CHAPTER 1

Introduction

Preface

This chapter starts with a small introduction on propagation channel modeling and presents a survey of the literature dealing with the modeling of urban scenario using deterministic approach. It also presents the objectives of the thesis and concludes with the organization of the thesis.

1.1 Introduction

Due to ever-demanding high-data rate by mobile customers in 3G/4G networks (e.g. in 4G, significantly higher bit rate than 2Mbps and 100Mbps as maximum), there is great interest in multiple-input multiple-output (MIMO) technology which enhances channel capacity by taking advantage of the multipath radio channel [1],[2]. This technology uses adaptive antenna whose performance strongly depends on the directional property of channel (such as delay spread, angular spread). This requires accurate modeling of the propagation channel [3].

The characterization of propagation channel requires either extensive measurement or propagation model. Extensive measurement is not always easy to do. It is more expensive also. Therefore, one requires good prediction tool to have a fair estimate of the channel. There are several kinds of propagation tool available, e.g., statistical, empirical, semi-empirical, theoretical and deterministic model [4]. Empirical or statistical propagation models give, either directly or by statistical means, certain characteristics observed from measurements of the mobile channel. Theoretical models are based on few ideal assumption about the propagation environment such as constant height of building or equal spacing between two buildings. On the contrary, deterministic model gives prediction of the channel characteristics based on simulation of the actual physical wave propagation process . Deterministic model makes use of detailed information about the topography and the buildings and hence gives more accurate predictions than statistical or empirical models [5],[6]. In addition to that, it gives clear insight into the physical phenomenon taking place in the channel.

Among different propagation models available, deterministic models are most preferable prediction tool as they can give accurate prediction in various kinds of scenarios without any need of measurement. Deterministic model based on the ray approximation of electromagnetic field is most suitable when the scattering body is electrically large. Thus, ray model finds ideal applications in the building scenarios where buildings are involved. The process of ray tracing can be broken down into two stages, 1) ray path identification and 2) electromagnetic modeling. Ray path identification is the process of finding possible ray paths between the transmitter (Tx) and receiver (Rx). Electromagnetic modeling then applies various approximated high frequency models, such as the Fresnel reflection model and the uniform theory of diffraction (UTD) for each propagation mechanism in order to calculate the field strength at the Rx. Although numerical full-wave solutions such as the method of moments (MoM), finite-difference time domain (FDTD), and some hybrid MoM/UTD models can account for complex electromagnetic propagations (including multiple diffraction), their scope is restricted to much smaller structures (in terms of wavelength).

1.2 Literature Survey

1.2.1 Review of some high frequency asymptotic techniques

When the scattering object is electrically very large (i.e. high frequency assumption), then, the high frequency asymptotic techniques can be used to answer some of the difficult problems that, otherwise, remain unanswered by Geometrical Optics (GO). The basic assumption in all these techniques is that at high frequency i.e. $k \rightarrow \infty$ (k is a wave number), diffraction phenomenon is a locally determined phenomenon. In other words, diffracted field at the point of diffraction can be determined based on the local property of incident wave such as incident angle and polarizations.

Some of the common high frequency asymptotic techniques are Geometrical Theory of Diffraction (GTD)[7],[8] and Physical Theory of Diffraction (PTD). Keller's GTD is basically the extension of geometrical optics. It answers some of the questions that remain unsolved simply by applying GO. For instance, what happens in the shadow of a wedge when its one face is illuminated by wave. Thus, GTD supplements some corrections in the GO theory by introducing diffraction phenomenon.

The physical theory of diffraction was introduced by Ufimtsev [9]-[11]. This theory supplements physical optics to provide corrections that are due to diffractions at the conducting surface edge. Ufimtsev suggested the existence of non-uniform edge currents in addition to the uniform physical optics surface current [12]-[14].

Uniform theory of diffraction [15] is an extension to GTD. The GTD has singularity at the incidence shadow boundary (ISB) and the reflection shadow boundary(RSB). That is, the value of diffracted field at RSB and ISB becomes infinite. Hence, GTD becomes invalid when observation point is near shadow boundaries. Uniform theory of diffraction overcomes this limitation by introducing another discontinuity term that compensates for the singularity. The main difference between GTD and UTD is that the GTD solution is

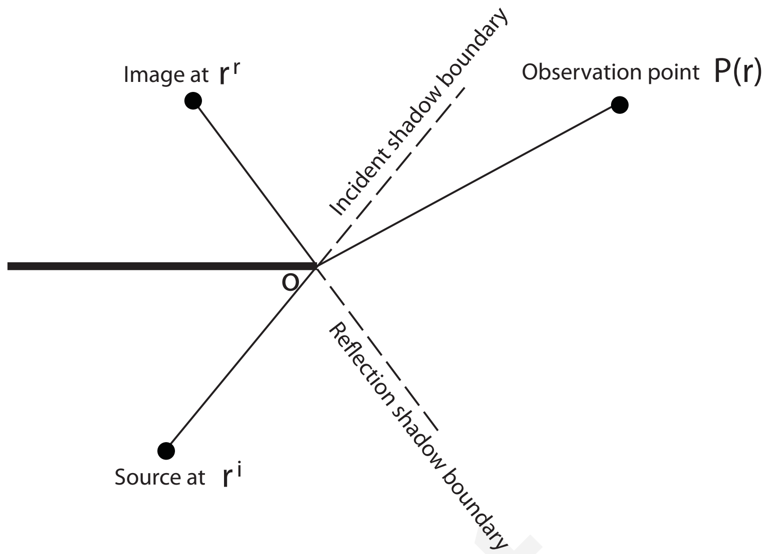

Figure 1.1: Diffraction from Half-plane illuminated by source [16]

obtained based on the conventional method of steepest descent [17],[18] which is applicable only when the observation point is away from the shadow boundaries.

Uniform theory of diffraction, on the other hand, is based on the Pauli-Clemmow method [17],[18]. The solution provided by the Pauli-Clemmow method has an additional discontinuity term (called transition function) that compensates for the singularity along the shadow boundaries. Away from the shadow boundaries, these transition functions are nearly unity and Pauli-Clemmow method reduces to the conventional method of steepest descent.

GTD and UAT

As per Keller's GTD , the total field at an observation point P is given as (See Fig. 1.1)[16]

$$u^t(r) = u^g(r) + u^d(r) + O(k^{-1}) \tag{1.1}$$

Here, $u^g(r)$ is the geometrical optics term that consists of incident field and reflected field. $u^d(r)$ is the diffraction term.

The uniform asymptotic theory of diffraction (UAT)[19]-[21] overcomes the limitation of GTD. It does it by modifying the GO term in (1.1). For same diffraction problem, as shown in Fig. 1.1, the total field u^t according to UAT is given as [16]

$$u^t(r) = u^G(r) + u^d(r) + O(k^{-1}) \tag{1.2}$$

The UAT expresses the GO field as a product of the original Keller's GO term and the term made up of the difference between a Fresnel integeral and modified Fresnel integral as shown below:

$$u^G(r) = [F(X^i) - \hat{F}(X^i)]u^i(r) + [F(X^r) - \hat{F}(X^r)]u^r(r) \tag{1.3}$$

Hence, when $|X^{i,r}| \rightarrow \infty$, then, $u^G \rightarrow u^g$, thus, UAT solution reduces to that of GTD. If $|X^{i,r}| \rightarrow 0$, GTD fails because $u^t(r)$ in 1.1 becomes infinite and discontinuous. On the contarry, UAT solution remains valid.

Limitation of UTD

In a multiple diffraction problem, it has been noted [22]-[26] that a satisfactory solution cannot be obtained by direct application of single diffraction. This is especially when the second edge lies in the transition region of the first edge [27]. For example, considering the PEC single building scenario, an application of UTD to the consecutive edges of the building results in zero field in the shadow of the building [28]. An heuristic approach was suggested by Luebbers [29] to add slope term to the total diffracted field in order to make the total field continuous in the shadow regions. It may be noted that the heuristic approach is not based in any formal sense on the Maxwell's equation. The slope term is obtained by differentiating first order diffraction coefficient. Total field at the observation point is the sum of the first order term and the slope diffraction term. In certain cases when the separation between two consecutive edges is very small, it has been noted that the UTD augmented by slope diffraction may not give the satisfactory result. An alternative solution is to use double diffraction [27], [30].

Rigorous Maliuzhinets diffraction coefficients

Diffraction of a plane wave by a wedge with surface impedance is a good canonical problem. The exact solution to this problem was given by Maliuzhinets [31]. A rigorous formulation in UTD-like form was presented by Tiberio *et al.* [32],[33]. This formulation can directly be used with ray tracing for the modeling of radio channel. The difficulty with this UTD-like formulation is that the Maliuzhinets function involved in this formulation does not have simple expression for arbitrary wedge angle. However, for the lossy wedge with wedge angle 90° and 270°, simple and explicit formulation exists. As a result, it finds suitable application in microcellular scenario [34],[35]. An approximate solution to the Maliuzhinets function for arbitrary wedge angle is proposed by various researcher [36],[37],[38]. In [36], a numerical computation formulation is presented for the Maliuzhinets function. In [37], the function is approximated as a cosine term. The approximate cosine function used with UTD-form has been validated with available measurement for arbitrary wedge angle [39].

UTD for lossy dielectric wedge

In order to make UTD applicable for lossy dielectric wedge, it was modified by Luebbers [40]. Luebbers used Fresnel reflection coefficient as multiplying factor. Thus, the solution obtained was heuristic and could predict scattered field around lossy dielectric wedge. Holm [41] further improved the diffraction coefficient by redefining the multiplying factor of the coefficient and also included additional terms to consider the case of grazing incidence. This resulted in a coefficient that was close to the accurate rigorous Maliuzhinets coefficient [32] in the deep shadow region. However, in the illumination region, it was not accurate. In addition to that, it did not satisfy reciprocity requirement. El-Sallabi *et al.* [42] modified the coefficient by defining the incident and reflected angle used in the calculation of Fresnel reflection coefficient. The coefficient was close to the rigorous solution, however, it was not reciprocal. Daniela *et al.* [43] modified the Holm's coefficient by incorporating the reflection angle as suggested by Aidi *et al.* [44]. The coefficient was reciprocal only when the transmitter and receiver were on opposite sides of the wedge. The coefficient was in good agreement with the Maliuzhinets' solution; however, it still lacked the accuracy in some particular regions e.g. in deep shadow region [[43], Fig. 5] and illumination region [[43], Fig. 2, Fig. 3]. Moreover, the coefficient was compared with Maliuzhinets' solution for right-angle wedge case only.

In the first part of the thesis, a new reciprocal heuristic diffraction coefficient for lossy dielectric wedge is presented which is applicable for arbitrary positions of transmitter and receiver in a complex channel environment. The prediction obtained using proposed coefficient is compared with those obtained using rigorous Maliuzhinets' solution. It is shown that the proposed coefficient is perfectly reciprocal and is more accurate than that of Daniela and Holm in both the illuminated and deep shadow regions.

1.2.2 Review of three dimensional dyadic diffraction coefficient

Two-dimensional diffraction coefficients are for the fields polarized either parallel or perpendicular to the diffracting edge, whereas in three dimensional cases, the field may be obliquely incident and the field can be polarized in any direction relative to the edge. This necessitates the use of dyadic diffraction coefficient [45],[46]. In [47],[48], the three dimensional dyadic coefficient for dielectric slab is presented which also includes transmission through the wedge. In this development, edge-fixed coordinate system is used and the incident field is expressed in the components parallel and perpendicular to the edge-fixed plane of incidence (the plane containing the incident ray and the edge of the wedge). The approach used here is that a reflection point is considered infinitesimally close to the edge of the wedge so that reflected ray lies on a diffraction cone on the lit side of RSB.

In this work, a novel three dimensional dyadic diffraction coefficient is presented. The proposed coefficient shows significant improvement when compared with published measurement. The result showed that dyadic diffraction coefficient with modified reflection coefficient gives significant improvement than dyadic coefficient with Fresnel reflection coefficient. Further, to validate the proposed dyadic coefficient, three-dimensional rooftop scenario was chosen and measurements of the electric field in the vicinity of edge of the building were carried out. Measurement results thus obtained were compared with predictions using proposed dyadic coefficient.

1.2.3 Review of ray tracing techniques

Review of basic ray-tracing method

As per GO theory, there are basically three kinds of the rays that are used in the ray technique; reflected ray, refracted ray and line-of-sight (LOS) rays. As per GO theory, since there is no field in the shadow of the building and hence there is sharp discontinuity at the boundaries of lit region. The Keller's GTD and its extension UTD predicts the field in the shadow and explains the presence of diffracted rays in the shadow of the building. When the Rx is in the shadow region, the contribution of diffracted ray becomes significant. In the ray techniques, there are two methods: (i) Ray Launching (ii) Ray Tracing.

Shooting and Bouncing ray tracing method

In Shooting and Bouncing (SBR) ray launching algorithm [49], ray is launched from the Tx in all the directions. In this scheme, number of rays considered depends on the spatial resolution. A finite samples of the possible directions of the source is chosen and ray is traced in the direction of the sample chosen. Each ray is traced whether it is hitting an object or not. If there are numbers of buildings to be hit, then, we have to find actually which building was hit by the ray. When the scattering object to be hit is wedge corner, then, incident ray at the edge generates a large number of diffracted rays. The diffraction point is considered as new source with ray being launched in the exterior angle of the wedge. As a result, ray launching is very time consuming because ray launching algorithm has to start afresh from each of the diffraction point considering it as a new source. Therefore, number of the diffraction to be considered in ray launching is limited to 2 or at the most 3. In ray launching there are certain issues to be addressed. First is how to know if a ray has hit the obstacle. Second how to determine if the ray has been received by the receiver.

There are two basic principles on which ray tracing methods work. First, it is based on Fermat Principle. As per this principle, the ray obtains its shortest path from the transmitter to the receiver. Second principle i.e. principle of local field states that a high frequency ray generates reflection, refraction and diffraction when it hits the surface. The scattering depends on the local property of scatterer in the immediate neighborhood of the point of intersection [50].

Reception test

The reception of the ray is done by reception sphere. The reception sphere is constructed about the receiving point. The radius of the sphere is chosen such that the ray at the receiver is just received once by the sphere. If the radius is chosen larger, then, the adjacent ray will also be received and would count the same ray twice. If the sphere is small, it is likely to miss the ray. Therefore, the optimum selection of radius of reception sphere is crucial. In [51], it is shown that if the radius of sphere is chosen to be $\frac{\alpha d}{\sqrt{3}}$ (where d is the unfolded distance between Tx and Rx and α is the angle between two adjacent rays as shown in Figure 1.2, then, the ray at receiving point will be received just once. The limitation of shooting and bouncing technique is that it is much more time consuming especially when the scenario is quite complex. Second limitation is that the accuracy of the prediction depends upon the angle of resolution. For instance, if angle of resolution is 2 degree, then, there can be total of 180 rays to be traced. Thus, for higher accuracy, the angle of resolution should be minimized but this will increase the computation time.

Image method

The second method to trace the path is based on computation of an image of the source [52]. This method is faster as compared to SBR method. If there are N reflecting sources, then, there will be N first order image sources, N(N-1) will be second order image

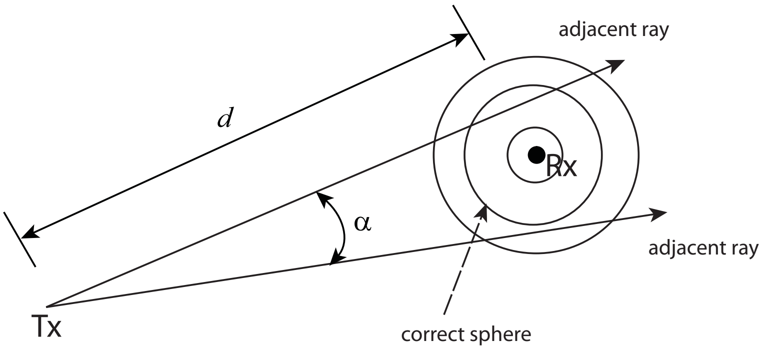

Figure 1.2: Reception test

sources and so on [53]. Another image based method to trace the path using visibility tree is proposed in [54]. The approach is based on ray tube method. In this, ray tubes are constructed around Tx, reflecting and diffracting points. The visibility tree is constructed based on the given structure of the building scenarios.

Hybrid method

In order to improve the speed and the accuracy of the ray tracing model, some hybrid methods are also suggested in the literature [55],[56], [57] . In [55], the model proposed uses both the SBR technique and image based technique. SBR technique is used to quickly identify the ray path. The exact locations of reflection point and diffraction point are calculated using image based technique. The scheme uses the accuracy of image method and efficiency of SBR technique. In [56], two-dimensional ray tracing was applied in horizontal plane and vertical plane both and the results of these two cases were combined to produce the 3D rays . In [57], some hybrid combination of ray tracing and FDTD for more accurate modeling of the propagation environment has been reported. In this approach, the ray tracing is used to obtain prediction in the large scenario and wherever the receiving points are close to the structure, the accuracy of FDTD model is exploited.

Review of speed up techniques of ray model

For the simple scenario, the ray tracing tool may take several hours to produce the prediction result [58]. Therefore, the key to ray tracing is to obtain computationally fast ways to determine significant rays to provide accurate prediction of the path loss. In literature, various approaches have been suggested to accelerate the speed of the ray tracing tool which are as follows:

Two-dimensional ray tracing algorithm

When the heights of the building is much larger than the height of the transmitter and the receiver, the ray tracing tool can be simplified to trace the ray paths in horizontal plane only and hence input database of the buildings does not require height information of the buildings. In such scenarios, the prediction results of two-dimensional ray tracing are shown to be adequate [52],[58], [59]. In this case, the rooftop diffracted rays are very weak and hence they can be ignored. Two-dimensional ray tracing also ignores the ground reflected rays. The relaxation of tracing the ray path in only horizontal plane enhances the speed of ray tracing tool significantly.

Quasi-three dimensional ray tracing

In two-dimensional ray tracing, the basic assumption is that the height of the transmitter and receiver is much smaller than the buildings height. Thus, rays need to be traced only in the horizontal plane. However, there are certain scenarios where three-dimensional model is required even if the transmitter height is much smaller than that of the buildings. It is due to the reason that there may be significant number of the buildings whose heights are lower than the average height. Hence, rooftop ray can not be neglected. Using quasi-three dimensional ray tracing (also called 2.5 D ray tracing), it is possible to obtain accuracy of the prediction comparable to 3D ray tracing model ,yet, using only 2D ray tracing, thus, input database requires only footprint of the buildings. In this approach, the suitable 2D ray path, obtained using 2D ray model, is converted into 3D ray path using an analytical formulation. This formulation requires the height of Tx and the Rx [60],[61].

Vertical plane method

The vertical-plane-launch (VPL) technique is based on the assumption that building walls are always vertical planar polygon [62]. The VPL approach accounts for specular reflections from vertical surfaces and for diffraction at the vertical edges and approximate diffraction along horizontal edges by restricting the diffracted rays to lie in the plane of incidence or in the plane of reflection. The VPL method is shown to give very good results when the Tx height is comparable to that of average height of buildings [63].In [64], an heuristic approach to VPL method was proposed. This approach finds ray paths for arbitrary height rooftop diffraction and for rooftop to building edge.

In the literature, various other approaches have been suggested to further enhance the speed of the ray tracing tool. For instance, in [61], it is shown that some ray paths are common between Tx and Rx. Thus, they can be computed by determining the ray path only once. This is done by decomposing the ray paths in four categories Tx-Rx, Tx-D, D-D, D-Rx where D stands for diffraction. The ray trajectory between Tx and Rx are established by appropriately concatenating the elements of the above categories. In [65], simplification of input database is proposed. In this approach, the two nearby buildings with same heights are joined. Second approach is to reduce input database by selecting "active set" of buildings and discarding rest of the buildings. Since on each diffraction the ray tends to spread in the forward direction, therefore, it is very time consuming to search the diffracted ray paths. In [66], Giorgio carluccio *et al.* uses modified Newton search algorithm for tracing the multiple diffracted paths assuming a series of arbitrarily placed wedges that are completely visible to each other. In [67], an approach to divide the outdoor space in rectangular grid is proposed. Here, it is assumed that the reflection and transmission surfaces are exactly coinciding the grid line. In [60] , the approach is based on the triangular division of outer space.

One of the main challenges faced in implementing the ray tracing tool is the sharp rise in the computational complexity with the increase in the order of scattering [58], [66]. This thesis proposes computationally efficient two-dimensional ray tracing algorithm which is based on processing of the geometrical database for speeding up the computation. This is done by splitting the visibility-tree of the entire building scenario into a number of sub-trees to attain speeding up of computation.

1.2.4 Review of transmission through building

In some cases, the physical phenomenon like reflection and diffraction alone are not adequate to accurately predict the total field in the shadow of a building. A number of studies on propagation loss in the buildings are available in literature [68], [69]. In [68], an empirical formulation was presented based on the measurement considering ten medium sized buildings. The results showed that penetration loss decreases with increase in the frequency. In [71], an empirical formulation was presented for the propagation loss through buildings. Y. L. C. de Jong *et al.* [72] showed that there is a significant field leaking through the buildings at UHF frequency. Further, in the literature, a number of work has been done to model the transmission through buildings using numerical techniques [73], [74]. In [73], method of moment (MoM) is used to model building penetration through building. In [74], finite difference time domain (FDTD) is considered to model transmission through building. In [75], [76], transmission through building wall has been investigated using ray tracing approach. In [58], a quasi 2-D model is presented for the propagation of radio waves through a building. In this, an empirical effective propagation coefficient was proposed to take into account the scattering inside the building in the transmission model. In this thesis, the urban scenario of Bern [58] is reconsidered with a more analytical formulation and the path-loss prediction using proposed model is compared with available measurement data.

1.3 Objectives

The objective of this thesis is to develop a deterministic propagation model for the characterization of the microcellular environment. The work in the thesis includes:

1. Development of a new reciprocal heuristic diffraction coefficient.
2. To carry out measurements in the vicinity of the building to validate proposed heuristic diffraction coefficient.
3. Development of a novel three-dimensional dyadic diffraction coefficient to take into account arbitrary incident angles and polarizations.
4. To carry out measurements in the three-dimensional rooftop scenario of the building to validate proposed dyadic diffraction coefficient.
5. Development of fast two-dimensional ray-tracing algorithm for the modeling a microcellular environment.
6. Development of ray based model for the case of transmission through the building.

1.4 Thesis Organisation

The thesis comprises of seven chapters. Chapter 1 titled '**Introduction**' presents the introduction and an extensive survey of the literature. It also contains the objective of the work to be presented in the thesis.

Chapter 2 titled '**GTD and UTD Formulation Used in the Modeling of Propagation Channel**' gives the mathematical derivation of the theory of diffraction used in the propagation modeling.

In Chapter 3 titled '**New Heuristic Diffraction Coefficient for Modeling of Wireless Channel**', a novel heuristic diffraction coefficient for lossy dielectric wedge is presented. Both the soft and hard polarizations are considered. The proposed coefficient is validated with rigorous Maliuzhinets solution for both the right angle and non-right angle wedge. The proposed heuristic coefficient is further validated with measurement carried out in the vicinity of the building and available measurement.

In Chapter 4 titled '**Novel Three Dimensional Dyadic Diffraction Coefficient for Wireless Channel**', a modified dyadic diffraction coefficient is presented to deal with the field that may be obliquely incident and polarized in any direction relative to the edge. The proposed dyadic coefficient is validated with available measurement. Further, measurement is carried out in the rooftop scenario and the proposed coefficient is validated with the measurement.

Chapter 5 titled '**Fast Two-Dimensional Ray-Tracing Algorithm for the Characterization of Urban Microcellular Environments**' proposes a fast two-dimensional ray-tracing algorithm to characterize urban environments. The computational efficiency of the proposed algorithm is compared with that of the available two-dimensional ray tracing tool. Further, the accuracy of the proposed algorithm is validated with available measurements in three different urban scenarios.

Chapter 6 titled '**Analytical Characterization of Transmission through a Building for Deterministic Microcellular Propagation Modeling**' deals with analytical modeling for the transmission through a building. In this model, the effects of trees and rooftop diffracted fields are also included. The prediction, thus obtained, is compared with the available measurement.

The thesis ends with Chapter 7 titled '**Conclusions and Scope for Future Work**' which talks about the conclusion and future scope of work. Chapters 3 to 6 constitute the main body of the dissertation work.