POS2-9

Modelling of RF Transmission through Buildings Using MoM Based Semi-Deterministic Approach

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1. Introduction

The ability to accurately predict radio wave propagation behaviour has become important with the increase in the mobile communication services. This poses the challenge of designing efficient propagation models in order to understand and predict radio propagation characteristics in various urban and suburban areas. The accuracy of the input data (environment database) and the ability of the prediction tool to model correctly the available information determines the prediction accuracy of a propagation model [1]. The current databases used in propagation prediction tools do not provide environmental details on the wavelength scale. Furthermore even if we have a precise database it is not possible to taken into account all the propagation effects using the current favourite models. For example the most commonly used ray tracing technique becomes cumbersome when dealing with multiple interactions between large number of building faces and edges. So we need a model which doesn't rely heavily on the vector database and at the same time is able to model the available information with reasonable prediction accuracy.

In this paper a MoM based full wave technique has been proposed to calculate radio wave transmission through buildings whose geometrical features have been modelled statistically; hence we call it semi-deterministic technique [2, 3]. Semi-deterministic technique provides a fast method for field strength prediction which is very flexible and does not rely heavily on the vector database used to describe the propagation scenario. In this model walls are replaced with a random distribution of conducting strips instead of plane surfaces for building faces and slit represents the doors, windows, gaps and other absorbing discontinuities on the building. A wall is generated with the assumption that strips and slits (gap) occur randomly and are modelled as a Poison process [4]. The methodology which is adopted for modelling transmission through buildings with large scale structural features resembles the methodology by Blaunstein [5]. In this paper, Channel Impulse Response (CIR) for transmission through buildings having large scale discontinuities; modelled semi-deterministically is calculated using MoM. Simulated CIR is validated with the actual field measurements and a good agreement is found.

The paper is organized as follows: In Section 2 we first give a detailed description of the method leading to the technique. Section 3 describes the simulation environment used in the calculation of CIR along with the comparison of semi-deterministic approach with the measured data. Finally conclusions are drawn in section 4.

2. Problem Formulation

A typical building in an urban microcellular environment consists of walls along with doors and windows as shown in Fig.1. (a). 2-D model of the building is represented in Fig.1 (b) in which walls are replaced with strips and gaps with slits. This building can be modelled as a random distribution of reflecting strips (walls) and slits (gap like doors and windows) as shown in Fig. 1(c). $T(x_t,y_t)$ and $R(x_r,y_r)$ represent the source and observation points respectively. $\mathbf{E}_{\mathbf{LOS}}$ is the line of sight component or through component. $\mathbf{E}_{\mathbf{ref}}$ is the reflected field component whereas $\mathbf{E}_{\mathbf{diff(i)}}$ and $\mathbf{E}_{\mathbf{diff(j)}}$ are diffracted field components due to i^{th} leading and j^{th} trailing edge respectively.

The random distribution of strips and slits is modelled as a telegraph signal function while the length of the strips (L_n) and slits (l_n) are stochastic parameters described by an exponential probability distribution function given by [4]

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$$\langle L \rangle^{-1} \exp\{-L/\langle L \rangle\} \qquad (1)$$

where, <*L*> is the average length.

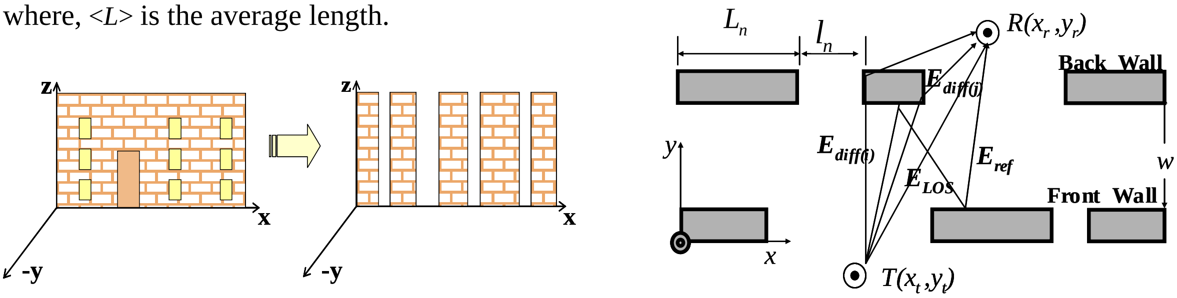


Fig. 1 (a) A Typical Building with doors and windows
(b) 2-D model of the building with walls replaced by strips and gaps by slits.
(c) Random Strip Grating Model of a building (Top View)

Initially the problem is addressed for a single strip and is then generalized for arbitrary number of strips. Furthermore in order to accurately model large number of edges present in the buildings numerical formulation is carried out. This method comprises of Maxwell equations and the boundary conditions and the resultant is an integral equation. This integral equation is then solved numerically using MoM. Two important integral equation formulations for time harmonic electromagnetics are Electric Field Integral equation (EFIE) and Magnetic Field Integral equation (MFIE). EFIE formulation which is the preferred choice for Perfectly Electric Conductor (PEC) is based on the boundary condition that tangential electric field on PEC surface of a scatterer is zero. This can be expressed as [6].

$$\mathbf{E}_t^t(r=r_s)=\mathbf{E}_t^i(r=r_s)+\mathbf{E}_t^s(r=r_s)=0 \qquad (2)$$

or

$$\mathbf{E}_t^i(r=r_s)=-\mathbf{E}_t^s(r=r_s) \text{ on } S \qquad (3)$$

where, $\mathbf{E}_t^t$ is the total field. $\mathbf{E}_t^i$ and $\mathbf{E}_t^s$ are the incident and scattered fields respectively. *S* represents the conducting surface of the scatterer and $r = r_s$ is the distance from the origin to any point on the surface of the scatterer. The subscript *t* indicates tangential components.

In this problem we have considered a line source with a current I_z (subscript *z* refers to z-direction).The field radiated by this line source is given by [6]

$$\mathbf{E}_z^i = -\frac{\beta^2 \mathbf{I}_z}{4\omega\varepsilon} H_0^{(2)}(\beta\rho) \qquad (4)$$

where, $H_o^{(2)}(\beta\rho)$ is the Hankel function of second kind and order zero. Part of the field given by (4) is directed towards the scatterer and it induces on it a linear current density $\mathbf{J_s}$ (amperes per meter) which in turn radiates a scattered field given by:

$$\mathbf{E}^s(r) = -j\frac{1}{\omega\mu\varepsilon}[\omega^2\nabla\mu\varepsilon + \nabla(\nabla.\mathbf{A})] \qquad (5)$$

where, **A** is the vector potential. Using the value of **A** and by restricting the observations points on the surface of the antenna or scatterer ($r = r_s$) we have using eqn. (3)

$$\mathbf{E}_t^i(r=r_s) = j\frac{\eta}{\beta}\begin{bmatrix} \beta^2 \iint\limits_S \mathbf{J_s}(r')\mathbf{G}(r_s,r')ds' + \\ \nabla \iint\limits_S \nabla'.\mathbf{J_s}(r')\mathbf{G}(r_s,r')ds' \end{bmatrix} \qquad (6)$$

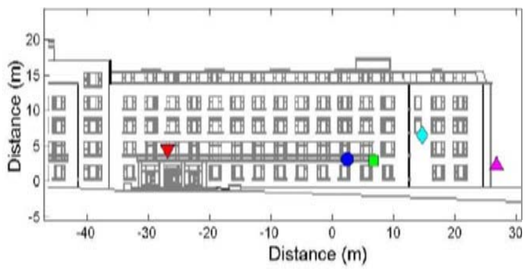
Eq. (6) is a general EFIE for a three dimensional problem and can be simplified for two dimensional geometries. Eq. (6) is used to find $J_s(r')$ at any point $r = r'$ on the surface of the scatterer using MoM in conjunction with Point Matching (collocation) method [6]. Concluding the above discussion total field at any point can be found as:

$$\mathbf{E}_t^t(\rho) = \mathbf{E}_t^i(\rho)+\mathbf{E}_t^s(\rho)$$
$$= -\frac{\beta^2}{4\omega\varepsilon}\left[H_0^2(\beta\rho)+\int_S \mathbf{J}_z(r')H_0^2(\beta R_N)ds'\right] \quad (7)$$

The above EFIE formulation is for an n^{th} single strip in which it is segmentized in such a way that each segment contains an observation point at its centre. The random strip grating model of a building consists of many such strips, so EIFE formulation is carried out for each such strip to obtain current density on the surface of all the strips and hence the net scattered field. A complete derivation for the total field can be found in [7].

3. Simulation Results

The simulation environment is the Arts building of University of Birmingham U.K. shown in Fig.2. It is a four storey red brick building of fairly conventional structure. The building had a fair



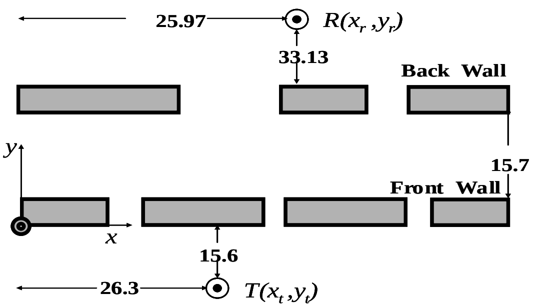
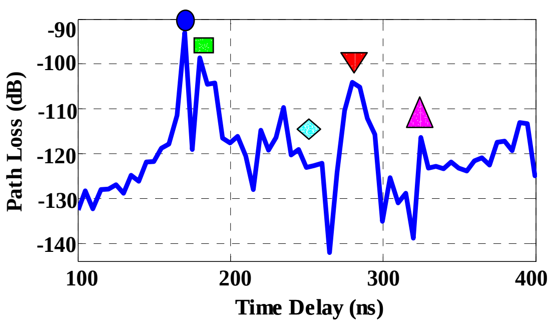


Figure 2 (a): Arts Building layout (b): Measurement layout (All dimensions in meters (m))

amount of large scale structure on its face such as window ledges and a two feet wide balcony on the first floor. A simplified plan view of the geometry along with the transmitter and receiver locations is shown in Fig. 2(b). The average length of the wall and the gap is taken as $\langle L\rangle=1.5$m and $\langle l\rangle=1.5$m respectively while the strip width is taken as 0.1m. Segment size is *10* points per wavelength. Length of the building is 40m while the width (w) is taken as 15.7m. For simplicity side walls have not been considered.

CIR calculated from channel transfer function using Inverse Fast Fourier Transform (IFFT) at a centre frequency of 2.5GHz with a bandwidth of 200MHz and a step size of 50KHz is shown in Fig 3(a) whereas the CIR obtained from on sight field measurements is shown in Fig 3(b) [8].



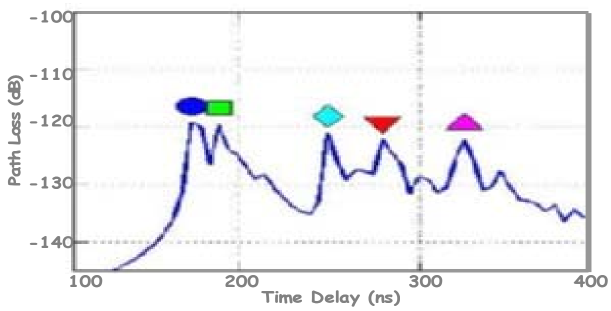


Figure 3 (a): CIR using Semi-deterministic Approach (b): From actual measurements [8]

It is seen that simulated results are in good agreement with the on sight measurement results except one component located at 249ns marked as light blue diamond. The peaks in the simulated CIR have approximately 20dB magnitude greater than the actual measurement. This is because in real scenario glass was the material used in windows which had approx. 8-10dB loss. As we are modelling transmission through buildings (two passes through the windows) so it equals 16-20dB which justifies our case.

4. Conclusion

It is concluded that semi-deterministic approach can be used to a high degree of accuracy for modeling transmission through buildings in urban microcellular environment. The advantage of this technique is that is doesn't require high-resolution building database and at the same time predicts field strength to a high degree of accuracy. A Monte Carlo simulation for the prediction of average field strength for an ensemble of large number of randomly generated walls is in progress which would give us a detailed insight into the usefulness of the technique. Furthermore development for the prediction of power delay profile, r.m.s delay spread is in progress which would further highlight our case. The MoM technique which has been used works well on a small scale (as in our case for modeling scattering from building faces) but is computationally expensive on a large scale for example in modeling streets of an urban environment. Henceforth an analytical solution must be found out for modeling dense urban environments.

Acknowledgments

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