virtual source, α is a street parameter, it is introduced here to specify street characteristics since there are no two identical streets. The parameter r_b is the break point distance [7], defined as

$$r_b = \frac{4h_t h_r}{\lambda} \quad (2)$$

where h_t is the base station antenna height and h_r is the mobile station antenna height.

IV. Numerical Results

In order to validate the given expression for received power due to the virtual source, we have computed the path loss for several urban street grids in Manhattan and Tokyo for comparison with published measurements in open literature [8].

Experimental data

In Manhattan data were collected at 900 MHz. The transmitting and receiving antenna heights were 30 ft and 6 ft, respectively. Polarization was vertical. In Tokyo data were collected at 1.5 GHz with vertical polarization and transmitting and receiving antennas were 5.3 m and 3 m, respectively.

Comparison

The above-mentioned experimental data and geometrical parameters from the corresponding city street plan views are used in computation. Comparisons between the prediction and the measurements for both Tokyo and Manhattan show good agreement. Having a closed form expression makes computation fast since there is no searching for rays that join the BS and the MS. Running a program written in MATLAB in standard PC, the computation lasts less than a second for more than 600 points along MS traveling route.

Figure 2 shows the model prediction and Manhattan measurement results [8]. The transmitter is located at Lexington Avenue and the mobile station is traveling along the 51st street (i.e., side street) as shown in Fig. 3 in [8]. The measurement results ('•') in Fig. 2 are obtained from Fig. 7 in [8]. The solid line represents computation results of formulation provided in Eqn. (1). The geometrical parameters are w_s=21 m, w_m= 36 m, x= 14 m, and r_s= 40 m. The street parameter α=1 for both sides of crossing street.

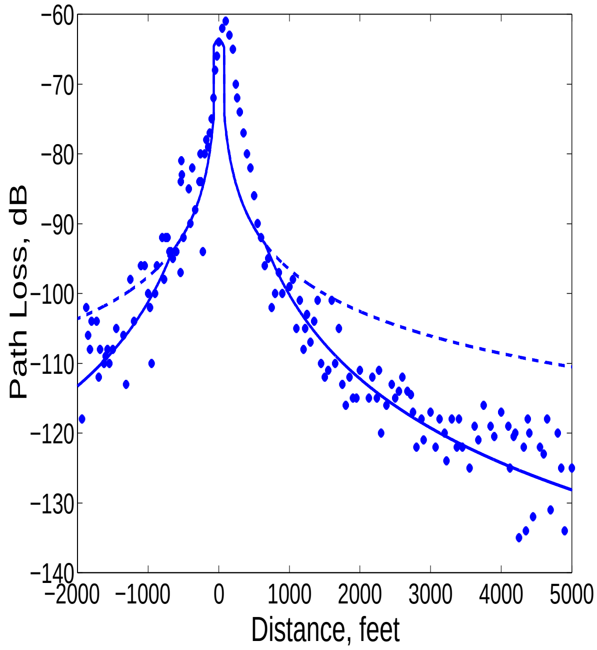

Fig. 2. Path loss along a side street (51st in Manhattan) with w_s=21 m, w_m=36 m, x=14 m, r_s=40 m.

It can readily be seen from Fig. 2 that the breakpoint seems to be valid for the side-street propagation when the virtual source is used. The dotted line represents the calculation results of Eqn. (1) utilizing the second power law loss. One can see that the measurement results show fourth power law loss beyond the break point. Using fourth power law loss show good agreement with the measurements at distance beyond the breakpoint.

Figure 3 and Fig. 4 depict the agreement with measurement results carried out along side streets in Tokyo. The solid line represents the computation results of expression of Eqn. (1). The bars represent the measurements results. The measurements, in Fig. 3 and Fig. 4, are obtained from Fig. 4 and Fig. 5 in [8], respectively. The geometrical parameters are w_m= 33 m, x= 5.5 m, w_s=15 m, r_s= 225 m for the side street of Fig. 3 and w_s=45 m, r_s= 710 m for the side street of Fig. 4. The street parameter is different from that used in Manhattan calculations since the two environments are quite different, $\alpha = \frac{1}{\pi}$ is used for the two side streets AC and BE as defined in Fig. 2 in [8] and $\alpha = \sqrt{\pi}$ is used for the two side streets AD and BF as defined in Fig. 2 in [8].

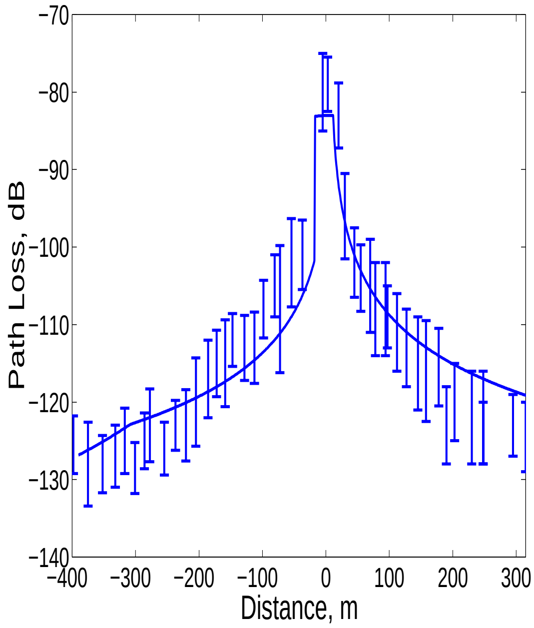

Fig. 3. Path loss along side street near Shinbashi station Tokyo with w_s=15 m, w_m=33 m, x=5.5 m, r_s=225 m.

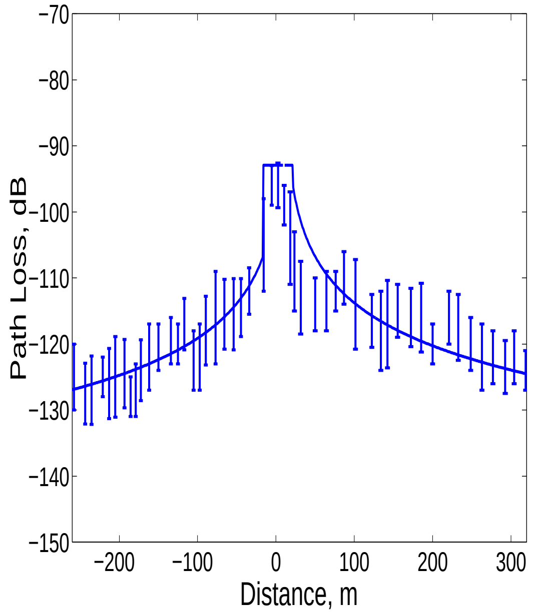

Fig. 4. Path loss along side street near Shinbashi station Tokyo with w_s=45 m, w_m=33 m, x=5.5 m, r_s=710 m.

For figures 2, 3, and 4, when the mobile station is traveling along the intersection and is in a location having line of sight with base station (BS), a line-of-sight model [9] is used in calculation rather than the virtual source. The zero of the distance label in the abscissa of figures 2, 3, and 4 are from the center of the intersection.

V. Conclusion

This work proposes a principle for a new fast path loss and cell coverage prediction technique for microcellular environment. The new technique proposed in this work makes the out-of-sight side-street propagation prediction problem simpler by mapping it to a line-of-sight propagation prediction problem. The received signal power at the MS is given in a closed form expression, which makes computation very fast. By comparison with measurements, it seems that the breakpoint is valid in the side street. The virtual source principle presented in this work opens a door for new fast computation techniques for propagation modeling in urban microcellular environment.

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