# ANALYSIS AND SIMULATION OF THE DIFFUSE SCATTERING PHENOMENON IN URBAN ENVIRONMENT

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**ABSTRACT**

*Sophisticated measurement data, including path-loss, delay spread and direction-of -arrival, are analyzed and compared with simulations performed with an advanced 3D ray tracing model which takes diffuse scattering into account. The results show that diffuse scattering plays a key role in urban propagation, with a particular impact on the time delay- and on the angular- spread of the signal at the receiver.*

## I - INTRODUCTION

Since the great majority of mobile radio communications take place nowadays in urban environment, the study of urban radio propagation is of crucial importance for both the design and the deployment of present and future mobile radio systems.

Urban propagation is a complex phenomenon which involves several mechanisms of interaction between the radio wave and the environment. According to the Geometrical Optics (GO) approach, two basic mechanisms are usually identified and separately modeled: diffraction due to building and rooftop edges and reflection due to the ground and building walls.

However, the GO approach is based on the hypothesis that building walls and edges are homogeneous and smooth. This hypothesis is evidently not valid in real urban environment. Deviations in building walls from smooth homogeneous layers, the presence of "small" objects such as windows, balconies, irregular bricks, internal beams etc. contribute to the scattering of the impinging radio power in unpredictable ways, also because the cited "irregularities" are generally unknown [1]. Diffuse scattering of the radio wave is especially relevant in the case of far buildings, which are very unlikely to produce significant reflection/diffraction effects due to the very narrow spread of the reflection cone. Unfortunately, far buildings are of major importance in the determination of channel dispersion and thus the wideband behavior of the urban mobile radio channel cannot be understood without taking diffuse scattering into account.

In the present work diffuse scattering in urban environment is investigated through both the analysis of experimental results and the comparison between measurements and computer simulations.

As diffuse scattering is a "non-deterministic" phenomenon, a statistically significant amount of experimental data is required to investigate its existence and relevance. Furthermore, information on the angular distributions of the signals is useful in separating signals propagated via scattering from those undergoing "deterministic" GO propagation phenomena like reflections and diffractions. The experimental part of this paper is based on large amount of measured 3D angular signal distributions giving thus a unique insight into the significance of scattering as a propagation phenomenon. The measurement setup is described in section II.

Computer simulations have been performed with an advanced three-dimensional Ray Tracing (RT) program. Diffuse scattering has been modeled according to the *effective roughness approach* described in [2][3]. The 3D RT algorithm is illustrated in section III.

Results (see section IV) show that by introducing scattering in the RT model a good agreement between simulation and measurement can be obtained, especially if power-delay profiled or power-DOA profiles are considered. Moreover, RT with scattering converges more rapidly than traditional RT even with a low order of events (successive reflections / diffractions / scatterings), thus sensibly reducing CPU time.

## II - MEASUREMENT SETUP AND DATA PROCESSING

We measured the angular power distribution separately for $\theta$- and $\phi$-polarized components of the incident field at the mobile station in small macrocelluar propagation environment using the measurement method presented in

[5][6]. The method is based on a spherical array of 32 dual-polarized antenna elements, and a complex wideband radio channel sounder. In the transmitter of the sounder, a cyclic pseudo-noise sequence (m-sequence) modulates the carrier at 2.154 GHz. The chip frequency of the m-sequence was 30 MHz in all measurements leading to a delay resolution of about 33 ns. In the receiver, the demodulated signal is divided into I- and Q-branches. The signal samples from each branch of the RF switch are then stored for off-line processing to compute the temporal and spatial information.

At the base station (BS), the signal was transmitted using a single fixed vertically polarized antenna in locations corresponding to typical BS antenna installations small macrocellular radio network configurations. At the mobile station (MS), the signal was received separately from the θ- and ϕ-polarized feeds of each of the 32 elements of the spherical array using a fast 64-channel RF switch. Compared to the synthetic aperture technique also applied for 3D radio channel measurements at the mobile station [7], the measurement is very fast and enables the acquisition of large amounts of data along continuous measurement routes. The spherical array was placed on a trolley and approximately five snapshots of the received signal were sampled and stored per each wavelength the mobile moved.

The measurement results utilized in this work have been measured in the center of Helsinki in small macrocellular scenarios. The BS was located at the rooftop of a parking house pointing to the east (see Fig. 1) at a height about 3 m above the rooftop. The transmitter antenna used at the base station was a modified GSM1800 base station antenna. The 6-dB beamwidth of the transmitter antenna is 120° in horizontal and 40° in vertical plane.

The delays, directions-of-arrival (DOAs), amplitudes, and phases of both θ- and ϕ-polarized components of the incoming waves at each measurement snapshot were found through sequential delay-domain and angular-domain processing. First the delay taps were then identified by detecting the local maxima of the impulse response averaged over the array elements. Corresponding to each delay tap, there may exist one multipath component or several components separated by their DOAs. Up to four multipath components per delay tap were estimated using the beamforming scheme with pre-computed array weights (2° beam spacing in azimuth and elevation), as described in [5]. At most four beams with powers exceeding -6 dB from the highest beam were accepted. The amplitudes and phases of the θ- and ϕ-polarized components of the incident waves were obtained by pointing θ- and ϕ-polarized beams in these directions.

## III - THE RAY TRACING MODEL

The adopted propagation prediction tool is based on an Image Ray Tracing technique [9] A full 3D approach is adopted in order to obtain a reliable description of diffuse scattering from far buildings, which could not be achieved with a 2D or 2D and-a-half approach. The implemented Ray Tracing Algorithm consists of two main steps: the creation of the *visibility tree* and the *backtracking procedure*.

### The Visibility Algorithm

The leading task of the visibility algorithm is the creation of the visibility tree, which consists of nodes and branches and has a layered structure. Each node of the tree structure represents an *object* of the scenario, that is a building wall (or part of it), a wedge or a receiving point, whereas each branch represents a visibility relation between two nodes. It's worth noting that the visibility relation among different nodes is strongly influenced by the considered interaction (i.e. reflection, diffraction, transmission and diffuse scattering). Starting from the root of the tree, which contains the transmitter (Tx), the visibility tree is recursively built: the nodes of the first layer contain all the objects that can be seen directly from the transmitter (Tx). Similarly, the nodes of the second layer contain the objects that can be "seen" from at least one node of the first layer, i.e. the objects that can be reached through a radio wave departing from the Tx and undergoing a given interaction with a first layer object. This procedure is repeated until the maximum allowed order of successive interactions is reached. When a receiver (Rx) is found a leaf of the tree is created. Since we are interested in investigating diffuse scattering, a full 3D approach must be followed, which makes the determination of the visibility relations extremely onerous. Therefore, an efficient algorithm is needed. In order to reduce CPU time, the 3D problem is split in two 2D problems, which can be solved more easily. Each node of the visibility tree is associated a virtual Tx [9]. Whenever a node is processed by the visibility algorithm, it results extremely helpful to consider the spherical reference system $(\rho,\theta,\phi)$ centred in the virtual Tx. In the first step, plane walls and edges are first represented as polar segments and then sorted in a non-ambiguous ρ-list according to a sweep line algorithm [10]. In the following step all the elements in the ρ-sorted list are virtually drawn in the $(\theta,\phi)$ plane as polygons according to the paraxiality hypothesis [10]. Using the information in the ρ-sorted list, visible objects are then simply determined with consecutive subtractions in terms of the geometrical area of the polygons. Whenever a visible object is identified, a node in the visibility tree is filled and the visibility algorithm will process recursively each new node.

**The Backtracking Procedure**

Once built the visibility tree, a backtracking procedure traces the optical rays that link the transmitting and the receiving antennas. Starting from each leaf of the tree containing a receiver position, the visibility tree is climbed up toward the root, so that ray paths can be traced. It has to be reminded that each branch of the tree is associated a propagation mechanism, so that the necessary information to compute the amplitude of rays is available [9].

## IV – RESULTS AND CONCLUSIONS

An urban small-cell scenario in the city of Helsinki has been investigated (see map in Fig.1). Because of the link configuration and of the over the roof-top location of the Tx antenna, many buildings are directly visible from both Tx and Rx and are expected to generate important scattering contributions. RT simulations have been performed with 2 successive interactions, including reflection, over-roof-top diffraction and scattering. An increase in the number of interactions did not yield any sensible improvement of the results.
Comparing measurements and simulations in terms of Path Gain (Fig.2) it emerges that the measured path gain slope around the quasi-LOS region (the LOS between Tx and Rx is slightly obstructed by a road bump: a diffraction loss occur) is not well reproduced by the simulation. It can be shown that diffraction over vertical edges cannot justify the measured path gain values beyond the LOS, which are probably due to different phenomena, not considered by the RT-tool, e.g. transmission through walls, local scattering from cars, trees etc.
Although the Path Gain agreement is fairly good, investigations in terms of Delay Spread (DS) and Azimuth Direction Spread (ADS) [11] are needed to highlight the role of diffuse scattering. From fig.3 it can be noticed that the measured DS is quite well reproduced by the model because of diffuse scattering from far objects. In fact, there are many buildings on the opposite side of the water basin with respect to the Rx positions, which contribute with long–delayed echoes to the signal at the Rx (see Fig.1). Such echoes widen the time impulse response and increase the DS, which would result much lower with reflections and diffractions alone.
The ADS comparison represents again a good result. The high values of the measured and predicted ADS, which are close to the maximum value obtainable with the adopted formulation [11], indicate that the signal at the Rx is made up of many components, spread over almost the whole azimuth plane. This behavior is easily explained observing the positions of the scatterers in fig.1.
In short, results show that by introducing scattering in the model a good agreement in DS and ADS comparison can be obtained. The Path Gain comparison is also fairly good, but a further improvement of the results would probably require the knowledge of the local scatterers located in the vicinity of the street crossing.

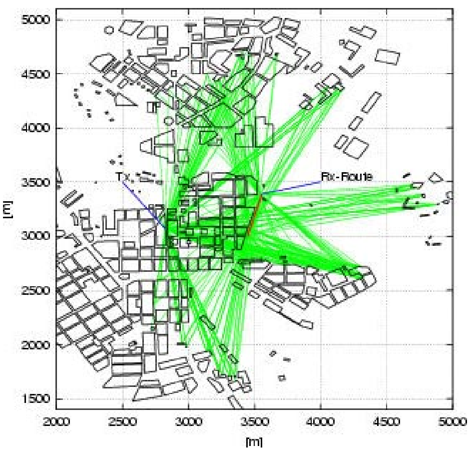

Fig.1: The urban scenario with a few scattered rays

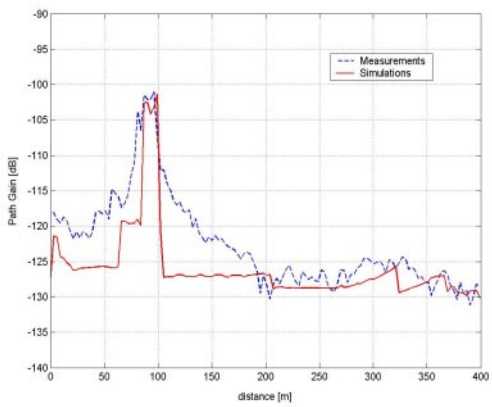

Fig. 2: Path Gain Comparison

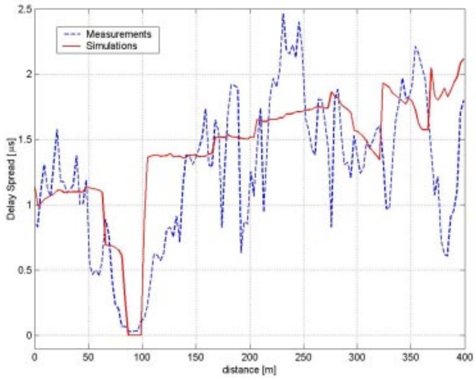


Fig. 3: Delay Spread Comparison

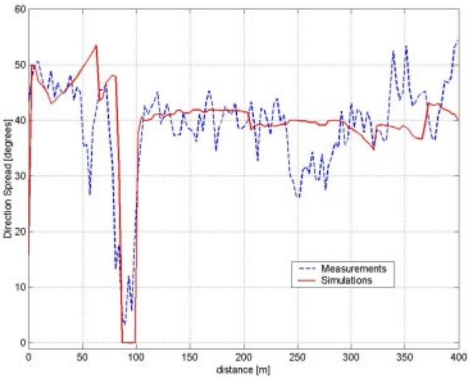


Fig. 4: Azimuth Direction Spread Comparison

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