EFFICIENT IMPLEMENTATION OF A GEOMETRY-BASED DIRECTIONAL MODEL FOR MOBILE RADIO CHANNELS

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Abstract - For the design and simulation of adaptive antenna systems, realistic and efficient spatial channel models are required. We investigate the so-called "Geometry-based Stochastic Channel Model" (GSCM), where the probability density function (PDF) of the location of the scatterers is prescribed. We analyse methods to efficiently implement GSCM, namely by nonuniform weighting of the scattering cross sections, and by combination with purely stochastic approaches. We then present various extensions of the model in urban environments, especially for wave guiding by street canyons.

I. INTRODUCTION

In the last years, adaptive antennas have emerged as a leading candidate for increasing the capacity of mobile radio networks [1]. The basic idea is to adjust the antenna pattern at the base station in such a way that the energy is focused towards the desired user, while as little energy as possible is transmitted to other users. In T/FDMA systems, this allows to either reduce the co-channel interference by spatial filtering (SFIR), which in turn enables a reduction of the reuse distance, or to serve several users within the same traffic channel (time/frequency slot) in the same cell (SDMA). In CDMA systems, adaptive antennas allow to place more users in the same cell. For the design and simulation of any of these systems, we need channel models that allow to predict performance in a wide range of realistic environments, but do not depend too much on specific locations.

Channel models for these applications have to include the directional information. However, most existing channel models, like the famous COST 207 wideband models, give only the power delay profile (PDP) and the Doppler spectrum (note that the Doppler spectrum is **not** uniquely associated with a directional distribution of arriving waves). The purpose of this paper is to present a channel model that fulfils the requirements for adaptive antenna simulations. We call it the "Geometry-based Stochastic Channel Model (GSCM)". Section 2 discusses the basic requirements for a spatial channel model. In Sec. 3, we analyse different ways of implementing the GSCM, and discuss the efficiency of the various approaches. Section 4 presents extensions of the channel model for urban environments. A summary concludes this paper.

II. REQUIREMENTS

The most important requirements for channel models are: (i) Correct reproduction of measured joint angular delay power spectrum (ADPS) (ii) Compatibility with previously used stochastic wideband channel models [2,3], in order to facilitate comparisons with previous simulation results. (iii) The model should clearly reflect essential physical propagation mechanisms. This makes the model easy to understand and enables realistic parameter selection by means of straightforward geometrical and environmental considerations.

A further, practically important requirement is (iv) *simplicity*, which should allow extensive simulations in short time. Unfortunately, this is usually in contradiction to requirement (i), i.e. faithful reproduction of measured results. Furthermore, for different applications, the balance between the two requirements may have to shift. This leads to a new model requirement, namely (v) *adaptivity*, i.e. the model should allow the user to define a set of functionalities included in the current simulation. This flexibility is especially important because future systems can have different requirements for the channel models.

There are two basic philosophies for channel models:

- *Deterministic models*: In such models, the environment (position of the base station, mobile

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station, location of scatterers,[1] reflection coefficients, etc.) is prescribed. Then Maxwell's equations, or some approximation to it, are solved. Alternatively, the angular impulse response can be measured and stored for repeated use.

- *Stochastic models*: Here the average ADPS and its statistical distributions is specified by the model. For the simulation, instantaneous ADPSs are then selected, where the probability of a specific realization is determined by the statistical distributions.

While both approaches have been successfully used in the past for wideband simulations, they have drawbacks when we try to include the angular domain. The deterministic approach relies too much on the specific simulation environment. In order to get a good overview over different channel situations, enormous databases would have to be established. The purely stochastic approach, on the other hand, requires a large number of statistical distributions, which are usually correlated with each other (e.g. the temporal evolutions of the times of arrival and the directions of arrival are correlated). This makes long-term simulations especially difficult.

A very promising model that circumvents those difficulties is the "Geometry-based Stochastic Channel Model (GSCM)" [4]. In this approach, the *statistical distribution* of the scatterers (and not their exact location, as in a deterministic approach) is prescribed by the model. For the actual simulation a specific realization of scatterers is selected at random from this distribution, and the angularly resolved impulse response is computed by a simple ray tracing algorithm. Of course, the scatterer distributions have to be chosen in such a way that the resulting power delay profiles (PDPs), angular power spectra (APSs), etc. agree reasonably well with typical measured values.

III. IMPLEMENTATION ISSUES

III.1 Standard implementation

The basic form of the GSCM is also known as "local scatterer model" ([5, 6, 7], see also [8, 9]) where all relevant scatterers are positioned around the mobile station (MS). The probability density function (PDF) is often assumed to be uniform in a disk around the MS. Alternatively, Gaussian and Rayleigh PDFs have been suggested [10]. As an extension, we suggested the inclusion of so-called "far scatterers" [4], which represent e.g. high-rise buildings, mountains, etc.; they are far away from both the MS and the base station BS (Fig. 1). While the local scatterers are always centred around the MS, the position of the far scatterers are fixed at an absolute position in space, which corresponds to physical reality. Finally, there can also be scatterers in the vicinity of the BS; these are mainly relevant for micro- and picocells, i.e. if the BS antenna is below the rooftops. Reference [4] proposed various configurations (number and distribution of local and far scatterers, Rice factor, etc.) for macro-, micro- and picocells that were either extracted from measurements or derived from physical plausibility considerations. Channel characteristics simulated by GSCM agree well with recent angular-resolved measurements [11].

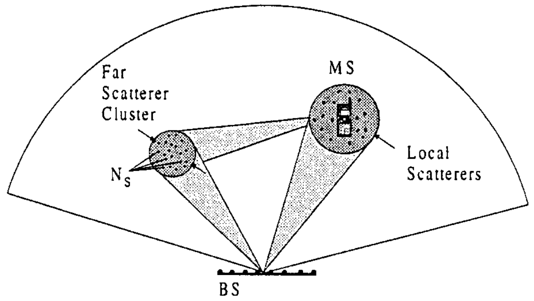

Fig. 1 Principle of GSCM

III.2 NSCS Implementation

In this paper, we also propose an alternative implementation, which we call NSCS (nonuniform scattering cross section). The PDF of the scatterers is uniform throughout the whole relevant cell area, but the cross sections of the scatterers are different (weighted), and may also change with time. This facilitates the simulation of the temporal evolution of the channel. The location of the scatterers is determined at the beginning of a simulation, and then remains constant, even when we move the MS.[2] The physical propagation mechanism is included in the model by weighting the scatterer cross section (Fig. 2). The correlations between the movement of the MS, the attenuation of each arriving ray, and the changes of the DOAs at the MS are correctly included in the model.

Another important point of the NSCS implementation is that the physical location of the scatterers is identical for different MSs, while their relative importance is different. Also this corresponds to the physical reality: a house or a car acts as a scatterer for a MS that is very close to it, as well as for another MS that is far away, only the attenuation is different. The correlation

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[1] Note that we are using the expression "scattering" irrespective of the fact whether "diffuse scattering" or "specular reflection" occurs.

[2] This description is valid if the MS moves, while the physical location of the scatterers (e.g. houses) stay constant. A straightforward extension of the model allows inclusion of the movement of physical scatterers (cars, people).

between the rays of different users, scattered, e.g., by a moving car, is modeled correctly by the NSCS model.

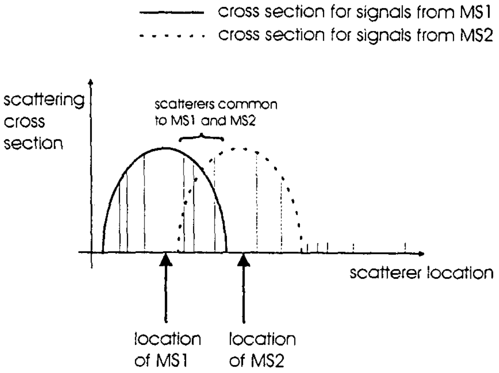

Fig. 2 Principle of the NSCS implementation of the GSCM. Signal from nearby MSs are reflected by the same scatterers, but with different cross sections

Figure 3 gives the mean absolute error as a function of the number of scatterers for a Gaussian distribution of scatterers. We computed the transfer function in an exact way by means of the transformation equations of Ref. [15], and compared it to the transfer function obtained from GSCM simulations. Errors for standard and NSCS implementation were almost identical.

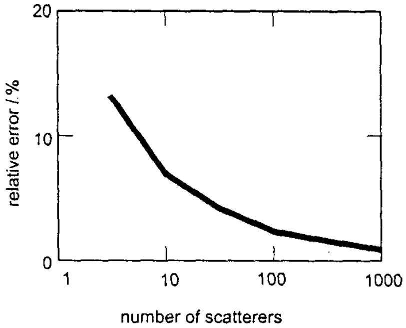

Fig. 3 Error in the transfer function as a function of the number of scatterers. A Gaussian distribution of scatterers is assumed.

III.3 Combination with purely stochastic models

In a purely stochastic model (e.g. SRCM [12]), the average ADPS is prescribed, and the instantaneous realizations of the ADPS are selected at random from this distribution. For short-term variations this model allows a very efficient implementation. For long-term simulations, however, the correlation of the quantities of interest (delays, DOAs, etc) lead to a drastic complication of the simulation. It has to be included by using (multi-dimensional) joint probability density functions, which leads to serious mathematical difficulties; while GSCM gives those correlations implicitly (see above).

As an extension, we propose to combine the advantages of the purely stochastic model with those of GSCM. First, we compute the location of the scatterers in the GSCM model (either according to the standard implementation or NSCS). Then, we semi-analytically compute the *average* ADPS ("averaged" means "small-scale averaged" when the MS moves over a small area, i.e. averaging over the Rayleigh fading). Note that we do not need to compute instantaneous realizations in order to obtain the average ADPS. As long as the MS moves less than about 10 wavelength, the average ADPS stays constant, and we can compute the instantaneous realizations of the ADPS by using the stochastic model. When the MS has moved a larger distance, we compute a new average ADPS from the GSCM, and so on. This allows on one hand to keep the high computing efficiency of the stochastic model, while at the same time getting the correct correlation of the parameters from the GSCM.

III.4 Single and multiple scattering

One important question for GSCM is whether multiple scattering plays a role, or whether consideration of single scattering is sufficient from a physical point of view. An analysis of the importance of multiple scatterings from measurements is possible if the ADPS at both the transmitter and the receiver is available [13]. First results indicate that the single-scattering assumption is often correct in macrocells, but breaks down in micro- and picocells. Waves guided in a street canyon, for example, suffer multiple reflections, as waves in indoor environments, where multiple reflections from walls, floors, and ceilings are common. However, a correct implementation of the multiple scattering leads to a significant increase in computational complexity, and is thus not advisable.

The question of single-scattering can also be considered from a slightly different point of view. Under the assumption of single-scattering, the ADPS and the scatterer location are related by a bijective mathematical transformation. Thus, for a given ADPS (e.g. from a measurement), we can assign a scatterer distribution that is not necessarily the true physical distribution, but allows to reproduce the correct ADPS by ray-tracing under the assumption of single-scattering [14, 15]. Now a computation of a scatterer distribution just for the sake of reproducing a single ADPS (which formed the basis of the scatterer distribution anyway) would not be useful in practice. More interesting is the question whether the scatterer distribution produced that way can, e.g., extrapolate the ADPS correctly when the MS is moved. Straightforward geometric considerations show that this extrapolation cannot be exact, but is a good approximation if either the distance between transmitter and last effective scatterer is small, or the area over which the extrapolation is done is not too large. If multiple scattering is dominant, we also need separate scatterer distributions to model the DOAs at the BS and at the MS.

We also point out that in purely stochastic methods, the assumptions about the number of scatterings are even more restrictive. In purely stochastic models, the directions, amplitudes, and phases of incident planar waves are prescribed according to a given probability density function. In our language, this is a zero-scattering approach, i.e. there are virtual signal sources in the direction of the DOAs, and at a distance prescribed by the delay of the waves. In propagation scenarios with *multiple*-scattering, GSCM is not totally accurate in predicting downlink and long-term behaviour. Stochastic models have those problems even when *single*-scattering occurs (which always is the case).

IV. GENERALIZATIONS FOR URBAN ENVIRONMENTS

The evaluation of channel sounder measurements conducted in dense urban microcellular environment [16] indicates that the guiding of waves along the streets that are orthogonal to the one in which the MS is situated is an important effect. This effect is especially important if the receiver is on a plaza or near a street crossing. Multiple reflections significantly influence the ADPS. Since the GSCM is most efficient if single scattering is assumed, we have to place "equivalent" scatterers. These scatterers are not aligned in parallel to the streets, but more in the direction from the receiver to the street aperture (Fig. 4).

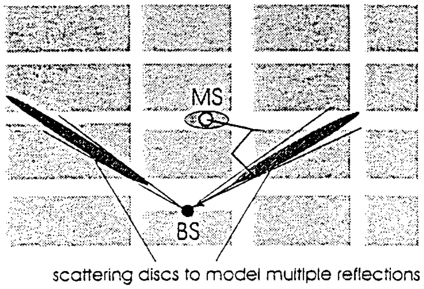

Fig. 4 "Equivalent" scatterers for modelling multiple scattering at the BS.

We also find that the geometrically direct propagation component between the local scatterers and the BS suffers a diffraction over the edge of the rooftop. Thus we introduce an additional attenuation factor for the paths coming via local scatterers, which means that the local scatterer power does not dominate the whole channel situation.

Concerning the DOAs at the mobile station, measurements show [17] that near-by scatterers all around the MS contribute to the power delay profile. In these measurements, the receiver antenna was below the rooftops, while the transmit antenna was above the rooftops; the situation is also similar for urban microcells.

We found that one important effect is the guiding of waves along the street in which the MS is situated. To implement this behaviour into the GSCM we suggest (see Fig. 5) to use for the scatterer distribution a line, a rectangular, or a bivariate Gaussian distribution.

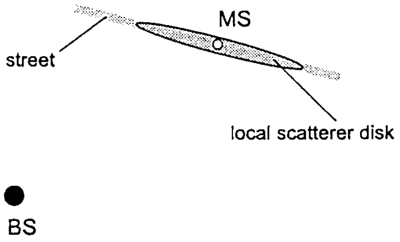

Fig. 5 Placement of scatterers for simulation of waveguiding along the streets in which the MS is situated. Local scatterers near the MS.

Figure 6 shows the APS as computed with the above model, and compares it to measurement results from Ref. [17]. Parts (a) and (c) show the APS of the power arriving within the first 0.4μs; parts (b) and (d) the power arriving after that. We see excellent agreement with measured results.

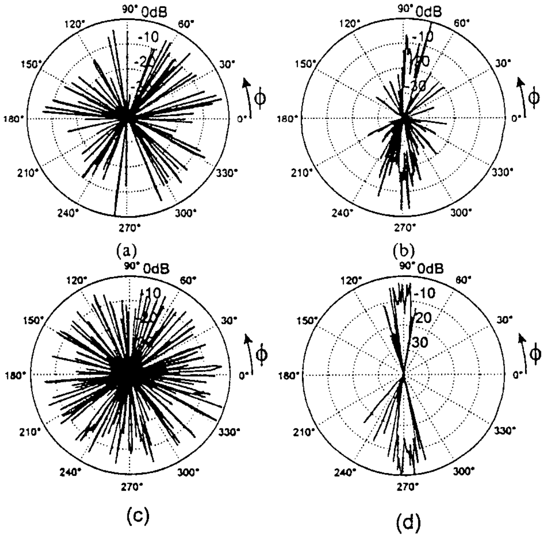

Fig. 6 Measured (a,b) and simulated (c,d) APS in street canyon. Simulation assumptions: uniform distribution of scatterers in a circle with radius 60m plus uniform in a rectangle (length 1km, width 100m); ratio of the number of scatterers in circle to rectangle =1. Distance BS-MS 1000m.

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V. SUMMARY AND CONCLUSIONS

We have presented generalizations and implementation methods for the "Geometry-Based Stochastic Channel Model" GSCM, which allow realistic and efficient simulations of spatially resolved signal reception and transmission. Compared to the purely stochastic approach, the GSCM has several advantages:

- its relation to the physical reality is immediately visible; the important parameters, like location of the scatterers, can often be determined from simple geometrical considerations.
- all necessary information is inherent in the distribution of the scatterers; therefore, possible correlations between PDP and APS do not lead to a complication of the model.
- the movement of mobile station and scatterers can be included in a straightforward way. Furthermore, also the shadowing, and the appearance and disappearance of transmission paths (e.g. because of blocking by obstacles) can be easily implemented. This allows to include long-term correlation (memory) of the channel in a straightforward way.

In the case of dominant multiple reflections like wave-guiding in street canyons, "virtual" scatterers are appropriately placed. The resulting scatterer distribution does not give the correct ADPS at **both** BS and MS if single-scattering is assumed. However, the ADPS at **either** BS or MS is reproduced correctly, and can also be used to extrapolate the ADPS over quite large areas.

The ease of implementation and efficiency of the simulation can be increased by a new type of implementation (NSCS), and by combining the GSCM with a purely stochastic approach for short movements of the mobile station. This allows extensive link-level simulations even for high-data rate systems and CDMA systems.

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