Implementation of Wideband Directional Channel for UMTS Link Level Simulator

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Abstract: This paper deals with the definition and the implementation of a Wideband Directional Channel Model (WDCM) based on the COST 259 recommendations. Cluster of replicas are introduced by means of Tapped Delay Line (TDL). Macro, Micro and Pico cells models are considered in different general radio environments. Proposed channel model can be used in a Link Level Simulator (LLS). A good compromise between accuracy of the model and complexity required by the simulator is guaranteed by a suitable statistic approach based on deterministic considerations. In this paper, only results about up-link channel model are presented and evaluated.

Introduction

Recently, wireless communication standardization process has put thrust in using Direct Sequence Code Division Multiple Access (DS-CDMA) techniques for 3rd generation of wireless systems [1]: main targets of these systems will be the integration of different types of traffic at a variable bit-rate with optimum resources management; particularly, 3G systems have to offer up to 2 Mb/s local data services and up to 384 kb/s full coverage services [2]. DS-CDMA appears to be attractive for such applications because its characteristics include large potential capacity increases and other technical factors such as anti-multipath fading capabilities. Wireless cellular communication systems are characterized by random location of the users around the base station: this makes possible to employ the information about direction of arrival of the signals to improve the multiuser detector performance through adaptive antenna array introduction [3-4]. Antenna array systems have been generally used so far to improve signals from a particular user or to reduce interference from other directions, independently of the demodulation technique. Multiuser detection techniques, coupled with spatial processing through the use of an antenna array [5] make maximum exploitation of the information at the receiver input possible. Moreover, Spread Spectrum techniques allow the receiver to discriminate each signal replica, considered here as independent virtual users, and, after space and time processing, to combine every contribution of the same signal, as in a classical rake receiver. As a consequence, in the last years great attention has been devoted to channel modeling and to the definition of the suitable simulation tools [5]. Particularly, research activities developed in the framework of COST259 Action and included in the final report help in providing a detailed description of the mobile wideband directional channel features. In [5] and in the papers referred therein, multipath components statistics are described, by resorting to cluster concept introduction: signals replicas are not uniformly distributed in definite temporal and angular intervals but gathered in clusters. Clusters are introduced in order to model groups of scatterers that generate signals impinging on the receiver with nearly the same delay and power.

This paper deals with the definition and the implementation of a Wideband Directional Channel Model (WDCM) based on the COST 259 recommendations: in this model, cluster concept is introduced through the use of Tapped Delay Line (TDL). Macro, Micro and Pico cells models are derived by taking into account different general radio environments as described in [5]. Proposed channel model aims at providing an effective simulation tool that can be implemented in a complete
Link Level Simulator (LLS). Aiming at a good compromise between accuracy of the model and complexity required by the simulator, a statistic approach based on deterministic considerations has been followed. In this paper, only results about up-link channel model are presented and evaluated. This paper is organized as follows: directional model and radio environments are presented in Section 1 and 2. Implementation of the model is described in Section 3. Simulation results are given in Section 4. Concluding comments are drawn in Section 5.

1. Directional Channel Model Description

In this section the proposed and implemented up-link channel model is introduced and described. The approach followed here aims at achieving a reasonable tradeoff between environment representation accuracy and a low computational cost of the simulator. Hence, instead of pure statistical or deterministic approach, we defined a model that follows a statistical approach based on determinist considerations: particularly, deterministic positioning of cluster inside the radio environment has been performed. In the proposed simulator, the channel model of three different types of cell, namely macro, micro and pico cells, has been represented and implemented: as it is known [5], channel model strictly depends on the type of cell to be represented. The signal received at BS is the superposition of several wavefronts, each with its own angle of arrival $\phi_i$, propagation distance $d_i$, average power $p_i$, delay $\tau_i$, reflection coefficient $\gamma_i$, and angle of departure $\gamma_i$ from the Mobile Station (MS) to the scatterers. If $L$ different paths are assumed, the baseband signal received at BS is the sum of all impinging replicas and can be represented as:

$$
\tilde{y}(t) = \sum_{i=0}^{L-1} \sqrt{p_i} \cdot e^{-j\phi_i} \cdot \tilde{a}(|\phi_i|) \cdot e^{-j(2\pi/L)dt} \cdot e^{-j(2\pi/L)\tau_i} \cdot e^{-j(2\pi/L)\gamma_i} \cdot e^{-j(2\pi/L)\gamma_i} \cdot e\left(0 - \tau_i\right)
$$

where the steering vector spatially describes the antenna array at Base Station (BS):

$$
\tilde{a}(\phi) = \left[ 1, e^{-j(2\pi/L)\cos(\phi)}, e^{-j(2\pi/L)\sin(\phi)}, ..., e^{-j(2\pi/L)\cos(N\phi)} \right]^T
$$

with $\delta_m$ equal to the total distance between the reference antenna, i.e. 0th element in Figure 1, and the $m$th antenna element. It is worth stressing that a Uniform Linear Antenna (ULA) is assumed at the BS.

In [6], impinging waves are shown to arrive at the BS in clusters: for example, in outdoor environment, the clustering is due to the fact that groups of scatterers make several replicas arrive at the base station with nearly the same angle, power and delay. Generally speaking, for any radio environment, clustering effect is motivated by about the same large scale behavior of impinging replicas. The signal received at the BS results from the superposition of all the impinging replicas gathered in clusters and can be represented as:

$$
\tilde{y}(t) = \sum_{n=1}^{N} \sum_{k \in K_n} \sqrt{p_k} \cdot e^{-j\phi_k} \cdot \tilde{a}(|\phi_k|) \cdot e^{-j(2\pi/L)dt} \cdot e^{-j(2\pi/L)\tau_k} \cdot e^{-j(2\pi/L)\gamma_k} \cdot e\left(0 - \tau_k\right)
$$

![Figure 1: BS Antenna.](image1)

![Figure 2: Real PDP (dark line) in comparison with approximated PDP (in red).](image2)
where \( i \in C_n \) indicates all the replicas from the \( n \)th cluster. The average power of the \( i \)th impinging wave is given by:

\[
P_i = PLW_i \cdot PDP_i \cdot PAP_i \cdot PEP_i
\]

where \( PLW_i \) is the term due to Path Loss and Shadowing, \( PDP_i \) is the Power Delay Profile (PDP), \( PAP_i \) is the Power Azimuth Profile (PAP) and \( PEP_i \) is the Power Elevation Profile (PEP): these factors describe the whole received power of the Directional Channel Impulse Response (DCIR) at the BS. Proposed Directional Channel Model is based on cluster concept: each cluster is modeled by a tapped delay line, and every tap represents a group of scatterers identified by the same delay \( \tau \). Hence, the signal received at BS from \( n \)th cluster can be expressed as

\[
\tilde{r}_{i}(t) = \sum_{j=1}^{Q_n} \sqrt{PLW_j} \cdot \sqrt{PDP_j} \cdot \alpha_j \cdot \sum_{l=1}^{Q_l} \sqrt{PAP_l} \cdot \alpha_l \cdot \tilde{g}_{j_l}(t) \cdot e^{-j2\pi(f_c(t-\tau_j))} \cdot e^{-j\frac{2\pi}{\lambda}r_j(t-\tau_j) \cos(\psi_f)}
\]

where \( Q_n \) is a number of tap in the \( n \)th cluster and \( \tau_j \) indicates the number of scatterers with delay \( \tau_j \). Any single cluster can be described by this model: in particular, each delay line is defined by a certain number of taps and each tap is characterized by a precise number of replicas, all identified by the same characteristic delay. Figure 2 helps to understand the main assumption underlying this model: even if the scattered signals that arrive at the BS haven’t the same delay, cluster modeling allow to represent every group of scatter (in blue in Figure 2) only by means of characteristic delay of the tap (in red) to which they are assumed; that is to say that received signal is temporally discretized. The correlation matrix of the received signal is equal to:

\[
E\left(\tilde{r}_{i}(t)\tilde{r}_{j}^H(t)\right) = \sum_{l=1}^{Q_l} \sum_{k=1}^{Q_k} \alpha_j \alpha_l \cdot \tilde{g}_{j_l}(t) \cdot \tilde{g}_{l_k}(t) \cdot e^{-j\frac{2\pi}{\lambda}r_{j_l}(t-\tau_j) \cos(\psi_f)}
\]

where the off-diagonal terms in the sum are zero because the expectation is equal to zero when \( k \neq l \). This result motivated the definition of the spatial correlation matrix as in [7], so assuming that:

\[
R = \frac{1}{T_f} \sum_{t=1}^{T_f} \tilde{r}(t) \tilde{r}^H(t)
\]

If fast fading phenomena are taken into account by introducing \( \tilde{g}_{j}(t) \), column-vector of independent complex-Gaussian process with Jakes fading statistics, the signal received at BS can be expressed as:

\[
\tilde{y}_n(t) = \sum_{j=1}^{Q_n} \sqrt{PLW_j} \cdot \sqrt{PDP_j} \cdot \tilde{g}_{j}(t)
\]

where \( s_j \) is chosen so that \( R = SS^H \) and \( E\left(\tilde{y}_{j}(t)\tilde{y}_{j}^H(t)\right)=1 \). For this channel model, the correlation is equal to:

\[
E\left(\tilde{y}_{i}(t)\tilde{y}_{j}^H(t)\right) = \sum_{l=1}^{Q_l} \sum_{k=1}^{Q_k} \alpha_j \alpha_l \cdot \tilde{g}_{j_l}(t) \cdot \tilde{g}_{l_k}(t) \cdot e^{-j\frac{2\pi}{\lambda}r_{j_l}(t-\tau_j) \cos(\psi_f)}
\]

It is worth underlining that (6) and (9) present the same statistics. If \( R \) is positive definite, matrix \( S \) can be determined by performing Cholesky decomposition of \( R \). Furthermore, each tap is provided as independent Fast Fading process for any antenna and the correlation matrix \( S \) is derived from the array geometry at the BS, angle of arrival of the scatter with delay \( \tau_j \), PAP and PEP in conformity with Cost 259 indications.

2. Radio Environments

As indicated before, in our model Macro, Micro and Pico cells are modeled and implemented in compliance with the Cost 259 indications.
**Macro Cell**

For what concerns macro cells, Cost 259 describes four radio environments: GTU (General Typical Urban), GBU (General Bad Urban), GRA (General Rural Area) and GHT (General Hilly Terrain). In the macro cell, radio environments present a minimum number of clusters equal to 1 and a variable mean number of additional clusters for any specific radio environment. Moreover, the macro cells are characterized with the probability of Los (Line of sight) and with no elevation spread [5].

**Micro cells**

Cost 259 describes four micro cell radio environments: GSL (General Street Los), GSX (General Street Crossing), GSN (General Street NLos) and GOP (General Open place). For all these radio environments, the micro cells have a minimum number of cluster variable from 1 to 4, while, the mean number of additional clusters varies from 0 to 4. Anyway, the main difference in comparison with macro cells can be identified in the characterization of the Inter-cluster and Intra-cluster distribution. Moreover, the clusters are characterized from delay spread, azimuth and elevation spread [5].

**Pico cells**

Cost 259 describes five indoor radio environment: GOL (General Office Los), GON (General Office NLos), GCL (General Corridor Los), GCN (General Corridor NLos) and GFH (General Factory Hall). The minimum number of clusters is 1 or 0, depending on the Los component presence. The mean number of additional clusters is much larger: therefore, in pico cells the number of generated clusters is high.

3. **WDCM Implementation**

As stated before, proposed simulator is based on clustering concept described in the section 1 and depends on the cell type. In the following, cluster functional implementation will be described for the up-link macro cell case: we stress that, starting from this model, the implementation of clusters for the other environments is straightforward. In Figure 3 the block diagram of the implemented cluster is depicted: in this diagram, three antennas and two TDLs are assumed. Transmitted signal $s(t)$ is delayed by cluster characteristic delay $\tau$. TDL time resolution is equal to $T_c/2$ where $T_c$ represents the chip interval.

For each cluster, Fast fading, Path Loss, Shadowing and Time and Spatial Spread are to be generated whereas elevation spread is not considered. Main difference between macro cellular cluster and micro and pico cell ones can be identified in the Gaussian generator providing the three correlated
variables [5] that are to model Shadowing, Time Spread and Spatial Spread phenomena. Red dashed block in Figure 3 is controlled by cluster Mobility Model and has to be defined in order to provide spatial information about cluster, BS and MS. In Figure 4 the typical macro cellular radio environment configuration is shown in the case of two type of clusters, namely main and additional clusters. Main cluster is considered when radio environment is characterized by Los component: this cluster is supposed to be located around MS for any type of cell; on the contrary, additional cluster is positioned in conformity with the considered radio environment. In the proposed simulator Doppler effect is implemented for any kind of cluster, based on the simulated MS trajectory simulated: this effect is introduced by means Fast Fading samples filtering, with the classical Jakes spectrum.

![Figure 4: Cluster positions in the macro cellular environment.](image)

**Time-Space Resolution**

The sampling time is assumed equal to a submultiple of chip interval $T_c$; as it can be easily foreseen, the larger the sampling rate is, the higher the time resolution, the longer the simulation time. Path Loss and Shadowing are assumed constant on interval equal to 2.5 meter for macro cell and 1 meter for micro and pico cells: all parameters indicated in Figure 4 are assumed to be constant in this interval. Moreover, Time and Space resolutions are correlated with MS velocity: in Table 1 the MS mobility implemented in the simulator is shown.

<table>
<thead>
<tr>
<th>MS Velocity [km/h]</th>
<th>Spatial Resolution</th>
<th>Spatial Resolution</th>
<th>Spatial Resolution</th>
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<tr>
<td></td>
<td>Macro cell [m]</td>
<td>Micro cell [m]</td>
<td>Pico cell [m]</td>
</tr>
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<td>1</td>
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<td>1</td>
<td>-</td>
</tr>
<tr>
<td>250</td>
<td>2.5</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 1: Implemented Mobility.

**Additional Cluster Position**

The positioning of the macro cell clusters is randomly determined inside the cell coverage area; micro cell clusters are defined according to deterministic consideration about the structure of radio environments [5]: in Figure 5 we show the typical positions of the clusters in a GSX radio environment: $C_{l2}$, $C_{l3}$, $C_{l4}$ indicate the additional clusters defined by deterministic considerations. Since pico cells present a higher number of additional clusters, cluster position is not considered and each additional cluster is defined by relative delay characteristic provided in [5]. Furthermore, cluster generation has been modeled by a birth and death process [9-10]. Finally, the angle resolution is not limited since any angle of arrival is exactly determined by Mobility Model.
Mobility Model

Mobility Model takes into account the MS mobility inside the radio environment and gives spatial information to the red dashed block in Figure 3: particularly, Mobility Model supplies spatial information such as Direction of Arrival (DoA) at the BS, angle of departure at the MS and relative distances between clusters, BS and MS. In the simulator, same clusters are used to model the channel behavior for both up-link and down-link transmission.

4. Simulator Processing

The UMTS Directional Channel Simulator is implemented by non-iterative algorithm: firstly, the cell type, the relative radio environment and the MS trajectory inside the radio environment are to be defined. Main and additional clusters have to be updated after proper refresh time: this means that both the number and the position of the clusters have to be updated, depending on radio environment. In particular, in macro cells, number of the clusters is updated once in ten refresh times of path loss and shadowing; in micro cells the number and position of clusters are constant for all the simulation; in the pico cell environment birth and death process are considered \[9-10\]. Mobility Model provides the spatial information needed for the description of all clusters generated during the simulation time. Finally, the clusters contributions are coherently summed, taking into account relative delay. Omnidirectional antennas have been implemented, even if generalization to directional case can be implemented enough easily. The polarization effect introduced by the channel has not been considered in the simulator.

5. Simulations

In this section, simulation results achieved by the proposed tool will be presented. The results are obtained for macro e micro cell cases, trying to highlight the differences between channel responses in the different radio environments.

Macro cell

In the macro cell case, GTU (General Typical Urban) and GHT (General Hilly Terrain) environments have been considered. In Figure 6, we report channel response as it is observable from the receiving antenna in the case of MS moving away from the BS with radial direction for 15 m at 120 km/h speed. In GTU environment, it can be noted that shadowing components cause non negligible effects: particularly, in \[5\] shadowing standard deviation is assumed equal to 9 dB. Moreover, in this environment, as described in Figure 7, power levels of the taps in main and additional clusters are remarkably different: particularly, additional cluster contribution to whole channel response is much less than main cluster term. For the sake of clarity, we highlight that with tap 24 we mean path loss and shadowing power contribution of the 4th tap of additional cluster. Figure 8 shows the Power Azimuth Profile (PAP) as a function of distance and number of replicas for single tap: this profile is characterized by Laplacian distribution \[5\]; besides, the replicas are distributed around DoA at the
BS with Gaussian Statistics. GHT environment has been simulated to show how different the term due to path loss and shadowing term is in comparison with the previous case: as it can be seen in Figure 9, if the MS run through the same distance inside the cell, attenuation is much less than in GTU environment. This result is caused by the different path loss models [11]; moreover, as it is indicated in [5], in GHT shadowing standard deviation is equal to 6 dB.

**Micro Cell**

In the micro cell case, General Street Crossing (GSX) environment has been considered: particularly we considered a MS in a typical crossing, as depicted in Figure 10. In Figure 11 we report channel response as it is observable from the receiving antenna in the case of MS moving away from the BS with radial direction for 10 m at 50 km/h speed. In this micro urban environment, shadowing contribution presents strong variation: as for the GTU case, reported in Figure 6, shadowing standard deviation is assumed equal to 9 dB [5]. In Figure 13, power levels of the taps in main and additional clusters are reported: in this case, additional cluster contribution to whole channel response is remarkable in comparison with main cluster term. Figures 14-15 show the Power Azimuth Profile (PAP) and the Power Elevation Profile (PEP) as a function of distance and number of replicas for single tap: once again, PAP is characterized by Laplacian distribution [5] while PEP is 1-sided exponential, as indicated in [12].

6. Conclusions

In this paper, a Wideband Directional Channel Model is derived and implemented: derivation of the DCIR is performed by means of proper correlation matrix for any type of cells. Proposed model can be classified as statistical based on deterministic considerations for clusters positioning: this approach helps in limiting required simulator complexity. The model is developed for UMTS macro, micro and pico cells. Proposed model and simulator rely on the implementation of clusters in compliance with [5]: each cluster is modeled with tapped delay lines and each tap is formed by several replicas in order to represent spatial information. Proposed model has been implemented for up-link and down-link transmission using the commercial software Matlab©. Mobility Model considered in the simulator provides MS movement and spatial information between cluster, BS and MS. In the proposed tool, for all the considered environment, the number and the position of the clusters are assumed to vary during the simulation in order to represent way directional radio channel in a more realistic.

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References


[2] 3GPP recommendation #3GTS25.212 v3.3.0 (2000-06).


