Advanced Radio Channel Model for Magic WAND

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Abstract: *The stochastic radio channel model (SRCM) derived within the Magic WAND project takes into account all propagation effects which have an impact on the system performance. Special attention has been paid to obtain an accurate description of the time and direction dispersive character of real radio channels because the Magic WAND system exploits both, frequency and space diversity. In this paper, the modelling approach adopted for the WAND-SRCM is presented. This includes a description of the software implementation and an example of a channel impulse response generated with this tool.*

1. Introduction and Objectives

Radio networks have to cope with the partly deleterious, partly beneficial effects of multipath propagation. Thus, a profound knowledge of the propagation mechanisms is a prerequisite for the development and performance evaluation of wireless transmission systems. First, the channel key parameters such as delay spread (DS), coherence bandwidth, coherence time, number of dominant paths, etc., are needed for a detailed parameter optimization during the system design phase. Second, for a realistic performance evaluation by means of Monte Carlo simulations we require realizations of the channel impulse response (CIR) which accurately reflect the propagation conditions encountered in a real environment.

The stochastic radio channel model (SRCM) derived for Magic WAND is a parametric model, i.e., it is entirely characterized by a set of parameters. It has a relatively small computational complexity - this is most important for extensive performance evaluation studies - and it allows to synthetically generate CIRs that retain all the fundamental properties of real CIRs. For example, transitions describing emerging or vanishing paths are also included. In addition, this model allows to simulate situations where receivers exploit the polarization and space diversity, e.g., by making use of smart antennas. As a matter of fact, preliminary studies show that antenna diversity will be needed in order to achieve a good system performance.

The SRCM for Magic WAND is related to several previous radio propagation studies. First, the model developed for HIPERLAN [1] provides a basis for our investigations as it is also dedicated to the 5.2 and 17 GHz frequency bands. Other important results from earlier activities are the models derived by COST 207 [2] and within the RACE II projects CODIT [3] and ATDMA [4]. Although these models have been developed for a different frequency range (1-2 GHz), they still provide a lot of input and some of the features of the WAND-SRCM have been adapted from those models.

2. Modelling Approach

Various solutions have been proposed to simulate the radio channel: (1) stored CIRs [4], (2) ray-tracing or ray-launching techniques applied in reference environments to compute the CIR [5], and (3) stochastic parametric models for the CIR [2, 3]. The third solution has been selected in the WAND project since it presents some decisive advantages compared to the two other approaches. The implementation of the parametric stochastic models requires only a small data storage capacity and it has a relatively small computational complexity. Moreover, relying on these models theoretical investigations can be performed during the system design phase. Finally, their portability is also an important advantage. The challenge of stochastic modelling is twofold: Firstly, a suitable parametric model has to be elaborated which accurately and exhaustively reproduces all the features of the real propagation environment that are relevant for the system. Secondly, the model parameters have to be estimated from experimental data gathered during comprehensive measurement campaigns.

In general it is very difficult to predict which propagation mechanisms really have an impact on communication systems. This matter of fact has led to the decision to include from the very beginning all major propagation effects into the model. As illustrated in Figure 1 they have been grouped into five categories. Each effect is individually described by means of a parametric model. The WAND-SRCM results from combining all these partial models. Because simplicity is a prerequisite for the effective applicability of a stochastic model, emphasis has been laid on designing partial models of considerably low complexity, i.e., models which embody at most two parameters. A detailed description of the adopted models and the corresponding parameter settings is given in Section 3.

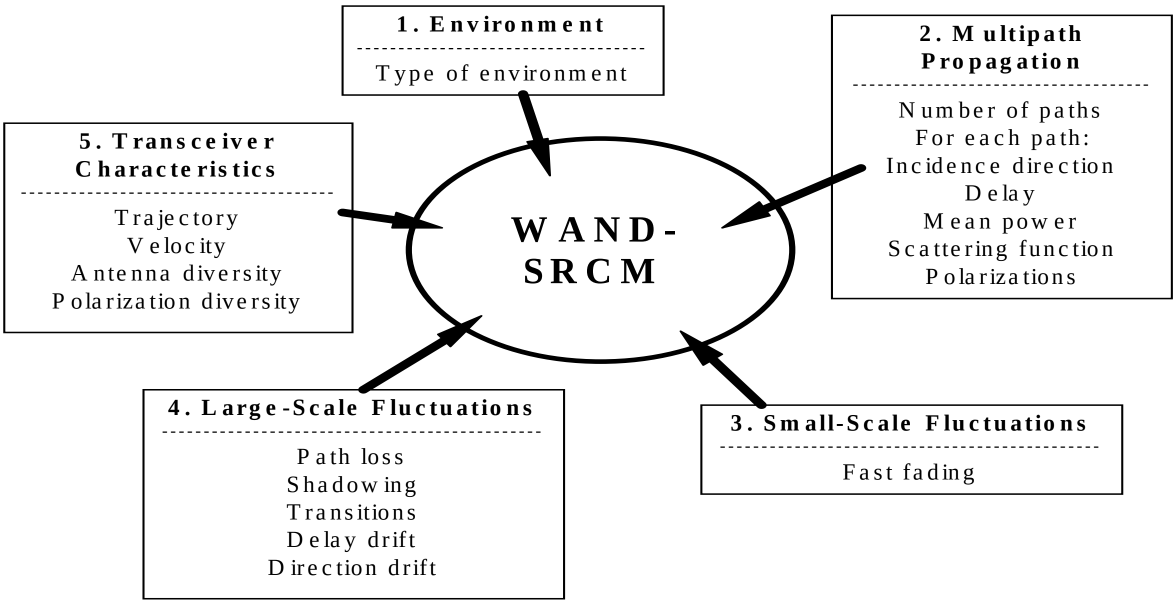

Figure 1: Propagation effects and transceiver features in the WAND-SRCM.

The WAND-SRCM reproduces three sources of randomness inherent in the radio channel. These are shortly discussed in the sequel. When we talk of an environment, e.g., the “Large Rooms” environment, we implicitly understand a whole class of environments, all exhibiting the “typical” features (whatever typical means) expected in large rooms. In the WAND-SRCM each specific environment in a class is characterized by its own power delay-direction profile (PDDP). To reproduce the deviations of the various environments in one class this function is randomly selected according to specified probability distributions. These distributions are selected such that the average PDDP has a specified shape which describes the environment class. According to the common practice, the electric fields of diffusely scattered waves are described by uncorrelated random processes in the sense defined by Bello. Finally, the movement of the mobile station (MS) always embraces one or many random components, e.g., starting position and direction.

3. WAND Stochastic Radio Channel Model

3.1. Environment

Four typical indoor operating environments have been identified for WAND systems: small and large rooms, factory halls, and corridors. A profound specification of the parameters for each environment affords a thorough statistical analysis based on data gathered during comprehensive measurement campaigns. Unfortunately, the sparse experimental results available in the 5.2 and 17 GHz bands prevent from this ambitious procedure. Instead, the parameter settings proposed below have been selected either by making use of results published in the literature and obtained from experimental investigations carried out in the WAND project or by applying rationales drawn from the theory of wave propagation. Due to the lack of measurement results the model specification for corridors had to be deferred.

3.2. Multipath Propagation

The electric field at one location is the superposition of the fields of several impinging waves with distinct propagation delays and incidence directions. The location dependent field delay-direction spread function (FDDSF) $E(\vec{x},\tau,\Omega)$ describes how the electric field is spread both in time and direction. Here, $\vec{x}$ denotes the antenna position, while τ and Ω are the delay and direction variables, respectively. According to the common practice Ω is regarded as a point on a sphere of arbitrary radius having its center at the antenna location. The direction Ω is uniquely determined by the azimuth φ and the coelevation θ in a spherical coordinate system. Under far field conditions, the FDDSF is a two-dimensional vector with each component corresponding to one polarization. For the sake of simplicity only one component is considered here, i.e., $E(\vec{x},\tau,\Omega)$ is a scalar function. This function is the superposition of the FDDSFs of all the impinging waves, i.e.,

$$E(\vec{x},\tau,\Omega)=\sum_{m=1}^{M}E_m(\vec{x},\tau,\Omega)\ , \tag{1}$$

with M denoting the number of paths (waves). The CIR at location $\vec{x}$ follows according to $h(\vec{x},\tau)=\int f(\Omega)\ E(\vec{x},\tau,\Omega)d\Omega$, where $f(\Omega)$ is proportional to the electric antenna field pattern.

A particular environment *A* within the considered class *C* is characterized by its PDDP

$$P(\tau,\Omega;A)=\mathrm{E}\left[\left|E(\vec{x},\tau,\Omega)\right|^2\right].$$

Assuming that the components in (1) are independent it follows that

$$P(\tau,\Omega;A)=\sum_{m=1}^{M}P_m(\tau,\Omega).$$

In the WAND-SRCM the terms $P_m(\tau,\Omega)$, $m=1\ldots M$, are of the form $P_mS_m(\tau-\tau_m,\Omega-\Omega_m)$ with P_m, τ_m, and Ω_m denoting the mean power, mean propagation delay, and mean incidence direction of the *m*th wave. The non-negative function $S_m(\tau,\Omega)$ satisfies the identity $\int S_m(\tau,\Omega)d\tau d\Omega=1$. It is proportional to the scattering function of a hypothetical scatterer from which the *m*th wave originates. The random parameters *M*, P_m, τ_m, and Ω_m, $m=1\ldots M$ reflect the random fluctuations of $P(\tau,\Omega;A)$ within the class *C*.

The following distribution functions have been identified. The number of paths *M* is Poisson-distributed with expectation $\overline{M}$. The delays τ_m, $m=1\ldots M$, are uniformly distributed over the delay interval $[0,\tau_{max}]$ where the normalized power delay profile (PDP) $\tilde{P}(\tau)$ (see below) takes significant values. Following COST 207 $\tau_{\max}$ is the argument for which $\tilde{P}(\tau)/\tilde{P}(0)$ falls below the -30dB level, i.e., $\tau_{\max}=(3/\log e)\sigma$ where σ is the DS. The azimuths φ_m, $m=1\ldots M$, are uniformly distributed over $[-\pi,+\pi)$. In a first approximation, the waves are assumed to propagate horizontally, i.e., $\theta_m=\pi/2$, $\forall m=1\ldots M$. In order to keep the number of parameters small, all scatterers are assumed to exhibit the same scattering property, i.e., $S_m(\tau,\varphi,\theta)=G(\tau,\Delta\tau)\cdot G(\varphi,\Delta\varphi)\cdot\delta(\theta-\pi/2)$, $m=1\ldots M$. In this expression $G(z,\Delta z)=1/(\sqrt{2\pi}\Delta z)\exp(-z^2/(2\Delta z^2))$. The selected values for $\overline{M}$, Δτ and Δφ are given below in Table 1. Note, that to ensure a constant mean density of the number of paths over the interval $[0,\tau_{max}]$, $\overline{M}$ has to be chosen proportional to σ. The values for Δτ and Δφ have been determined based on the geometrical dimension of the scatterers.

A given environment class *C* is specified by its PDDP $P(\tau,\Omega)$, which we refer to as the global PDDP to distinguish it from the local PDDP $P(\tau,\Omega;A)$ that describes a particular environment *A* within class *C*. For consistency reasons it is required that averaging the local PDDPs over the environments within C yields a PDDP close to $P(\tau,\Omega)$, i.e., $P(\tau,\Omega) \approx \mathrm{E}[P(\tau,\Omega;A)]$. The global PDDPs have been selected to be of the form $P(\tau,\varphi,\theta) = P \cdot \tilde{P}(\tau) \cdot \tilde{P}(\varphi) \cdot \tilde{P}(\theta)$. The factors in the latter product are specified as follows: P is the average power determined from the transmitted power and the path loss, $\tilde{P}(\tau) = (1/\sigma)\exp(-\tau/\sigma)$, i.e., the normalized PDP decays exponentially, $\tilde{P}(\varphi) = 1/(2\pi)$, i.e., the waves are impinging uniformly from any direction (azimuth), and $\tilde{P}(\theta) = \delta(\theta - \pi/2)$, i.e., the waves are propagating horizontally. Notice that the global PDDPs and therefore the corresponding classes are entirely determined by only one parameter, the DS σ. The parameter setting for σ shown in Table 1 has been taken over from the HIPERLAN model [1].

Environment	DS	Local PDDP			Path Loss		Shadowing	
	σ [ns]	$\overline{M}$	Δτ [ns]	Δφ [°]	n	α [dB/m]	ζ [dB]	γ [m]
Small Rooms	50	10	3	20	2	0.4	6	2
Large Rooms	100	20	10	20	2	0.4	6	3
Factory Halls	150	30	20	30	2	0.4	6	5

Table 1: Proposed parameter setting for the WAND-SRCM.

3.3. Small Scale Fluctuations

The classical technique for generating the components $E_m(\vec{x},\tau,\Omega)$ is applied in the WAND-SRCM [2, 3]. Each component is written as a sum of numerous plane waves with random characteristics (amplitude, delay, incidence direction). The distributions of these parameters are selected such that $\mathrm{E}\left[\left|E_m(\vec{x},\tau,\Omega)\right|^2\right]$ is close to $P_m(\tau,\Omega)$.

3.4 Large Scale Fluctuations

In the WAND-SRCM the path loss is described by an extended linear model [6] $L(d) = L_0 + 10n\log(d) + \alpha d$, where L_0 is the free-space loss at 1m distance and d denotes the distance between the access point (AP) and the MS. Investigations [6] have shown that taking a power decay exponent $n = 2$ and a path attenuation $\alpha \in [0.2, 0.6]$ dB/m yields a good agreement with experimental results. Each of the M incident waves is assumed to independently experience log-normal shadowing. To account for this effect, the mean power P_m of the mth wave is weighted by the function $10^{(\Delta L_m(x)/10)}$ where $\Delta L_m(x)$ is a real zero-mean Gaussian process specified by its autocorrelation function. In the model this function takes the form $R_{\Delta L_m}(\Delta x) = \zeta^2 \exp(-\Delta x^2/(2\gamma^2))$. The two parameters ζ and γ are the variance and the decorrelation length of ΔL_m, respectively. The value of ζ listed in Table 1 has been taken from [4], while the corresponding values for γ can be motivated by considering the geometrical dimensions of the main obstacles in the corresponding environments.

Assuming that plane waves are impinging at the antenna position, the location dependency of the delays τ_m, $m = 1 \ldots M$, which is caused by the modification of the corresponding path length when terminals move, is expressed as $\tau_m(\vec{x}) = \tau_m - (\langle \vec{e}(\Omega_m) | \vec{x} \rangle / c)$, where $\vec{e}(\Omega_m)$ is the unit vector pointing towards the direction Ω and c is the velocity of light. No model has been elaborated yet to characterize the distance dependency of the incidence direction.

The components $E_m(\vec{x},\tau,\Omega)$, $m = 1 \ldots M$, are active only over a certain segment of the MS trajectory. Following [7] the locations along the trajectory where the components become active form a homogeneous Poisson process with occurrence rate $1/\Lambda_a$. The lengths of the "active" segments are exponentially distributed random variables having the same expected value Λ_ℓ. The transition behavior of the components in the range where they arise or disappear are described by smooth monotone functions in a way similar to [3]. The determination of the shape of the transition functions and values of the parameters Λ_a and Λ_ℓ is not completed yet.

3.5. User Mobility

It is assumed that the MS performs random movements with a constant velocity in a circular cell whose center coincides with the AP location. The beginning and the end of the MS trajectory are random vectors having a uniform distribution over the cell.

4. Software Implementation and Simulation Results

In order to limit the computational effort for extensive Monte Carlo simulations it has been decided to give the user the opportunity to select the propagation effects to be incorporated into the WAND-SRCM according to the purpose of the simulation. Three levels of modelling complexity have been defined: (1) reduced complexity, where only the issues regarding the environment, the multipath propagation, the path loss, and the MS mobility are incorporated, (2) medium complexity, where in addition to (1) all effects leading to large-scale fluctuations are taken into account, and (3) full complexity, where the MS is further assumed to exploit polarization diversity and to use smart antennas.

The WAND-SRCM is implemented using the object-oriented programming language C++. From the user point of view there exists only the "Channel" class. The set-up of an object of that class is shown in Figure 2. The CIR is written into the "CIRMatrix" array. Each column vector of this matrix represents a time-sampled CIR for a specific polarization or antenna. The "MovementGenerator" computes the location of the MS and the "Zero" function initializes all matrix elements to zero. Now, the computation of the CIR proceeds as follows: each "Path" object adds the contribution of one propagation path to the CIR. The "Path" objects have an inner set-up with objects corresponding to the different propagation effects.

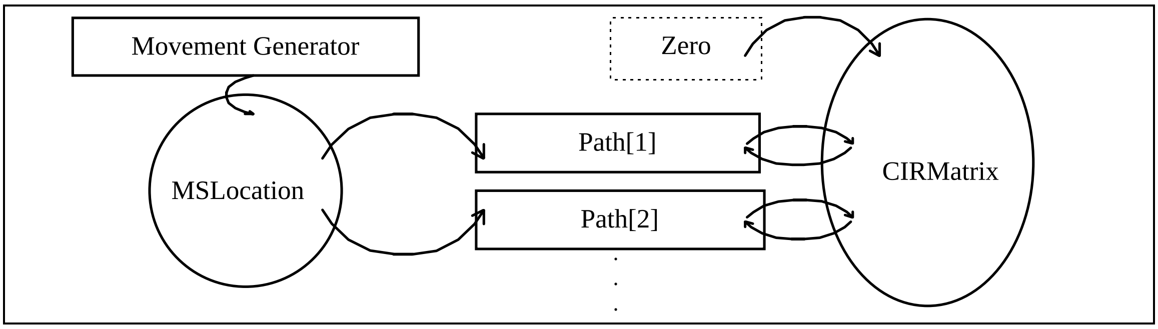

Figure 2: Set-up of the "Channel" class.

The user can call four public member functions: the constructor, "Step", "NewParameter", and the destructor. The constructor is used to initialize the "Channel" object. The "Step" function generates a new CIRMatrix whereby the user can specify the time elapsed since the last call of the "Step" function. In this way event-driven simulations are possible and computations of unused CIRs can be avoided. Calling the "NewParameter" function generates new outcomes of the random variables. Thus the propagation constellation for a new specific environment is generated. Finally, the destructor frees the memory allocated for the "Channel" object.

The CIR shown in Figure 3 has been generated using the reduced complexity WAND-SRCM for "Large Rooms" considering a carrier frequency of 5.2 GHz. The MS moves with a velocity of 1 m/s from 4 meters distance to 2 meters distance towards the AP. It can be seen that the amplitudes of the CIR components increase as the MS approaches the transmitter due to the reduction of the path loss.

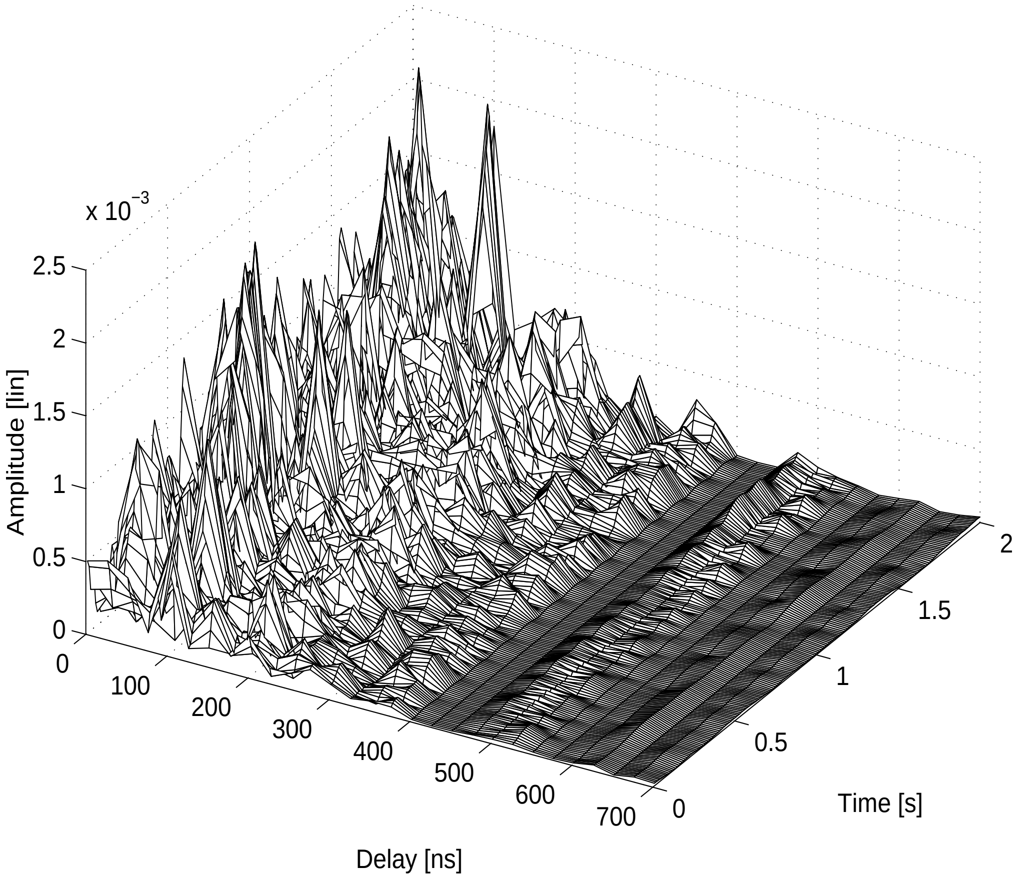

Figure 3: Example CIR generated using the reduced complexity WAND-SRCM for “Large Rooms”.

The global PDP for “Large Rooms” as well as the local PDP used to generate the sample CIR given in Figure 3 are reported in Figure 4. This figure also includes the average of 100 local PDPs. Obviously, the local PDP exhibits an irregular behavior, while the average of 100 local PDPs is close to the global PDP as desired.

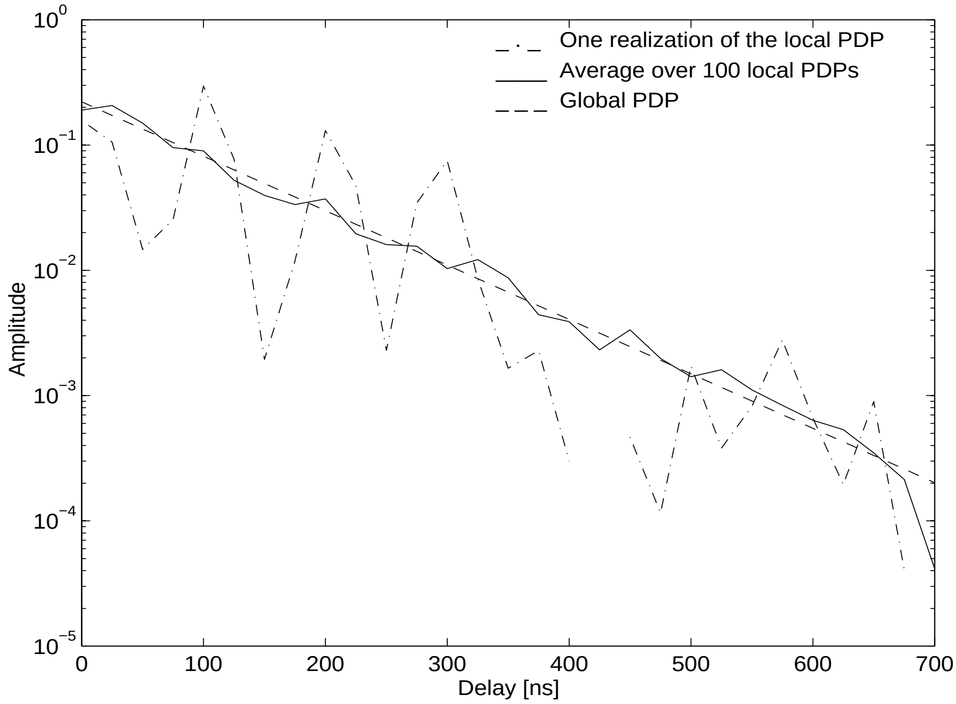

Figure 4: Global PDP and realization of a local PDP for “Large Rooms”.

5. Comparison with other Models

The reduced complexity SRCM for Magic WAND is essentially an extension of the COST 207 and the HIPERLAN channel models to include the random variations of the local PDPs within the environment categories. All these models exhibit the wide-sense-stationary uncorrelated-scattering property of the radio channel. However, in contrast to the COST 207 model the frequency correlation functions of the WAND-SRCM will not be periodic which makes it well suited for the performance evaluation of broadband communication systems that exploit frequency diversity. The WAND-SRCM of medium complexity is similar to the CODIT model in the sense that both take into account the effects leading to large-scale fluctuations. Finally the full complexity SRCM extends the previous models in the sense that it includes the waves' polarization and it allows to consider systems which use smart antennas. This latter feature is actually rather important since space and frequency diversity must be exploited in order to guarantee a good system performance for the planned ATM services.

6. Conclusions

As it is difficult to judge which propagation effects have an impact on the performance of the magic WAND system they have all been built in the stochastic radio channel model (SRCM). However, the model complexity is small in the sense that the number of parameters necessary to describe each effect is kept small. The SRCM accounts for the dispersive behavior of physical channels in time, direction and polarization. It also can reproduce the dynamic evolution of the propagation constellation when waves appear or disappear. In particular, solutions have been found regarding two main issues addressed by Subgroup 2 (SG2) of Special Interest Group 1 (SIG1), namely the development of accurate characteristics for the frequency and space diversity of real channels. In order to limit the computational effort for extensive Monte Carlo simulations of specific scenarios, three different complexity levels have been implemented in the software tool. Moreover, event-driven simulations avoid the computation of unused channel impulse responses.

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