

Discrete Propagation Model for Mobile Communications in Urban Environment

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ABSTRACT

The need for wireless communication data has increased considerably in past decades. In this paper we have introduced new propagation model for the streets and avenues in urban areas that can be thought as a wave-guide for EM-waves. Using our developed model it is possible to calculate the contributions of each direct and scattered wave separately. We don't assume the sidewalls as perfect conducting materials in our developed model unlike the previous studies. Our simulations revealed that developed model is applicable for broadband of frequencies. If the shape of the wave-guide is entered to simulation program in great detail, the output can be very close to results that are obtained by measurements. Even the shape is not entered very accurately; an approximate result can be obtained if the fast result is needed.

1. INTRODUCTION

Many studies have been done by the scientists so far, and now we have many propagation models of EM-waves for various kind of building structures. We have seen that the position of the buildings in the streets in the urban areas or the corridors in the office buildings can be thought as wave-guides for EM-waves. For each kind of building structures, a different mathematical model has been proposed and very good approximations have been done by successful studies [1-6]. The evaluation by means of "Multislit Street Waveguide Model" (constructed by Blaunstein) [2-3] is introduced to describe the propagation characteristics along straight rectangular streets in cases where both antennas, receiver and transmitter, are placed in direct visibility (LOS conditions) at lower than rooftop level. In the same work [2], the conditions of regular terrain are considered further in the obstructive conditions (no-line-of-sight NLOS). Antennas are described in the case of urban environments with a rectangular crossing street plan for different positions relative to the rooftops. Furthermore, "Crossing Waveguides Model" [2-3] and the "Two Dimensional Multidiffraction Model" [4] are presented to describe the propagation characteristics and the coverage effects. 'UHF radio propagation characteristics in straight open-groove structures' especially the frequency characteristics and propagation attenuation constant are presented in [5]. The study of "UHF ray tracing propagation model for corridors" is touched on in [6]. They have used the "Ray Theory" and "Uniform Theory of Diffraction (UTD)" to predict wave strength. Finally

"Modeling and Measurements of EM-Wave Propagation" [7] has been presented. In this paper we will introduce a new propagation model for the streets and avenues in the urban areas, which can be thought as a wave-guide for EM-waves. In the next section we will present a new model. Then this model will be studied more with new application and will be improved to fit to use for urban areas. Finally the results will be compared with the ones obtained from the previous studies that are mentioned previously.

2. DISCRETIZED APPROACH FOR SCATTERING AMPLITUDES

In this section we will discuss 'briefly' an approximate solution to determine scattering amplitudes of arbitrary shapes [1]. This method is valid when surface is small compared to wavelength in one direction. If this thinness criterion is satisfied, the results are valid in all frequency regions. The results are obtained by employing a quasi-static approximation to find the fields inside the surface.

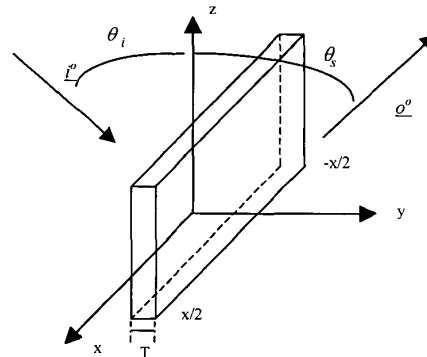


Fig. 1. Scattering from a thin dielectric sheet.

The well-known integral form of scattering amplitude of scattering fields is [1]:

$$f(\underline{o}^0, \underline{i}^0, \underline{q}) = \frac{k_0^2(\epsilon_r - 1)}{4\pi} \int (\underline{I} - \underline{o}^0 \underline{o}^0) \cdot \underline{E}_{int}(\underline{x}', \underline{q}) \cdot e^{-ik_0 \underline{o}^0 \cdot \underline{x}'} d\underline{x}' \quad (1)$$

where \underline{i}^0 is the incident direction, \underline{o}^0 is the scattering direction, k_0 is the wave number, ϵ_r is the relative permittivity of surface, \underline{I} is unit dyadic and \underline{q} is the polarization unit vector. Assuming we have arbitrary surface, which is electrically thin, quasi-static techniques

can be used to find approximate results for the scattering amplitudes of this scatterers. Thus under the quasi-static approximation the internal electrical field (\underline{E}_{int}) of small rectangular strip of surface in equation 1 is calculated by the following formula [1]:

$$\underline{E}_{int}(\underline{x}, \underline{q}^0) = \left[\underline{q}^0 - \frac{\epsilon_r - 1}{\epsilon_r} (\underline{q}^0 \cdot \underline{n}^0) \underline{n}^0 \right] e^{-i k_0 \underline{\rho}^0 \cdot \underline{x}'} \quad (2)$$

where \underline{n}^0 is the normal vector of surface. Using (2) in (1) scattering amplitudes for the plate can be expressed as follows [1]:

$$\underline{f}^{(i)}(\underline{\rho}^0, \underline{l}^0, \underline{q}^0) = A(\underline{l} - \underline{\rho}^0 \underline{\rho}^0) \left[\underline{q}^0 - \frac{\epsilon_r - 1}{\epsilon_r} (\underline{q}^0 \cdot \underline{n}_i^0) \underline{n}_i^0 \right] V_i \quad (3)$$

where,

$$A = k_0^2 \frac{\epsilon_r - 1}{4\pi} \quad (4)$$

$$V_i = \int_{V_i} e^{i k_0 \underline{\gamma} \cdot \underline{x}_i} d\underline{x}_i \quad (5)$$

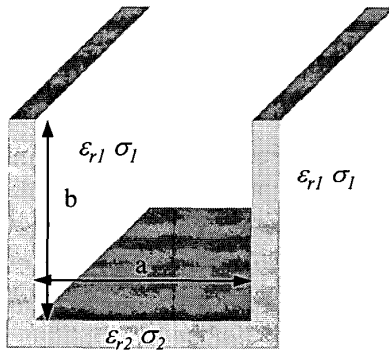


Fig. 2. 3D Cross Section of rectangular waveguide.

The scattering amplitudes for an arbitrary surface can be determined by using (3). Now we will explain how to discretize the arbitrary shapes:

1. The surface is divided into small approximately rectangular strips (discretization), which can be described in terms of x_i, y_i, z_i .

2. The normal vector \underline{n}_i^0 of each strip is determined. The internal fields are determined, and then scattering amplitudes are computed from each sheet using (2).

3. Each scattering amplitude originating from the discrete plates are added in order to obtain the scattering amplitude of surface [1] as:

$$\underline{f}(\underline{\rho}^0, \underline{l}^0, \underline{q}^0) = \sum_{i=1}^N \underline{f}^{(i)}(\underline{\rho}^0, \underline{l}^0, \underline{q}^0) e^{i k_0 \underline{\gamma} \cdot \underline{x}_i} \quad (6)$$

where N is the number of rectangular strips.

As a part of the study, a software code involving the implementation of the above approach was modified and the scattering cross section (RCS) of thin curved cylindrical surface with $\epsilon_r = 29.1 - j13.3$, radius $R = 27.5$ cm, thickness $T = 0.2$ mm, length $L = 1$ m and $f = 100$ MHz. was computed [1]. The results were compared with those obtained by using the "continuous" approach developed

in [8] for verification. Comparison clearly shows that the solution obtained by discretizing method (developed model) very close to published results in literature. This validates the approach.

3. DEVELOPMENT OF THEORY FOR EM WAVEGUIDES

In the real world, there are many objects and gaps on the streets that contribute the loss of electromagnetic wave at the receiver point. If we want to model the buildings in the urban areas, we have to take into account these contributions to get reasonable results.

Now we will enhance our model to use with the wave-guides that have both sidewalls and slits (gaps between side walls).

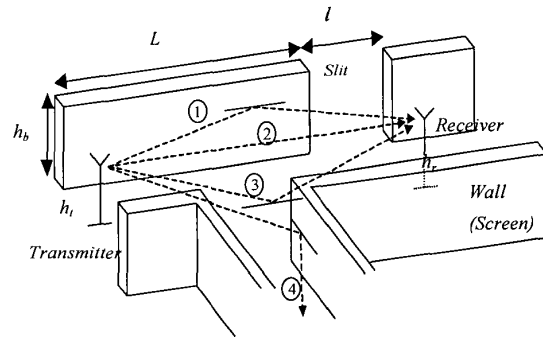


Fig. 3. 3D Illustration of the urban areas.

As seen from the fig. 3 the total field density at the receiver is the sum of waves, which are scattered from the inner side of wave-guide. These scattering occur trough walls or ground. Since the antennas' height is lower than the rooftop level the diffraction from the roof edges have been omitted.

Some of the parameters seen in the figure are h_t transmitter height, h_r receiver height, h_b average building height, l length of slits, L length of sidewalls. Waves 1 and 3 can reach to receiver antenna trough wall and ground respectively. Wave 4 cannot reach to receiver and get lost in the side streets.

Only one scattering (first order) from the walls and ground is illustrated in the fig. 3. However, we know that second and third scattering also contribute the field intensity. Therefore we have added these scattering into our calculation. After the third scattering, the loss of electric field so increases that the contribution of this multiple scattered waves can be neglected.

As seen from the fig. 3 some of the waves cannot reach to the receiver antenna like wave 4. Therefore we have to choose the waves, which can reach to antenna to find total field. Scattering from the walls is taken into account by introducing the special *brokenness parameter* χ as presented in [2].

$$\chi = \frac{L_i}{L_i + l_i} \quad (i=1,2,..) \quad (7)$$

The magnitude of χ shows the density of the buildings and takes the value between 1 and 0 ($0 < \chi < 1$). If χ is "0", it means there is no sidewall. The result must be

equal to the loss of free space. If χ is "1", there is no slits or any gaps in the wave-guide. This wave-guide is closed in each side. As a result the following can be written:

$$\chi = \begin{cases} 1 & \text{AT = Loss for no gap} \\ 0 & \text{AT = Loss for no sidewall (free space)} \end{cases} \quad (8)$$

where AT is the total attenuation at receiver antenna and calculated using $20\log(E_s/E_i)$ where E_s is the electric field at observed point and found by [1,8]

$$\underline{E}_s = \underline{f} \frac{e^{i k_0 R}}{R} \quad (9)$$

where \underline{f} is the scattering amplitude, and R is distance, and the incident electric field E_i is taken as 1.

In the developed software we moved the receiver antenna along the street and computed average total electric field for certain distances from the transmitter for both broken and unbroken wave-guide models. Then we calculated the path loss along the street for the LOS conditions. As a result we can write the following field attenuation equation for multislit wave-guide:

$$AT = AT_{unbrk} + (AT_{open} - AT_{unbrk}) \times (1 - \chi) \quad (10)$$

where AT_{unbrk} represents attenuation at unbroken wave-guide, AT_{open} represent attenuation for free space. We have chosen the parameter χ according to the density of the buildings in the referenced surveys. Some of the surveys already include these parameters.

4. THE SIMULATION RESULTS

We have run our software for the study of Open-Groove Structures [5] as seen in figure 2. Following parameters have been used for the simulation: $f=2\text{GHz}$, $\epsilon_r=4.18$, $\sigma=0.026\text{S/m}$ as stated in the study, the dimension of the corridor has been entered by an external file. These dimensions also have been divided to small sheets for discretization process. The field density has been calculated for the distances from 120m to 250m. The distances are different from the case in the literature, but it is not matter since the important point is to find the relative loss along the distances as it is stated in the literature [9]. And the angle of scattering from the surfaces has been calculated for each scattering case.

At the end, we obtained separate solutions for the vertical and horizontal field density. Vertical scale represents relative 1dB Loss for each division, and horizontal scale represents distance from the source in meter for each division.

In Figures 4 and 5 comparison of the theoretical field strength attenuation with the measured one is presented for horizontal and vertical polarization respectively. Dashed line represents our new model. Crosses are for the measured results and straight continuous line is for the results of the previous study [5].

We can see from the figures that our result for vertical and horizontal polarization are not very different from each other and gives the average result for both case. And as it is seen, our result has roundness in respect of the theoretical solution, which is more reasonable since the

loss is not a straight line in practice. Ultimately our new model is better at giving the solution for average loss for vertical and horizontal cases and applicable for a broad range of frequencies.

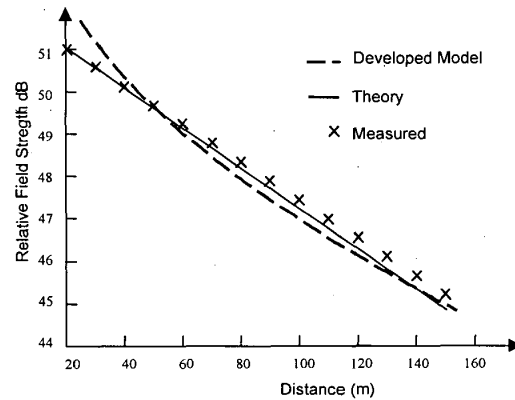


Fig. 4. Comparison of field strength for horizontal polarization.

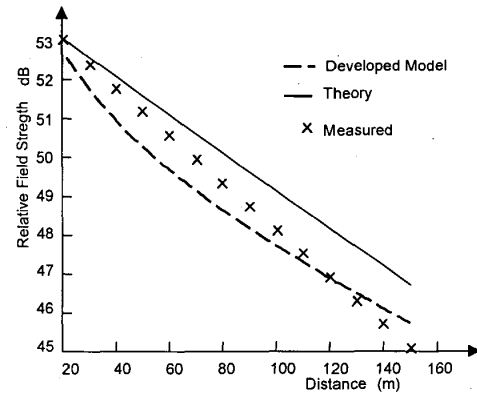


Fig. 5 Comparison of field strength for vertical polarization

Second simulation has been done for the experimental data presented in [9] for conditions of direct visibility along streets in Manhattan, New York. We used the same conditions of measurements as presented in [9] such as $h_b=50\text{m}$ for average building heights, $f=900\text{MHz}$ for the operating frequency, $a=30\text{m}$ for the street width, $\epsilon=15$, $\sigma=7$ for dielectric properties of the sidewalls and $\chi=0.8$.

What we can extract from the graph is the software output highly depends on the shape of the wave-guide and the more the shape of wave-guide is uncertain, more difficult to get accurate result. As we add the slits to our wave guide the rays that can reach receiver antenna decreases. This leads lower signal power at receiver point. But other objects at the street like trees, vehicles and people contribute to signal and increases the power. Therefore the signal at the receiver point may be powerful than the expected from the theoretical result.

The fig. 6 shows actual measurements in the New York City. We will compare both previous theoretical results and the experimental values with our simulation output. Dotted line represents our simulation result, two dashed lines represent theoretical results by Rustako as

presented in [9] for two different mathematical models $1/r^2$ and $1/r^4$ respectively, and continuous line represents actual measurements.

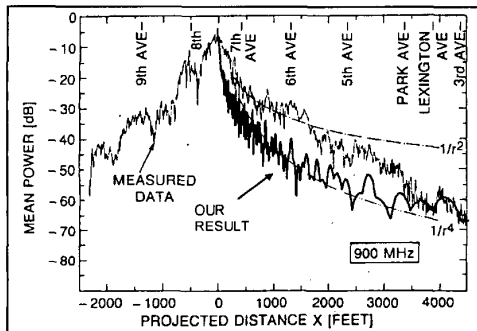


Fig. 6. Comparison of simulation results and measurements in New York.

The result of our simulation follows 10 dB lower than the experimental results. This is because the contribution of the scattered waves from the other objects in the street. Also the dielectric properties of the buildings, vehicles and unexpected objects affect the total signal power at the receiver. Since we have roughly used the same dielectric properties for all sidewalls in our simulation what we get from the computer program cannot match very well. If we use the model closer to the actual wave-guide and take into account dielectric properties of the each objects and measure sidewall and slit dimensions accurately, we could get much better result.

5. CONCLUSIONS

We presented our model to study radio wave propagation for urban areas and again compared it with the experimental measurements in the real world. Ultimately, our developed model, the total field density in the observed point is calculated by adding the line-of-sight and scattered wave contributions to each other. Furthermore, higher order scattered waves can also be calculated.

The developed model has the following advantages:

1. Using our developed model it is possible to calculate the contributions of each direct and scattered waves separately.
2. We don't assume the sidewalls as perfect conducting materials in our developed model unlike the previous studies.

3. Most of the previous works in wave propagation have focused on specific frequency ranges. Our simulations revealed that developed model is applicable for broadband of frequencies.

4. If the shape of the wave-guide is entered to with great detail, the output can be very close to results, which are obtained by measurements. Even the shape is not entered very accurately; an approximate result can be obtained if the fast result is needed.

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ACKNOWLEDGEMENT

This work is supported by Bogazici University Research Foundation. Project No;BAP03A207.