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WINNER WIDEBAND MIMO SYSTEM-LEVEL CHANNEL MODEL
- COMPARISON WITH OTHER REFERENCE MODELS -

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ABSTRACT

WINNER and COST 273 channel models have been developed for generic (multiple-environment) representation of the wideband MIMO radio-channel. Although both models belong to the class of Geometry-based-Stochastic-Channel-Models, and use similar concepts, there are still significant differences in model structuring and parameterization. This paper compares modeling strategies adopted by WINNER and COST 273 and analyses relevant differences. In general, appearing differences could be associated with different optimization criteria: complexity (WINNER) versus universality (COST 273). It shows (as expected) that a more universal concept is more difficult to parameterize and to validate: WINNER model currently has more parameterized scenarios. Additionally, introduced simplifications made WINNER model appealing for relevant standardization bodies - the ITU-R has accepted the WINNER approach as reference for evaluation of IMT-Advanced radio interface technologies.

Index Terms - Generic multipath MIMO channel model, spatial/wideband/system-level channel modeling, measurement-based parameterization

1. INTRODUCTION

The aim of WINNER (Wireless world INitiative NEw Radio) project [1] was to define a single ubiquitous radio access concept for beyond 3G systems, being scalable and adaptable to different short range and wide area scenarios and considering frequencies up to 5 GHz and bandwidths of 100 MHz. Since the radio interface have been seen as the key part of this concept, realistic propagation models covering many different environments were required for its design. Developed WINNER-channel-Model (WIM) [2] has advanced 3GPP SCM [3] concepts toward a single generic framework that is capable to represent all targeted indoor/outdoor environments (scenarios). Different (scenario-specific) parameter sets for the generic model are based on series of wideband, polarimetric, MIMO radio-channel sounding experiments.

Somehow in parallel, a generic COST 273 [4] model is developed from the COST 259 framework, having similar objectives as WIM. Since results of COST 259 action have influenced 3GPP SCM as well (SCM is in essence also Double-Directional-Channel-Model), it is reasonable to expect that WIM and COST 273 model share some similarities. However, SCM have been developed for system-level performance analysis and therefore introduced many simplifications to reduce complexity (computation time).

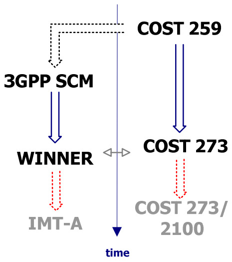

Figure 1. Relation between modeling activities: majority of contributions originate from academy (COST) or industry (SCM/WINNER).

COST 273 model designers have claimed that introduced simplifications could restrict the general applicability of the model and therefore decided to provide more universal concept. In similar manner, descendant action COST 2100 [5] has continued tuning and parameterization of the COST 273 model, disregarding WIM/SCM simplifications.

In the meantime WIM concept (WINNER+) has impacted IMT-Advanced standardization. ITU-R M.2135 Report takes slightly modified WINNER model as reference for evaluation of IMT-Advanced radio interface technologies. [6]

The paper will further discuss global relations between COST, 3GPP and WINNER. The rest of the paper will be organized as follows: section 2 will give the basic insights into WIM construction. In the section 3 concepts and methodology of WIM and COST 273 model will be compared. The analysis of relevant and parameterized scenarios will be performed in section 4. The last section will summarize the most important findings.

2. WINNER CHANNEL MODEL

WIM is Geometry-based-Stochastic-Channel-Model (GSCM), in which a time-variable Channel-Impulse-Response (CIR) is constructed as a finite sum of Multi-Path-Components (MPCs).

2.1. Geometry Aspects

The constituting MPCs are characterized by departure (from Tx) and arriving (to Rx) directions, propagation delay and power. During model synthesis MPCs are generated in clusters, not individually: CIR between transmitter antenna element s and receiver antenna element u is generated by summing contributions of N clusters, each having M MPCs:

$$\mathrm{h}_{u,s}(t;\tau)=\sum_{n=1}^{N}\sum_{m=1}^{M}\mathbf{F}_u^T\left[(\theta,\varphi)_{n,m}^R\right]\boldsymbol{\alpha}_{n,m}\mathbf{F}_s\left[(\theta,\varphi)_{n,m}^T\right]\cdot \\ \cdot e^{j2\pi\upsilon_{n,m}t}\delta\left(\tau-\tau_{n,m}\right) \quad (1)$$

The superposition (1) of specular paths with different propagation delays $\tau_{n,m}$ results in the correlation between antenna elements and temporal fading with a geometry dependent Doppler spectrum.

The complex, polarimetric response of an element in the antenna array:

$$\mathbf{F}(\theta,\varphi)=[\,F_\theta(\theta,\varphi),F_\varphi(\theta,\varphi)]^{\mathrm{T}}\cdot e^{j\mathbf{k}(\theta,\varphi)\mathbf{d}} \quad (2)$$

describes deterministic influence of antenna to a propagation channel. A directional filtering of an antenna is defined for two orthogonal polarizations by field patterns $F_\theta(\theta,\varphi)$ and $F_\varphi(\theta,\varphi)$. The spatial displacement of an antenna element inside array, described by vector $\mathbf{d}=d_x\mathbf{i}_x+d_y\mathbf{i}_y+d_z\mathbf{i}_z$, will cause phase shift $e^{j\mathbf{k}(\theta,\varphi)\mathbf{d}}$ that is dependant on angle of departure/arrival, since

$$\mathbf{k}(\theta,\varphi)=\frac{2\pi}{\lambda}\left[\sin(\theta)\left(\cos(\varphi)\mathbf{i}_x+\sin(\varphi)\mathbf{i}_y\right)+\cos(\theta)\mathbf{i}_z\right] \quad (3)$$

A global influence of the environment to the orthogonal wave polarizations is described by log-normally distributed cross-polarization discrimination ratios (XPRs). Random XPR realizations, κ, are used for the construction of 2x2 matrix $\boldsymbol{\alpha}_{n,m}$. Additionally, elements of this matrix incorporate complex MPC gains: all MPCs in cluster have the same power and random (independent) uniformly distributed phases Φ.

$$\boldsymbol{\alpha}_{n,m}=\sqrt{\frac{P_n'}{M}}\begin{bmatrix} e^{j\Phi_{n,m}^{vv}} & \sqrt{\kappa_{n,m}}e^{j\Phi_{n,m}^{hv}} \\ \sqrt{\kappa_{n,m}}e^{j\Phi_{n,m}^{vh}} & e^{j\Phi_{n,m}^{hh}} \end{bmatrix} \quad (4)$$

Term $e^{j2\pi\upsilon_{n,m}t}$ in (1) describes changes of MPC phases that are consequence of terminal movement, and it is used to simulate small-fading effects.

An evolution of MPC parameters cannot be based on the ray-tracing since <u>positions of scattering clusters are unknown</u>. Instead, they are chosen/evolved using randomly driven algorithms.

2.2. Randomness

The entire process of WIM parameter synthesis can be analyzed in three hierarchy levels. In the first two levels majority of random parameters are generated, while mainly deterministic calculations are performed on the third level.

1) At the first level, <u>Large-Scale-Parameters</u> (LSPs): shadow fading (SF), K-factor, CROSS-Polarization-discrimination-Ratio (XPR), delay (DS) and angular spreads (AS) are drawn randomly from tabulated log-normal PDFs. With the exception of XPR, all other LSPs are generated as CORRELATED random variables. Distance-based intra-cell correlations of LSPs are also taken into account (Figure 2).

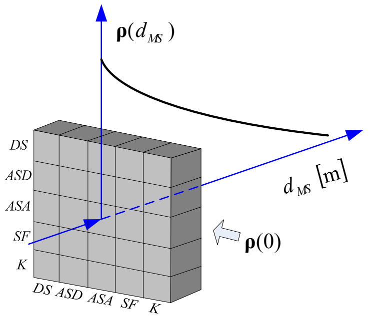

Figure 2. Distance dependent correlation coefficients used in WINNER channel model.

2) On the second level, cluster parameters are determined. For the sake of the simplicity this level of freedom is somehow reduced in SCM/WIM, since all clusters share the same (scenario dependant) intra-cluster angular spread (CAS). Additionally, irrespective from WIM scenario, intra-cluster delay spread (CDS) can be either 0 or 3.9 ns. Zero-Delay-Spread-Clusters (ZDSCs) are introduced in SCM since that concept offers straightforward analogy to tapped-delay-line (TDL) model. Since disregarding of CDS increases frequency correlation, ZDSC concept is not fully suitable for wideband models. As a compromise two strongest clusters are spreaded in WIM, by using the constant CAS of 3.9 ns. Therefore, only cluster centroid (CC) parameters are drawn randomly from tabulated marginal distributions. Randomly generated LSPs from the first level are used to parameterize marginal distributions at the second level: DS controls decay for exponentially distributed CC delays, while AS controls dispersion of CC DoD/DoA having wrapped Gaussian distribution (Figure 3).

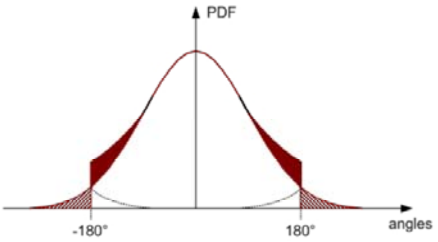

Figure 3. Wrapped Gaussian distribution.

3) In order to further simplify cluster characterization SCM/WIM does not deal with random placement of MPCs in “delay-directional” domain. Instead, on the 3rd level, the same, simple internal structure of the cluster is used and MPC parameters are calculated in deterministic manner. This structure assumes fixed number of MPCs with equal power. Angular separations between MPCs account for assumed Laplacian PAS and given CAS. This WIM functionality is realized by scaling predefined angular offsets with wanted CAS, what is possible when “one-degree” offsets are symmetric around mean cluster direction, and MPCs have the same power. In ZDSCs all MPCs share the same propagation delay corresponding to cluster centroid. Clusters with 3.9 ns delay spread are constructed by the fixed delay offsets of 0, 5 and 10 ns in respect to a reference CC delay. The normalized powers of formed sub-clusters are 10/20, 6/20 and 4/20, what means that delay offset of 0 ns is assign to 10 from 20 available MPCs, 5 ns offset to 6 MPCs and 10 ns offset is given to 4 MPCs in cluster. This is illustrated in Figure 4.

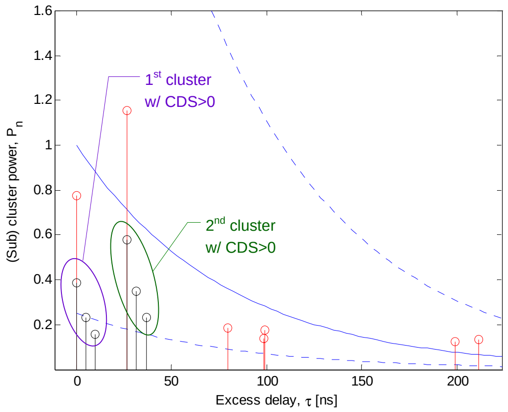

Figure 4. An introduction of the delay dispersion to the two strongest WIM clusters.

MPC’s Doppler shift is related to the mobility pattern, i.e. velocity of Mobile-Terminal (MT).

At this stage, the geometric setup is fixed and the only free variables are the random initial phases of the scatterers (Φ in expression (4)). By (randomly) picking different initial phases, an infinite number of different realisations of the model can be generated.

2.3. Scenario-specific Parameterization

The WINNER system is designed to support ubiquitous coverage. This concept relies on the system-deployment schemes for Wide Area (WA), Metropolitan Area (MA), and Local Area (LA). With every system-deployment scheme appropriate Reference-Propagation-Scenarios (RPS) are associated. These scenarios are dependent upon the following of system-deployment parameters:

- coverage type (e.g. ubiquitous, localized),
- propagation environment (e.g. indoor),
- station deployment (BS/MT position and height),
- mobility model (terminal speed).

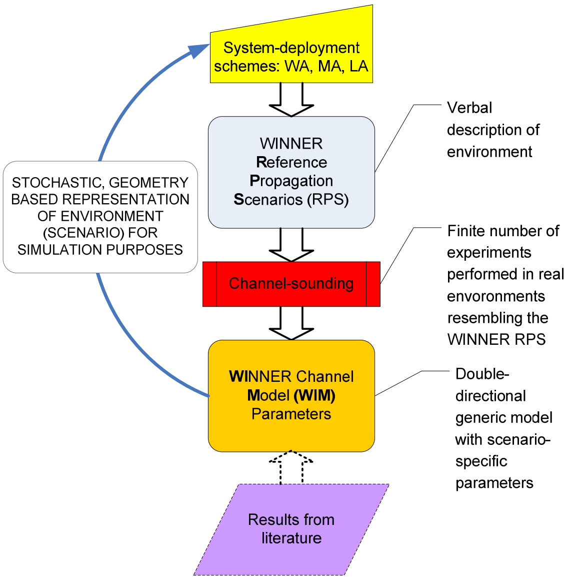

Figure 5. WINNER reference propagation scenarios.

Necessary scenario-specific model parameters are determined from channel measurement data, gathered during the WINNER project [7], and results found in a literature. The latter are analyzed in order to come up with the most typical representatives for targeted scenario. The WINNER measurement campaigns are conducted in radio environments providing the best possible match to defined reference scenarios. The WIM is currently parameterized for 12 different scenarios: A1–Indoor (small office/ residential), A2–Indoor-to-outdoor, B1–Typical urban micro-cell, B2-Bad urban micro-cell, B3–Indoor hotspot, B4–Outdoor-to-indoor, B5–Stationary feeder links, C1–Suburban, C2–Typical urban macro-cell, C3 Bad urban macro-cell, D1–Rural macro-cell, and D2–Moving networks, and distinguishes LoS/NLoS in all applicable scenarios. The full set of WIM RPS parameters can be found in WINNER deliverable D1.1.2 [2].

3. COMPARISON WITH COST 273 MODEL

Both models support representation of *wideband MIMO* radio-channel between *multiple* transmitting and receiving *stations*.

Transmission-loss models are defined explicitly (separately from other features) in both COST 273 and WIM. This allows use of the existing transmission-loss models, however, WIM’s transmission-loss models are mainly based on measurements taken during the WINNER project [7].

In both models power ratio between orthogonal signal *polarizations* is expressed by log-normally distributed CROSS-Polarization-Discrimination-Ratios (XPD in COST 273 and XPR in WIM).

For *LoS* cases ratio of direct power and reflected/diffracted power is adjusted in both models. In WIM this parameter is called Ricean K-factor (following analogy with narrowband case), while COST 273 termed this quantity “LOS power factor”. In both models this is log-normal random variable.

Both WIM and COST 273 use GSCM approach, where MPCs are grouped into *clusters*.

3.1. Global vs. Cluster-Level Characterization

It is necessary to be cautious, when comparing WIM and COST 273 models since similar terms are applied on different levels of the model characterization: WIM is introducing Large-Scale-Parameters (i.e. angular and delay spreads, shadow fading, K-factor) on the global level, while COST 273 is often using the same parameters on cluster-level.

If we disregard the level at which characterization is performed it is possible to recognize that the general approach is the same: the control variables are generated as correlated random numbers from predefined distributions. There is however difference in the number of the correlated control variables: SCM e.g. uses shadow fading, delay spread, and spread of departure angles. COST 273 model additionally considers spread of arriving angles, referring to both azimuth and elevation angles (if applicable). In WIM there is one more parameter: K-factor is used under LoS conditions, what gives 7 correlated variables in total.

3.2. Cluster Generation

The COST 273 model makes a distinction between clusters involved into single and multiple interactions. This model allows two different strategies for cluster generation: “geometric” and “angular spectrum”. The geometric generation assumes cluster placement in a referent coordinating system via the concept of “visibility regions”. Different geometric strategies are proposed for both single and multiple interaction clusters. In “angular spectrum” approach mean DoD, DoA and delay are generated as random variables from predetermined distribution (like in WIM). The “angular spectrum” strategy is intended only for multiple interaction clusters.

In the SCM/WIM models there are no distinction between clusters based on the number of interactions and the only “angular spectrum” strategy is used for their generation. This can be considered as one of the essential differences between COST 273 and WIM. It follows from different viewpoints of measurement-based characterization (WIM, i.e. “angular spectrum”) and synthetic model generation (“geometric” strategy). After acquiring MPC parameters from high-resolution algorithms, antenna centric view of the channel is obtained. This analysis gives power distribution over delay, direction and polarization domains. Such a representation is suited for “angular spectrum” approach, and enables straightforward extraction of model parameters. The missing part, that makes this approach different from geometric cluster generation, is distance between BS/MT and the last interacting cluster. This step is however necessary if we would like to determine scatters positions from the measurement data. Some related work can be found in [8] and [9].

3.2.1. Impact of scatterer positioning to model parameterization/validation

The positioning of Interacting-Objects (IO) in the *geometry* domain during model synthesis makes model less suitable for the experimentally-based parameterization, since additional transformation of the measured features from *parametric* domain (Doppler, delay, angular, polarization) into IO positions is required. It can be recognized that this type of analysis tremendously increases data analysis requirements, which have been already very high due to high-resolution parameter estimation. (The procedure is simple only for single interaction case [10].) In contrast, the WIM model is synthesized in *parametric* domain, without excursion into geometry domain, what enables straightforward parameterization from measurements.

Additionally if “visibility regions” of single clusters should be determined from measurements, it would be necessary to perform rendering of the complete 2D plane/3D volume. Typically, measurements have been performed mainly over straight routes since storage capacities and necessary analysis time are putting limit to reasonable number of snapshots that should be taken during the measurements. Having this in mind, it becomes clear that verification of geometric cluster generation cannot be easily performed from measurements!

There is another approach to this problem: a development of mechanisms for geometric cluster positioning that mimic observed signal statistics. For this purpose COST 273 proposes different strategies for clusters with single and multiple interactions.

3.2.2. Number of Clusters

In COST 273 model cluster visibility regions (geometry approach) are placed to reflect constant number of visible clusters in average. “Angular spectrum” approach, determines the number of “visible” clusters as random variable with predefined distribution. WINNER model introduces further simplification and for given scenario uses constant number of clusters that is equal to the mean number of clusters observed in measurement data.

3.2.3. Space-Time Channel Evolution

A placement of the visibility regions in COST 273 model is indirectly defining space-time evolution of the propagation channel (e.g. for given trajectory of the MT), and correlation between different spatial positions. In the original SCM concept a quasi-static approach is used that does not take care about evolution – consecutive simulation "drops" correspond to random locations of the MT. In WIM concept evolutionary transitions between neighboring "drops" (local stationarity intervals exhibiting small changes of LSPs and propagation delays, DoA/DoDs) are supported. Since WIM does not use IO positioning (i.e. environment structure), (dis)appearance of the clusters is considered in parametric "delay-directional" domain. In order to emulate ST evolution in parametric domain WIM uses distance-based correlation of the Large-Scale-Parameters. Transitions between LoS/NLoS propagation conditions and different scenarios are also supported with this concept.

3.3. Cluster Structure

In COST 273 model each cluster (opposite to WINNER, section 2.2) is characterized with its own (correlated) angular and delay spread parameters. These spreads are controlling INTRA-cluster angular (Laplacian) and delay (exponential) power distributions.

SCM/WIM use predetermined cluster structure where all MPCs in cluster share equal powers. This is not the case in COST 273 model where the power of MPCs is characterized by a Ricean distribution. It should be noted that COST 273 approach differs from the usage of per-cluster K-factor in [11]. The latter model assumes that MPCs have equal power (like WIM), but allows existence of group with coherent MPCs (forming dominant scatterer).

4. CORRESPODENCE BETWEEN WINNER AND COST 273 SCENARIOS

WIM scenarios are based on "typical" environments. This means that WINNER RPS does not attempt to parameterize environment itself and therefore parameters as average rooftop height, width of roads, distance between buildings, road orientation with respect to direct path, size of rooms, number of floors between BS and MT, are not explicitly used. Some of them are implicitly included into WINNER scenario definitions.

The WIM LoS and NLoS conditions are not distinguished only by the existence of the single strong LoS component. Instead, all scenario-dependent parameters are calculated separately for the LoS and NLoS propagation conditions. When simulations are performed without knowledge of street grid or building layout, the WIM model rely on a set of scenario-dependent expressions for LOS probability.

In the parameterized COST 273 scenarios LoS occurrence is determined using the "visibility region" concept. The probability of LoS regions decreases rapidly with the BS-MT distance, and becomes zero after cut-off distance.

The classification of the COST 273 scenarios is shown in Figure 6. As in the case of the WINNER RPS COST 273 scenario definitions are model independent, but all of them are being represented by the single generic channel model.

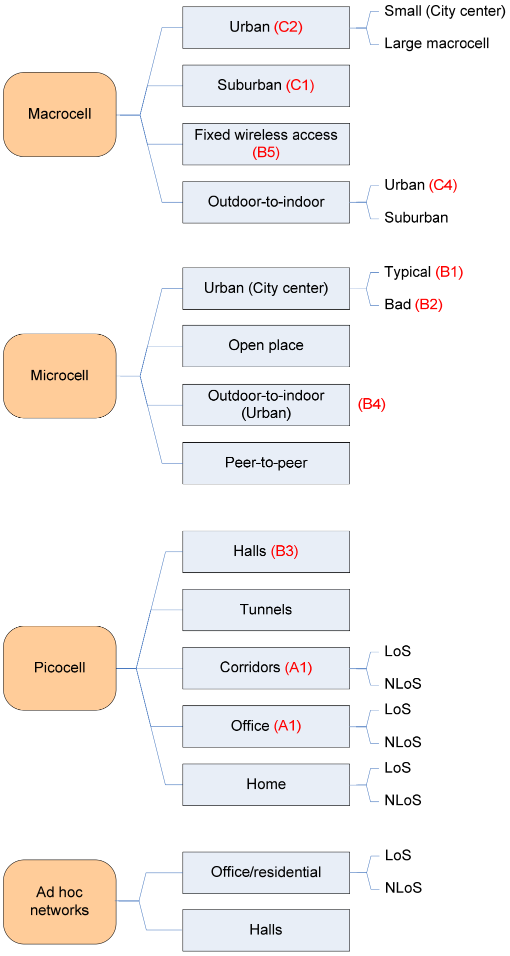

Figure 6. COST 273 model scenarios (WINNER matching scenarios are indicated in brackets).

From Figure 6 it can be recognized that significant overlap exist between COST 273 and propagation scenarios investigated in WINNER project. Some COST 273 scenarios (microcell open space, tunnels and home environment) have not been analyzed in WINNER. On the other hand, some WINNER scenarios: Indoor-to-outdoor, Rural and Moving Networks are not included into COST 273 scenario classification. Additionally number of parameterized scenarios will be further extended within ongoing WINNER+ project [1].

5. DISCUSSION

It can be noticed that significant similarity exist between WIM and COST 273 models. This becomes especially pronounced when WIM is compared to "angular-delay" approach of COST 273 model. Opposite to COST 273, WIM has not proposed any "geometric" analogy to "angular-delay" representation. In that sense, the key driving parameter in the COST 273 geometric model is a density of the visibility regions (later transferred into the number and cluster positions), while WIM characterizes the measured Power-Delay-Directional-Profile by using Large-Scale-Parameters (angular and delay spreads, shadowing). The significant difference between these models is also related to the degrees of the freedom in cluster characterization: WIM have introduced many simplifications in order to reduce complexity.

In the course of the WINNER project, SCM, SCME and WIM (phase I and II) models are implemented in MATLAB/C and made available through the official web site [1]. The current WIM implementation considers only 2D ray-propagation in the zero-elevation plane, however the suitable polarimetric representation for 3D antenna arrays was proposed [12] and distributions of elevation angles were provided for indoor scenarios [2].

The MATLAB implementation of the COST 273 model is provided by Helmut Hofstetter, from Telecommunications Research Center Vienna (FTW). Supported CIR calculations are valid only for the short MT movements, since the long term evolution of the model is missing. The implementation covers the core part of the model (with the placement of the clusters and IOs) and it is available at [13]. Further extensions/completion of this implementation is envisioned within COST 2100 action.

Some aspects of a radio-propagation (moving scatterers, diffuse scattering, multi-link large scale correlations …) that are not properly addressed in described models could be further investigated within WINNER+ project or COST 2100 action. Among different aspects the model validation can be recognized as the most important for both WIM and COST 273 models.

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