Implementation of a COST259 geometry based stochastic channel model for macro and micro cells

Helmut Hofstetter[1], Andreas F. Molisch[2] and Martin Steinbauer[2]

[1]FTW Forschungszentrum Telekommunikation Wien,
Maderstraße 1, A-1040 Vienna, Austria
email: hofstetter@ftw.at

[2]Institut für Nachrichtentechnik und Hochfrequenztechnik,
Technische Universität Wien, Vienna, Austria,
Gußhausstraße 25/389 A-1040 Vienna, Austria

Abstract

The European research initiative COST 259 has developed a directional channel model (DCM) that will play a vital role in the development and testing of third- and fourth generation mobile radio systems. We present results of a practical implementation (in MATLAB) of this model based on the "geometry-based stochastic channel model" (GSCM) implementation method. The model has been implemented for both uplink and downlink, and multiple antennas at either the base station or at the mobile station are possible. Due to the modular structure of our program, every relevant parameter can be adjusted independently. Special attention is paid to computational efficiency, also with respect to possible real-time implementations with signal processors.

I. INTRODUCTION

Good channel models are a vital prerequisite for the development, simulation, and testing of mobile radio systems. In order to compare results, a standardization of the channel models is highly desirable, and supports the general acceptance of simulation results. For example, the COST 207 channel models [1] have played a vital role in the development and type-approval of the GSM system [2]. However, currently existing models are insufficient for the purposes of third- and fourth-generation systems, as they do not include directional information, and also usually do not include micro- and picocells.

In order to alleviate those problems, the European research initiative COST259 [4] (successor to the COST207 and COST231 programs) has developed a directional channel model (DCM) that has been approved by the roughly 100 participating institutions, and which shall become as popular as its simple predecessors [1], [3]. Based on these model specifications, we have implemented a "geometry-based stochastic channel model (GSCM)", which will also be implemented on a DSP for real time channel simulations. The requirement for real-time capabilities, coupled with the comparatively high complexity of the COST259 DCM makes the implementation a non-trivial task. In this paper, we will describe our approach for tackling these tasks.

The rest of the paper is organized the following way: Section 2 gives a very brief overview of the COST259 DCM for macro- and microcells. Section 3 reviews the principle of the GSCM, and explains how it can be related to the COST259 specifications. Next, we describe how various aspects of COST259 are implemented in order to achieve real-time capability by making use of the multi-layer structure of the model. A summary concludes this paper.

II. COST 259 CHANNEL MODEL

COST259 specifies four macro- and five micro-cell radio environments [4]. The names of these environments start with G (for generalized, followed by an abbreviation for the considered environment. For the macrocells, these environments are the same as in COST207 [1]: TU (typical urban) BU (bad urban), RA (rural area) and HT (hilly terrain). For the microcells, we have SN (street non-line-of-sight), SL (street line-of-sight), SX (street crossing), and OP (open place). Specifications for picocells are also given, but are beyond the scope of this paper.

For each environment, a set of external, global and local parameters is given. Global parameters are those that stay fixed through all simulations, e.g. frequency band or average height of base stations. Local parameters determine the angular delay power spectrum within a range of some ten wavelengths, e.g. the Rice factor, number of scatterer clusters, etc., averaged over ten wavelengths. Global parameters determine the probability density functions of the local parameters.

The COST259 model differs from the COST207 model mainly in two respects:
(i) it includes the information about the direction-of-arrival at the base station and the mobile station
(ii) it includes large-scale changes, e.g., of the number of clusters, narrowband field strength, Rice factor, and the interrelation between those changes.

The versatility and generality of the model is bought at the price of a more complex specification and implementation. The COST259 final report does not specify a certain implementation method, but recommends two possibilities: a purely

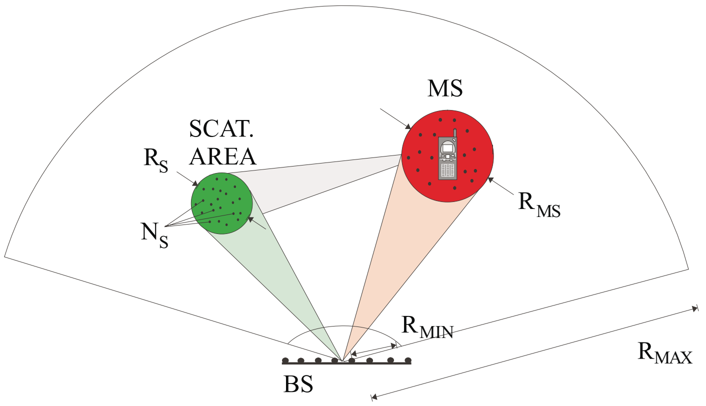

Fig. 1. Principle of the GSCM.

stochastic approach based on a tapped-delay line model, or an implementation based on the geometry-based stochastic channel model (GSCM).

III. GSCM - GEOMETRY BASED STOCHASTIC CHANNEL MODEL

In our geometry based stochastic approach we prescribe the geometrical distribution of the scatterers and then calculate the multipath delays and directions of arrival using a simple ray-tracing approach, assuming that each of the scatterers carries one multipath component to the base station [5], [6]. Even multiple scattering processes can be emulated by placing "virtual" scatterers at locations that give the correct delays and angles-of-arrival. When we sum up all these contributions with correct phase, we can reproduce the small-scale fading. Also, possible correlations between the signals at antenna array elements are automatically reproduced correctly. In our model, we put a scatterer cluster around the mobile station (in the literature called first or near cluster) and additional far clusters might be distributed in the cell, depending on the specific global scenario.

IV. IMPLEMENTATION ASPECTS

In the following, we describe the implementation of the model for multiple antennas at the transmitter, as this is one of the major applications of the COST259 DCM (the use of multiple antennas at the receiver is completely analogous).

First, we give the input-output relation of the system, which is the ultimate goal of a channel simulator. The output signal Y is calculated by summing up the impulse responses of all the scatterers (NS…near scatterer, FS…far scatterer) and the LOS path multiplied with the input matrix X.

$$Y = H_{LOS}X + \sum_{k=0}^{N_{NS}} \left[H_{NS}\left(k\right)X\right] + \sum_{n=0}^{N_{FC}} \sum_{m=0}^{N_{FS}} \left[H_{FS}\left(n,m\right)X\right]$$

where

$$H_{LOS} = A_{LOS}SF_{LOS}AntFactor_{BS-MS}AntFactor_{MS-BS}LOS_{visibility}e^{2\pi j * \frac{PathLegth_{LOS}}{\lambda}}$$

and similarly for H_{NS} and H_{FS}.

As mentioned above, contributions from the far scatterers have an important influence on the performance. The number of far scatterer clusters can change as the mobile station moves through the cell. In the COST259 DCM, this effect is modeled by so-called "visibility regions", i.e. a far cluster is only visible if the mobile station is located in an associated visibility region (which is distributed throughout the cell according to a specified distribution [7]. This is described by a visibility factor $FS_{visibility}$. Analogously, we specify the factor $LOS_{visibility}$, having a range from 0 to 1. The Near scatterers are always visible for the receiver. The scatterer areas A_{xx}, as described below, and the shadow fading SF_{xx} are also used for the computation of the amplitudes. There is also a model part for specifying antenna patterns for each antenna. The corresponding antenna factors are taken into account in $AntFactor_{xx-yy}$ which gives the value at position xx in direction of yy. For the computation of the phase, the path length $PathLength_{xx}$ is needed.

Parameter updates

It is unfeasible to update the channel impulse response for every bit - the computational effort would by far exceed the computational power available in today's signal processors. Thus, a lot of attention was devoted to an efficient method of channel updates. In our approach we use a two step update process (see figure 2), as is also implicitly suggested

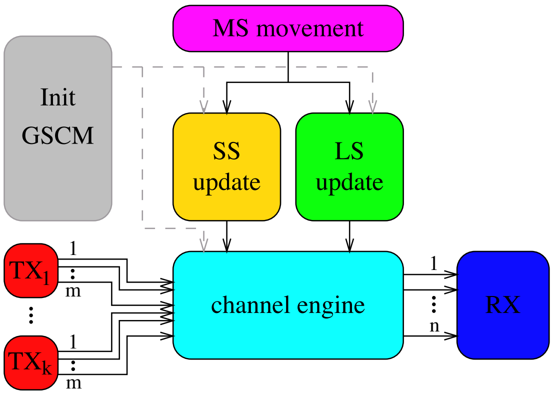

Fig. 2. Structure of the GSCM engine.

in the layered structure of the COST259 DCM. In the inner loop, the so called *Short Scale Update,* the fast changing variables are recalculated. Such variables are for example, the position of the mobile station, the shadow fading and the rice factor. A SS-Update is done after a MS-movement of $\frac{\lambda}{2}$ and linear interpolation between SS-Updates is used.

The less frequent changing parameters are updated in the *Large Scale Update* procedure. The LS-Update has to be done each tenth SS-Update, but the computational effort of the LS-Update is due to a lot of geometric calculations also very high. Some typical parameters which are changed in the LS-Update are the visibility factors, the scatterer areas and the position of the near cluster.

Large Scale Fading

The Large Scale Fading is modeled as a stochastic process that depends on the movement of the mobile station (Δx). An exponential shape for the autocorrelation function with a correlation length d_{corr} depending on the specific scenario is used. Note that the autocorrelation function depends only on the absolute distance between two mobile-station positions, and not on the direction of the movement. Thus, the large scale fading is implemented as a first order Markov model with the output sequence X:

$$R\left(\Delta x\right) = e^{-\frac{|\Delta x|}{d_{corr}} \ln 2}$$

$$X\left(x+\Delta x\right) = X\left(x\right) \cdot R\left(\Delta x\right) + \sqrt{1 - R^2\left(\Delta x\right)} \cdot Z$$

where Z is a normally distributed stochastic process with zero mean and variance σ_Z^2.

Delay/ Azimuth/ Elevation Dispersion

The clusters (both near and far clusters) are characterized by their position, spread, power and shape. In macro-cells, clusters have exponential decay in delay τ, Laplacian shape in azimuth φ and elevation ϑ,

$$P_s\left(\tau,\varphi,\vartheta\right) = \frac{1}{1-e^{-\frac{\pi\sqrt{2}}{S_\varphi}}} \cdot \frac{1}{1-e^{-\frac{\pi\sqrt{2}}{S_\vartheta}}} \cdot \frac{1}{\pi\sqrt{2}\cdot S_\tau S_\varphi S_\vartheta} \cdot e^{\frac{-\tau}{S_\tau}} \cdot e^{-\sqrt{2}\cdot\left|\frac{\varphi}{S_\varphi}\right|} \cdot e^{-\sqrt{2}\cdot\left|\frac{\vartheta}{S_\vartheta}\right|}$$

As specified in COST 259, the cluster-specific large scale fading and the delay and azimuth dispersion are correlated stochastic processes. The prescribed correlation can be enforced by first performing a Cholesky decomposition of the specified correlation matrix Γ, and then multiplying this matrix C by a vector of independent random variables X. The result of that multiplication, Y, which contains in each row the instantaneous values of delay spread, angular spread, and shadowing, has the required correlation properties

$$Y = C \cdot X.$$

For the computation, the correlation matrix

$$\Gamma = CC^T,$$

$$\Gamma = \begin{bmatrix} 1 & \rho_{xy} & \rho_{xz} \\ \rho_{yx} & 1 & \rho_{yz} \\ \rho_{zx} & \rho_{zy} & 1 \end{bmatrix}$$

with the correlation coefficients $\rho_{xy} = -0.75$,$\rho_{yz} = 0.5$ and $\rho_{xz} = -0.75$ is needed. The correlation matrix Γ is required to be positive semidefinite, otherwise no solution exists. Then C is the Cholesky factorization of Γ, and C is a lower triangular matrix. The Cholesky factorization satisfies the requirement $\sigma_X^2 = \sigma_Y^2$.

Doppler spread

A very important item is the implementation of the Doppler spread. Since, each path has a different DOA, also the Doppler shift differs. With the help of the geometry information of each scatterer it is easy to assign them the right Doppler shift. The Doppler shift is computed once per short scale update (see below) and summed up for the following symbols.

Mobile station view

Most channel models describe the impulse response at the base station. Taking the mobile station view with several antennas at the mobile station into account results in some implementation problems. There are still very few measurements for parameter estimation available in the literature and some assumptions of the COST259 DCM are not consistent with a single scattering model.

One major problem in microcells is that waves from far clusters are assumed to be incident from all directions. Physically, this assumption can be justified by a propagation mechanism that first reflects the waves from the BS at the far clusters, then possibly includes some waveguiding in the street canyon, and finally some additional reflections near the mobile station. However, this mechanism is not covered by our single-scattering assumption. We solved that problem the following way: any reasonable array at the mobile station has an element spacing that is about half a wavelength. Since the waves are incident from all directions at the MS, the signals at the antenna elements are decorrelated. We now enforce the decorrelation not by the DOA-spectrum (which we cannot model exactly with the single-scattering assumption), but rather by adding a different random phase to the signals at the antenna elements. All other data, like pathloss, are computed from the cluster position as in all other cases.

Pathloss

For the overall narrowband pathloss, the COST231 Hata and COST231 Walfish-Ikegami model are prescribed for macrocells [3], while the model of Feuerstein et al [8] is prescribed for microcells. For the model implementation, the narrowband pathloss does not enter the model directly but is used for the computation of the attenuation of the first cluster. Furthermore, the used narrowband pathloss models give a deterministic description of the pathloss that depends only on the distance between base station and mobile station, while the GSCM computes the instantaneous power of a specific realization. If we want to ensure compatibility, the sum of the instantaneous cluster powers averaged over all global parameters must be equal to the narrowband power as specified in COST231 and the Feuerstein model.

We solve that problem by establishing correction tables for the scatterer cross sections. The best way for setting up those tables is a Monte Carlo simulation: we first assign a unit value to the scattering cross sections, and compute the total power for many different realizations of the channel, and a specified distance between base and mobile station (note that the location *vector* of the mobile station is allowed to change, only the absolute distance must remain constant). We then average the narrowband power over many simulations. Comparing this averaged value to the value prescribed in the COST231 model, we obtain the required correction factor. Note also that the correction values can be saved in tables or even hard-wired in a channel simulator.

The above description was still somewhat oversimplified, because the dependence of the Rice factor on the total power as specified in COST259 DCM complicates things. We require the following interpolation process:

1. Compute single realization
2. compare with COST values
3. adapt Rice factor and correction factors
4. recompute single realization

Steps two to four are done until the values fit the COST model with an accuracy of better than 2% (typically 1-3 iteration steps are necessary). This procedure has to be done according to the Monte Carlo simulation at least 1000 times per point. The high number of simulations is necessary due to the high number of stochastic variables with some dependencies in the model. For a whole cell, a table with about 100 points and linear interpolation is used in practice. A Monte Carlo simulation result for the GTU scenario is shown in figure [3].

V. SUMMARY, CONCLUSIONS AND OUTLOOK

We have implemented a geometry based stochastic channel model for macro- and micro cells, consistent with the specifications of the COST259 directional channel model. The COST259 DCM is anticipated to become the new standard in channel modeling for third-and fourth-generation systems. The model is very flexible and allows simulations in complex micro cell environments with various base stations and users as well as high speed scenarios with consideration of the Doppler spread.

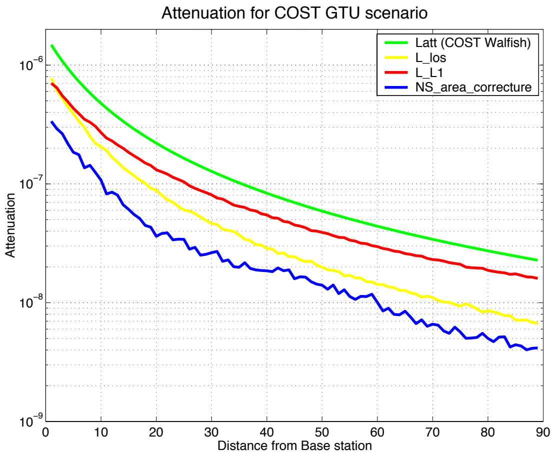

Fig. 3. Results of the additional attenuation from MC simulations.

The simulation effort is relatively high, as it is typical for geometry based models. However, real-time implementation on a DSP-based seems possible, and is currently under way at our laboratory.

References

[1] M. Failli (ed.): *Digital Land Mobile Communications. COST 207 Final Report*, 1989.

[2] M. Mouly and M.B. Pautet: *The GSM System for Mobile Communications;* 1992.

[3] E. Damosso (ed.), *COST 231: Evolution of Land Mobile Radio (Including Personal) Communications (Final Report)*. Springer, 1996.

[4] M. Steinbauer, H. Asplund, I. de Coster, D. Hampicke, R. Heddergott, N. Lohse and A. F. Molisch, "COST 259 SWG 2.1 Mission Report: Modelling Unification Workshop

[5] J. Fuhl, A.F. Molisch and E. Bonek: *Unified channel model for mobile radio systems with smart antennas*; IEE Proceedings on Radar, Sonar and Navigation, Vol. 145, No. 1, pp.32–41, Feb. 1998.

[6] A.F. Molisch, J. Laurila, and A. Kuchar, *Geometry-base stochastic model for mobile radio channels with directional component*, Proc. 2nd Intelligent Antenna Symp., Univ. Surrey, 9th -10th July 1998.

[7] H. Asplund and J.E. Berg: *An empirical model for the probability of line of sight in an urban macrocell*, COST259, Temporary Document TD(99)107, Leidschenam, The Netherlands, Sept. 1999.

[8] M.J. Feuerstein, K.L. Blackard, T.S. Rappaport, S.Y. Seidel and H.H. Xia, *Path loss, delay spread and outage models as functions of antenna height for microcellular system design*, IEEE Transactions on Vehicular Technology, vol. VT-43, no. 3, pp. 487-498, 1994.

[9] T. Klingenbrunn, P. Mogensen, *Modelling Cross-Correlated Shadowing in Network Simulations*, Proc. VTC '99 Fall, pp.1407-1411,1999.