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A set of channel and propagation models for early link and system level simulations

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Abstract:
This report includes a list of channel models, which are intended for preliminary link and system level simulations. They are selected from existing channel models. The most suitable models are selected to ensure comparable simulations in the beginning of the project.

Keyword list:

Channel model, propagation, fading, link-level, system-level

Disclaimer:

Executive Summary

This report introduces widely known radio channel models. Early assumptions on propagation scenarios and WINNER radio system were exploited when selecting the most promising existing MIMO models for more deep analysis. Based on the analysis, the most suitable models are selected for immediate use in WINNER project. MIMO techniques have been seen crucial in B3G systems. Thus, main focus in this work was aimed to MIMO channel models, namely IEEE 802.11n, METRA and 3GPP SCM.

Technical selection criteria were the applicability of the model to WINNER scenarios, frequency range, bandwidth, supported antenna configurations, mobility, path loss, short-term and long-term fading, correlation characteristics and possibility to modify antenna pattern. Other selection criteria were simplicity, model availability, reality and available software implementations.

Only cellular mobile and WLAN channel models were analyzed. It was noticed, that most of the existing models have been developed for either only cellular or only WLAN applications. It was assumed that cellular applications are quite close to WINNER wide-area scenario, and WLAN applications quite close to WINNER short-range scenario in radio propagation point of view.

The selection is as follows. IEEE 802.11n models will be used for short-range scenarios while 3GPP SCM models will be used for wide-area scenarios. Unfortunately, both models have essential limitations and drawbacks. During the WINNER project, more advanced models will be developed.

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1. Introduction

This deliverable introduces widely known and standardized radio channel models for immediate use in WINNER project. Early assumptions on propagation scenarios [18] and WINNER radio system were exploited when selecting the most promising existing MIMO models for more deep analysis. Based on the analysis, the most suitable models are selected for immediate use in WINNER project.

MIMO techniques have been seen crucial in B3G systems. Thus, main focus in this work was aimed to MIMO channel models, namely IEEE 802.11n, METRA and 3GPP SCM. Other standardized models have been designed for SIMO or SISO channels.

Technical selection criteria were the applicability of the model to WINNER scenarios, frequency range, bandwidth, supported antenna configurations, mobility, path loss, short-term and long-term fading, correlation characteristics and possibility to modify antenna pattern. Other selection criteria were simplicity, model availability, reality and available software implementations.

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This document is organized as follows. Section 2 discusses the background of this deliverable. It introduces the general assumptions, propagation scenarios and assumed division between link level and system level models. Section 3 describes the standard models. Main focus is on the pre-selected three models (IEEE 802.11n, METRA and 3GPP SCM). Other models are briefly introduced. Section 4 compares the three pre-selected models. Pros and cons of each model are listed. Section 5 describes the selection between the three models. Section 6 concludes this deliverable.

1.1 Terms and Abbreviations

3GPP	3rd Generation Partnership Project
3GPP2	3rd Generation Partnership Project 2
AoA	Angle of Arrival
AoD	Angle of Departure
AS	Angular Spread, Azimuth Spread
AWGN	additive white Gaussian noise
B3G	Beyond Third Generation Mobile and Wireless Communications
BRAN	Broadband Radio Access Networks
BS	Base Station
CIR	Channel Impulse Response
COSSAP®	Commercial product (system level design tool)
COST	European Co-operation in the field of Scientific and Technical research
DCM	Directional Channel Model
DL	Downlink
DoA	Direction of Arrival
DoD	Direction of Departure
DoT	Direction of Travel
DPS	Doppler Power Spectrum
DS	Delay Spread
EDGE	Enhanced Data for GSM Evolution
ETSI	European Telecommunications Standard Institute
FDD	Frequency Division Duplex
FH	Frequency Hopping
FITNESS	Fourth generation Intelligence Transparent Network Enhanced through Space-time Systems (project name)
FSC	Far scatterer clusters
GSM	Global System for Mobile Communication
HSDPA	High Speed Downlink Packet Access
I/C	Interferer to Carrier Ratio
IEEE	Institute of Electrical and Electronics Engineers, Inc.

I-METRA	Intelligent Multi-Element Transmit and Receive Antennas (project name)
IR	interim report
IST	Information Society Technologies
ITU	International Telecommunication Union
ITU-R	International Telecommunication Union, Radio Sector
JTC	Joint Technical Committee
Kronecker model	Model where MIMO correlation matrix is Kronecker product of Tx and Rx correlation matrices.
LL	Link Level
LOS	Line-of-sight
Matlab©	Commercial product (numerical calculation software)
MBWA	Mobile Broadband Wireless Access
METRA	Multi-Element Transmit and Receive Antennas (project name)
MIMO	Multiple Input Multiple Output
MS	Mobile Station
MTMR	Multiple Transmitter Multiple Receiver
NLOS	Non-Line-of-Sight
PAS	Power Azimuth Spectrum
PCS	Personal Communication Services
PDF	Probability Density Function
PDP	Power Delay profile
PDS	Power Delay Spectrum
PL	Path Loss
RMS	Root Mean Square
RV	Random Variable
Rx	Receiver
SCM	Spatial Channel Model
SF	Shadow Fading
Short-Range	WINNER scenario for short-range hot-spot and WLAN applications
SIMO	Single Input Multiple Output
SISO	Single Input Single Output
SL	System Level
SW	Software
TBD	To Be Defined
TDD	Time Division Duplex
TGn	IEEE 802.11 Technical Group n, “high throughput”
Tx	Transmitter
UE	User Equipment
ULA	Uniform Linear Array
UL	Uplink
UMTS	Universal Mobile Telecommunication Services
Wide-Area	WINNER scenario for outdoor mobile systems
WINNER	Wireless World Initiative New Radio
WLAN	Wireless Local Area Network
WP	Work Package
WP5	Work Package 5 of WINNER project, “Channel Modeling”
XPD	Cross-Polarization Discrimination

2. Background

2.1 WP5 assumptions for T5.1

2.1.1 General assumptions

In the WP5 interim report IR5.1 the following general assumptions were made for the channel models [18]:

- Frequencies are in the range 1 – 6 GHz.
- Maximum RF bandwidth will be 100 MHz.

2.1.2 Propagation scenarios

The propagation scenarios were defined as shown in the table Table 1.

Table 1 Propagation Scenarios.

Scenario		**Mobility** km/h	**Frequency** GHz
Wide-Area	Rural	200	2 & 5
	Suburban	100	2 & 5
	Urban	50	2 & 5
	Outdoor to indoor	5	2 & 5
Short-Range	Urban	5 & 50	2 & 5
	Indoor	5	2 & 5
Multiple link		TBD	2 & 5

The scenarios were defined in [18] for the center-frequencies 2 GHz and 5 GHz, see the table. The initial models will cover these only partially, see 5.6. For the initial models there are apparently no multiple link models available.

2.1.3 Assumed division to link level and system level models

The division of the models to link-level and system-level ones has been defined in [18] as follows:

1. Link-level simulations focus on one link only, which means from one antenna array to another.
2. The connection between BS and UE via several hops belongs already to a system-level simulation.
   -Each single connection, i.e., between two hops, is considered as link-level.

The definition of the division for the cases i) distributed antennas and ii) interference modeling were left open issues [18].

For the initial models considered here the situation is simpler, because the proposed models are not meant for distributed antennas. As well the definitions of interference are unambiguous for the different models proposed. Therefore the open issues are resolved for the initial channel models.

In spite of the afore mentioned facts, it seems that the link- and system-level models defined, and the corresponding simulations implied, in one of the proposed models, 3GPP SCM (see the paragraph 3.2), might be different from the ones assumed by the participants of the WINNER project.

2.2 Models considered

The models considered as candidates for the WINNER initial channel models are the following:

- 3GPP SCM [5]
- IEEE 802.11n [1]
- METRA [19], [21]

The reason for selecting these models as candidates for the WINNER initial channel models is the fact that they are the only well-defined MIMO channel models available. Note that METRA means here both IST METRA and the IST I-METRA.

Some other models will be discussed for reference, but they are not considered as candidates for the WINNER, because they are not MIMO models or they are in a premature phase of the specifying process. (See paragraph 3.3.1.)

3GPP SCM model is a ray-based (geometry-based) model. The other two models are stochastic.

3. Descriptions of the models

3.1 IEEE802.11n

3.1.1 General

Channel models of IEEE802.11n are designed to indoor environments for MIMO WLAN application. Modeled environments are from small offices and residential homes to large offices and open spaces with Line-of-sight (LOS) and non-Line-of-Sight (NLOS) conditions, rms delay spreads are from 15 to 150 ns. Propagation channel is directional by nature and dispersed in time, frequency and space.

Clustered structure of the propagation environment is assumed. In these models it means that multipath components with variety of delays and incidence angles are grouped into clusters where each cluster has a number of multipath components with different delays and powers but same angular characteristics. Number of clusters and multipath components varies from model to model, but maximum number of distinct delay components (channel taps) is 18. WLAN applications operate at 2 GHz and 5GHz bands. Experimental results from these two frequency bands are averaged to compose the models, thus a single set of models should be applicable on both bands. Channel taps are separated in delay at minimum 10 ns, so bandwidth of the model is 100 MHz. Principle in the generation of channel realizations out of IEEE 802.11n channel models is stochastic.

A reference implementation of the model for Matlab© exists [3].

3.1.2 Model description

Although model parameters are geometric like angles and array orientations, the creation of channel impulse response coefficients is based on spatial correlation matrices. Temporal correlation and spatial correlation are carried out by separate and independent filtering operations. Spatial correlation between two elements in an antenna array is analytical expression and a function of Power Azimuth Spectrum (PAS) and antenna geometry. Transmitter array and receiver array correlation matrices are combined to MIMO channel correlation matrix by Kronecker product. This approach assumes that transmitter and receiver power azimuth spectra of each channel tap are separable, which is not valid in general [4]. Actually the model does not state the generation of the coefficients explicitly e.g. correlation matrix based, but it is included in the model implicitly by for example giving Doppler power spectrum shapes.

3.1.3 Supported environments

Actual model includes tables of parameters for seven indoor environments. There is also given two different kind of Doppler power spectrums and descriptions of some special features. Parameter tables contain cluster structure and excess delay, power, Angle of Arrival (AoA), Angle of Departure (AoD) and Angular Spread (AS) of departure and incidence angles for each multipath component. Features of the models are path loss, shadow fading, deterministic LOS component and Doppler components due to fluorescent lights. Elevation AS is excluded from the model, thus antenna array orientation in a horizontal plane applies only. Cross-polarization discrimination (XPD) for LOS and NLOS conditions is defined, but not antenna correlation model for cross-polarized antennas. Thus the polarization model is not fully described and applicable.

- Model A (optional, should not be used for system performance comparisons), flat fading model with 0 ns rms delay spread (one tap at 0 ns delay model). This model can be used for stressing system performance, occurs small percentage of time (locations).
- Model B with 15 ns rms delay spread.
- Model C with 30 ns rms delay spread.
- Model D with 50 ns rms delay spread.
- Model E with 100 ns rms delay spread.
- Model F with 150 ns rms delay spread.

Model mapping to a particular environment is presented in the following table.

Table 2: Model to environment mapping.

Environment	Condition	Model
Residential	LOS	B – LOS
	NLOS	B – NLOS
Residential / Small Office	LOS	B – LOS
	NLOS	C – NLOS
Typical Office	LOS	C – LOS
	NLOS	D – NLOS
Large Office	LOS	D – LOS
	NLOS	E – NLOS
Large Space (Indoors and Outdoors)	LOS	E – LOS
	NLOS	F – NLOS

3.1.4 Statistical properties

Characteristics of the models are taken from several measurement results referred in [1]. Power azimuth spectrums are truncated Laplacian shape. Means to use uniform and truncated Gaussian PAS are also given in [2]. Doppler spectrums are caused by so called environmental scatterer speed. There are two Doppler spectrum shapes: one called 'bell shape' with very small Doppler frequency and another called 'bell with spike shape' which in addition to former has also non symmetric peak frequency caused by bypassing vehicle. Path loss function has two slopes and so called break point distance to separate the slopes. Shadow fading is drawn randomly from log normal distribution and is fixed for the single use of the channel model.

One special effect in the model are the Doppler components due to fluorescent lights. This takes effect by modulating several channel taps in order to artificially introduce an AM modulation in the received signal. Interferer to carrier energy ratio (I/C) is drawn randomly to scale the modulation. Ratio I/C is constant for the single use of the channel model.

3.1.5 Computational complexity

Calculation of the channel coefficients is computationally effective. For example correlation matrices for fixed antenna array geometry need to be calculated only once for each model. Most of the parameters are fixed and only few of them, e.g. shadow fading effect and interferer to carrier power ratio of fluorescent light effect, are drawn randomly for every realization. Drawbacks of the models are limited capability to model antenna arrays and assumption of separable Tx and Rx PAS of each tap. In principle all antenna geometries in horizontal plane are possible. However it is not possible to model antenna radiation patterns, all antennas are assumed strictly omni-directional. System level features are not supported in the model. All the parameters are given for a single link.

3.1.6 Evolution possibilities

Parameter tables, which are the essence of the IEEE 802.11n models can be used also with parametric ray-based modeling like with 3GPP SCM. Because parameters are geometrical they can be fitted to channel coefficient calculation of SCM is necessary. This would just increase complexity of calculations on some extent because every delay has several multipath components and in the SCM type model each multipath should be calculated separately.

3.1.7 Model summary

Summary table of the characteristics of the IEEE 802.11n model can be found in the appendix 1.

3.2 3GPP SCM

3.2.1 General

A drive towards MIMO channel modeling between 3GPP and 3GPP2 is done by a joint group, called 3GPP-3GPP2 SCM AHG. The joint group was formed with the purpose of harmonization of spatial channel modeling assumptions between the 3GPP2 SCM Ad Hoc group and the 3GPP MIMO Ad Hoc group. The scope of the 3GPP-3GPP2 SCM AHG is to develop and specify parameters and methods associated with the spatial channel model (SCM) that are common to the needs of the 3GPP and 3GPP2 organizations. The goal is to develop a model as a common reference for evaluating different MIMO concepts.

The 3GPP-3GPP2 Spatial Channel Model (SCM) consists of two "submodels": a) link level channel model and b) system level channel model. In this section we briefly describe the SCM modeling approach for both sub-models, their main parameters and key features. The technical details can be found in [5].

No reference implementation of the model for Matlab exists.

3.2.2 Model Description

3.2.2.1 Link Level Spatial Channel Model

The SCM link-level channel model considers a MIMO link where a single base station transmits to a single mobile station. It is an extension (to spatial domain) of the fixed tap-delay channel models specified in ITU-R Rec. M.1225. The difference from ITU power-delay profiles is in Case I where an optional line-of-sight component has been added. All paths are assumed independent and each is characterized by its own spatial channel parameters, power azimuth spectrum (PAS), angle spread (AS), mean angle of arrival (AoA). It is mentioned in [5] that the link level model is for calibration purpose, which might refers to only the 3GPP related work,

The described link level assumptions define a set of spatial parameters that correspond to static channel conditions. A variety of spatial channel model parameters examined for link level analysis is shown in Table 4.1 in [5]. Each channel scenario has its distinctive parameter values. Four different model cases termed "Case I" through "Case IV" are suggested. .

The assumptions of the link level simulation do not define specific array for either the BS or the MS. The proposed antenna patterns used for each sector, reverse link and forward link, are plotted in Figures 4.1 and 4.3 in [5] for 3-sector and 6-sector cells, respectively. These antenna patterns are targeted for diversity-oriented implementations (i.e. large inter-element spacing), for other applications, different antenna patterns can be used. For each antenna element at the MS, the antenna pattern is assumed omnidirectional with an antenna gain of -1 dBi. Since an omnidirectional MS antenna is assumed, the received power azimuth spectrum (PAS) per path will remain either Laplacian or uniform. The per-path Doppler Spectrum is not defined explicitly; it is implicitly determined by the direction of travel (DoT), the per-path PAS and AoA, and, to some extent, by the implementation of the model (correlation or ray-based).

3.2.2.2 System Level Spatial Channel Model

The principle of the SCM system-level channel follows some of the COST 259 recommendations. No specific antenna topologies are enforced, linear array geometry is discussed. The model is a ray-based model where a subset of the parameters are stochastic. The center frequency and bandwidth are 2 GHz and 5 MHz, respectively. As a geometric model its uplink and downlink are reciprocal in TDD operation, i.e. uplink AoDs are also the downlink AoAs, and vice versa. For FDD systems the phases between UP and DL are uncorrelated but are fully correlated for TDD systems. In the SCM the simulation is carried out as a sequence of "drops". During a drop, the channel undergoes fast fading according to the speed of the mobile station. The parameters are regenerated randomly after each drop. Large-scale channel parameters, such as angle spread, delay spread, shadowing stay constant during a drop; hence there is no transition behaviour in the model.

A key parameter in a geometric channel model is the number of rays along with their spatial, amplitude, and temporal properties. In the SCM each path is formed by summing together a number of rays (called subpaths) Hence each path consists of a superposition of several subrays (or, subpaths). The parameters of the sub-rays have been pre-defined to produce the desired angular spread. In the SCM model, 6 paths each with 20 sub-rays are used. The physical interpretation is that each path is the last interaction with a cluster of 20 scatterers. The principle is illustrated in Figure 1, where only one cluster, or path, is shown for simplicity.

In the beginning of a drop, for each mobile station, antenna orientation and gain parameters are fixed. Then composite rms delay spread, angle spread, and shadowing parameters are drawn from distributions functions with predefined parameters. Shadowing between MSs is uncorrelated. However, for a single MS, the shadowing, rms delay spread, and rms angle spread are correlated. Shadowing at the MS between different BSs is correlated.

The center positions of the clusters are determined randomly based on these rms parameters. Note that there are two levels of randomness: i) random rms parameters (delay/angle/shadowing deviations) drawn from pre-defined distributions and ii) random path parameters (delay/angle/shadowing) drawn from distributions defined by the rms parameters. However, it must be noted that while the cluster positions are random, the positions of scatterers within a cluster are fixed; this produces the fixed per-path angle spread (AS) as defined in the SCM. Each cluster has 20 scatterers, which causes the 20 subrays corresponding to one of the 6 rays. Each subray has the same delay and identical power but has different angle of arrivals and departure, which are predefined as a relative offset to the AoA and AoD of the corresponding ray. The subrays at the MS and BS are then randomly paired.

One of the characteristics of the model includes a narrow AS per path with a specific mobile station AoA and base station AoD models. The relationship between the temporal and spatial properties has been described by using the results obtained from [6]. In [6] a description of relationship between azimuth spread and standard deviation of AoA at the BS, as well as a description of the relationship between the distribution of ray delays and delay spread. The distribution of the occurrence of ray delays is given by an exponential distribution. Corresponding to the increasing delay is a reduction in power also having an exponential decay. The σ_{AS} and σ_{DS} are power weighted terms, and related to the σ_{AoA} and σ_{delay}, which describe the distribution of angle and delay occurrence, respectively. The relationship describing the power concentration in angle and delay (i.e., $r_{AS} = \sigma_{AoD} / \sigma_{AS}$ and $r_{DS} = \sigma_{delays} / \sigma_{DS}$) is used in generation of the channel realizations. The values of *r* are specified to describe the distribution of powers in delay and in angle domains to represent behavior of the channel. The SCM model follows these relationships. It uses different value for suburban macro and urban macro but not used for urban micro scenarios.

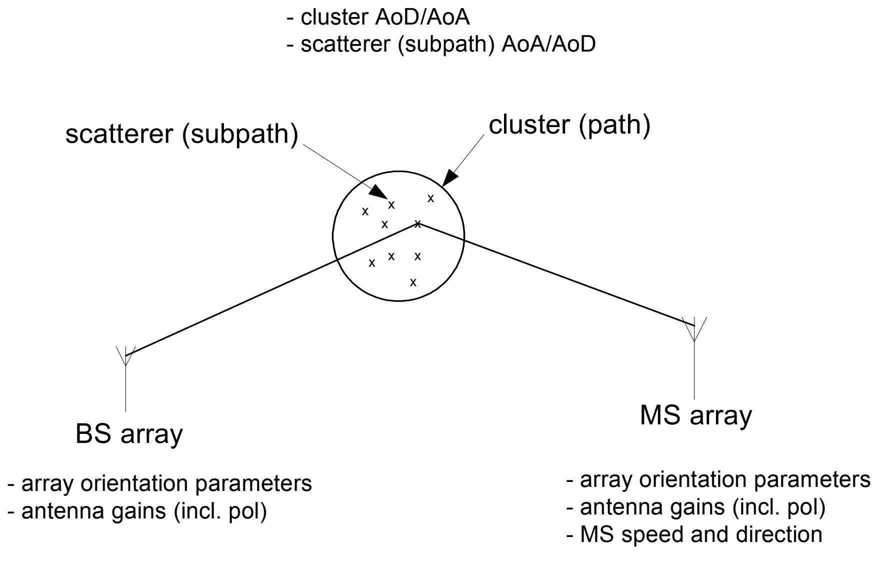

Figure 1. SCM model overview. Only one cluster is shown for simplicity.

The overall procedure for generating the channel matrices consist of three basic steps: 1) Specifying an environment, 2) Obtain parameters to be used in simulation, 3) Generate channel coefficients based on the parameters. In first step, selecting the scenario leads to specific path loss model. For suburban macrocell and urban macrocell environments, the modified COST 231 Hata urban propagation model is used in the calculations. For microcell environment, the COST 231 Walfisch-Ikegami model is used path loss calculations. Specific antennas height and environment parameters are assumed. Detailed generation steps of user parameters are given in [5].

3.2.2.3 Optional special cases

In addition to the characteristics described above, the following options exist:

- Polarized arrays: Cross polarization discrimination defined. Current model can cover different types of polarized antennas.
- Far scatterer cluster model urban macro: It models a bad environment where additional clusters are seen in the environment.
- Line of sight model: Rician factor is a function of the distance from the BS, LOS component appears with linearly decreasing probability with respect to distance, cut-off distance at 300 meters from the BS.
- Urban canyon model: When switched on, the model modifies the AoA of the paths arriving at the MS.

3.2.2.4 Modeling of intercell interference

Based on ranking the path loss and shadowing of all sectors, strong interferers are modeled as spatially correlated processes and the remaining sectors are modeled as spatially white Gaussian noise processes based on a flat Rayleigh fading process.

To minimize the complexity of the model, the spatial characteristics of the weak interferers are considered spatially white, while that of strong interferers are modeled spatially.

3.2.3 Supported environments

The SCM 3GPP-3GPP2 system level channel model considers three cases of channel scenarios:

- Suburban Macro (approximately 3Km distance BS to BS)
- Urban Macro (approximately 3Km distance BS to BS)
- Urban Micro (less than 1Km distance BS to BS)

The macro cell definition applies when the base station antennas are above rooftop height. The micro cell definition applies otherwise.

3.2.4 Statistical properties of the model

-Power Delay Spectrum
-Power Azimuth Spectrum
- The ratio between angular spread and standard deviations (i.e., r_{AS}) in angular domain
- The ratio between delay spread and standard deviations (i.e., r_{DS}) in delay domain

3.2.5 Computational complexity

Calculation of the channel coefficients might be made computationally effective.

3.2.6 Evolution possibilities

The SCM model can be extended to other environments, bandwidths, and center frequencies by redefining the key-parameters like

- minimum path delay difference,

- number of paths as proposed in IEEE 802.20 MBWA, (see Sec. 3.4.8).
- number of subpaths per path
- path-loss, distributions of rms delay spread, rms angle spread, shadowing deviation, and their dependencies
- The parameters r_{AS} and r_{DS}, defined earlier, are very important to consider for further improvements of the model for the defined scenarios or other new scenarios such as outdoor to indoor as well as the indoor.

3.2.7 Model summary

Summary table of the characteristics of the 3GPP SCM model can be found in the appendix 1. The parameters of the model have been shown in the tables in the appendix 2.

3.3 METRA

3.3.1 General

The METRA channel model was developed within the IST (Information Society Technologies) METRA (Multi-Element Transmit and Receive Antennas) and IST I-METRA (Intelligent Multi-Element Transmit and Receive Antennas) projects. The main objective of the IST METRA project was to analyze the feasibility and evaluate the performance of introducing multi-element adaptive antennas into mobile terminals in combination with adaptive base station antenna arrays for UMTS (Universal Mobile Telecommunication Services).

The purpose of the channel characterization work in I-METRA was to exploit deeper the measurement data collected during the SUNBEAM (Smart Universal Beam-forming) and METRA projects, in order to get a better insight in the properties of MIMO radio channels. Influences of a large set of parameters and contexts, such as correlation, polarization, directional information, power imbalance, and presence of a Line-of-Sight (LOS) component have been studied in I-METRA.

The latest version of METRA, 1.1 was delivered on February 7, 2001. It consists of a documentation and of a reference implementation in COSSAP® which implements the model and a link level simulation based on it. However, it is not mentioned how to base a system level simulation on the METRA channel model. The software implementation can be freely used, with the agreement on the distribution terms in the Appendix 2 at the end of the documentation [19].

The model supports a one-link system, i.e., one BS and one MS only. Thus multi-hop is not supported.

The latest version of the I-METRA channel model, 1.1 was delivered on October 31, 2002.
Outputs of the I-METRA project are [21]and the software link level channel model implemented in MATLAB®. The distribution terms of the MATLAB® implementation are similar to the ones for METRA mentioned above.

The philosophy of the channel model presented in IST METRA remained mostly unchanged in I-METRA. Upgrades are:
1) Complex correlation coefficient definition
2) Consideration of BPR (Branch Power Ratio) imbalance between the elements of the array. A branch is the output of an antenna element. The BPR is defined as the ratio between the powers P_n on the *n*th element's branches of the array.
3) Polarization is taken into account

More information about METRA and I-METRA can be found in [19] and [21] respectively, or at the Internet site: www.ist-imetra.org.

3.3.2 Model Description

The METRA model is a stochastic channel model. Its main strength lies in the fact that it condenses the correlation between the antenna arrays at the receiver and at the transmitter, in two correlation matrices. This is also its weak point. The characterization of the set-up is conventionally defined with Power Delay Spectrum (PDS) and Doppler Spectrum.

3.3.2.1 Description in the frequency domain

The power-Delay Spectrum (PDS) determines the realizations of the Channel Impulse Response (CIR) that can be modeled as a tapped delay-line. The taps of the CIR and their statistics in turn determine the temporal Channel Transfer Functions. The temporal evolution of the CIR is determined by the Doppler spectrum.

The PDS is modeled by a one-sided decaying exponential. However, in some environments, the power is not monotonically decaying with delay-time, as waves arrive at the termination gathered in clusters. This clustering effect has been modeled in the so-called ‘’hilly’’ outdoor environments of

[7]. A similar clustering process has been identified in [8] for indoor environments. Several tap-based models are proposed to model different environments. They differ in the number, spacing, and relative power of the taps. As a consequence, different terrain profiles are characterized by different Delay Spreads (DS). The DS is defined as the root second moment of the PDS.

3.3.2.2 Description in the time domain

The time domain characterization of the set-up is defined by the Doppler spectrum.
The fading characteristics of the taps are defined by shaping an over-sampled Doppler spectrum in the spatial frequency domain. The inverse Fourier transform of this Doppler spectrum defines the complex random fading coefficients in the space domain. Then, it is simple to convert them into the time domain, by taking into account the speed of the mobile. The predefined shapes of the Doppler spectrum are Classical (Clarke's spectrum) and flat. It is possible to have any user-defined Doppler spectrum as an input.

3.3.2.3 Correlation between the antennas

The spatial correlation of the antenna arrays is defined by two correlation matrices, namely RMS and RBS, which characterize the correlation at the mobile and the base station, respectively. The basic assumption for this approach is that the correlation properties of the two link ends can be treated separately, i.e., the BS and the MS are not spatially correlated. As a result of this assumption, the joint spatial correlation matrix R is approximated as the Kronecker product of the RMS and the RBS. The resulting matrix is than properly normalized, multiplying by the inverse of the total channel energy. The RMS and RBS matrices are calculated from the Power-Azimuth spectrum (PAS) and Azimuth Spread (AS). The Azimuth Spread is defined as the root second moment of the PAS.
Different shapes of the PAS are defined for different scenarios shown in Table 3.

Table 3. Different PAS shapes.

		BS	MS
Outdoor	Macro-cell	• Laplacian • Power of a cosine function • Truncated Gaussian • Uniform	Uniform
	Micro-cell		
	Pico-cell	Almost uniform	
Indoor		Uniform	

The various scenarios have different azimuth spreads: low in rural environments with tendency to increase as scattering becomes more significant, higher in micro- and pico-cells. AS increases with a decreasing distance between MS and BS. The larger (lower) values of the AS have as a consequence lower (larger) correlation between antenna elements. A table with values of AS for certain environments is provided in [19]. Having the DoA angles and choosing an AS, the PAS can be formed, depending on a chosen distribution. The RMS and the RBS can be calculated for any antenna topology and pattern.

Polarization of the arrays was not taken into account in the IST-METRA project, but it is included in the IST I-METRA project.

3.3.3 Supported environments

In principle any scenario can be modeled with the METRA channel model, given the proper correlation matrices R_{MS} and the R_{BS} and the description of the channel behavior in time and frequency. This is due to the fact that the parameters of the models have not been given, but have to be given during the realization of the channel coefficients. In this respect METRA model differs from the other candidate models.

In particular, Pico-cellular, micro-cellular, and macro-cellular environments have been investigated and evaluated.

3.3.4 Statistical properties of the model

The statistical properties of the model depend of the following characteristics:

-Doppler Spectrum
-Power Delay Spectrum
-Power Azimuth Spectrum.

In the METRA model these parameters can be selected flexibly. Therefore the model can in principle be applied to different environments. This is also the reason, why the METRA model is a model in different sense than the other two candidate models: the parameters have not been unambiguously fixed in the model.

3.3.5 Implementation

3.3.5.1 Computational complexity

Calculation of the channel coefficients is comparable to that of the IEEE802.11n model.

3.3.5.2 Parameters

The most significant input parameters of the COSSAP SW implementation are:

- number of antenna elements at the MS and at the BS
- distance between antenna elements
- number of taps
- sampling frequency of the taps
- velocity of the mobile
- carrier frequency
- Doppler spectrum type
- oversampling factor of the Doppler spectrum
- mean azimuth DoA angle at the BS
- mean elevation angle of the impinging waves at the BS
- in a SW implementation antenna radiation pattern must be defined

3.3.6 Validation

Several measurement campaigns have been undertaken in order to get data for validation of the model. The investigated scenarios were pico-, micro-, and macro-cell.

The validation of the model was done with an eigenanalysis of the synthetic channel impulse responses. The eigenanalysis has been performed computing the eigenvalue decomposition (EVD) of the correlation matrix R. This method allows to estimate the number of independent channels between two terminals. A channel matrix H may offer k parallel subchannels with different mean gains, with k defined as $k = Rank\ (R) \leq \min(M, N)$, where M and N denote the number of antenna elements at the BS and MS, respectively. The error between the averaged mean simulated eigenvalues and the mean measured ones has been computed at some outage level for each position and for each eigenvalue. In addition to it the standard deviation of the mean eigenvalue for each eigenvalue and position has been validated.

Output of the validation is that the models match well the measured data.

3.3.7 Evolution possibilities

The METRA model can be evolved to other environments by redefining the key-parameters. This way it is possible e.g. to change the center frequency and increase the bandwidth.

3.3.8 Model summary

The METRA channel model is a MIMO single-link channel model. Correlation in time and space is achieved considering the power delay and Doppler spectra, which are given as inputs. The spatial correlation is treated as in the Kronecker model. The model supports arbitrary antenna geometries given the patterns and the proper spatial correlation matrices. Polarization is included. Being a single-link model there is no multi-hop and multi-user capabilities. Multi-user interference is not considered in METRA documentation, but it can be implemented as in FITNESS project.

Summary table of the characteristics of the METRA model can be found in the appendix 1.

3.4 Other models

3.4.1 General

This sub-section introduces shortly other well-known standard models for WLAN and cellular environments. These models cannot be used directly for MIMO simulations: They either do not include the MIMO characteristics, or they are not finished at the moment.

There are some important channel models that should be mentioned like the following MIMO-models: IEEE C802.20 [21] and IST-FITNESS [20]. In addition there is a development work for MIMO models going on in the COST 273 project. Its final report will be available in the first half of 2005.

COST 259 –model is a well-known directional reference model [15], the ideas of which have been applied in many subsequent models. Then there are a number of 3G (SISO) models, like 3GPP-, 3GPP2-, ITU-R 3G and UMTS 30.03 models [23], GSM-models[9], some WLAN models, like ETSI BRAN, and various other models. IEEE 802.11n models have been developed on the basis of ETSI BRAN models. Thus, ETSI BRAN can be considered as a simplified SISO case of IEEE 802.11n.. Therefore ETSI BRAN models are not considered here any more.

From the models listed, the following will be discussed shortly further on the following paragraphs:

-IST-FITNESS
-COST 259
-GSM
-3GPP
-JTC
-IEEE 802.20
-UMTS30.03.

The reason is that there are some aspects also interesting to the WINNER channel modeling.

3.4.2 IST-FITNESS Channel Models

The FITNESS MIMO channel model is developed within IST-FITNESS project whose objective is to investigate Multiple Transmitter Multiple Receiver (MTMR) techniques for UMTS and WLAN simulations [20]. It identifies radio channel and interference models suitable to specify critical parameters and performance metrics. The carrier frequency and the bandwidth are the ones characterizing UMTS and WLAN systems: 2 and 5 GHZ, 5 and 20 MHz respectively.

The chosen geometry-based stochastic channel model follows the main assumptions of COST 259 and is based on the channel modelling efforts within 3GPP and ETSI BRAN. Furthermore a correlation matrices-based simplified version of this model, same approach as METRA, using second order statistics as statistical characterisation of the channel, is proposed to be used whenever sufficient for algorithm evaluation. It approximates the system as at each antenna array only the immediate surroundings determine the correlations between neighbouring antenna elements, with the purpose of decoupling the channel between transmitter and receiver accordingly to the Kronecker model.

Basically the FITNESS frequency-selective and time-variant MIMO channel at both the mobile and base stations is derived as follows:
- Each cluster is associated to a given delay and a given average power, taken in the power delay profile corresponding to ITU models.
- For each cluster, select a mean angle of arrival/departure according to a certain distribution (e.g., uniform, Laplacian or Gaussian) in a given sector/cell, characterised by its standard deviation and with mean in the direction of the mobile/base station.
- For each of the N scatterers (typically 20, 60 or 100 subrays) in a given cluster, select an angle of arrival according to a certain distribution (e.g. Laplacian at the base station, uniform at the mobile station) with mean equal to the mean angle of arrival of the cluster and angular spread. The N

subrays are of equal constant amplitudes α and with uniformly distributed starting phases between [0,2π].

An interference model is explicitly modelled as well. The spatial covariance matrix of the receiver noise can be modelled as spatially coloured or spatially white interference. The same MTMR channel model as for the desired signal will be used. The parameters in the model that are selected randomly (e.g. direction of arrival) will be generated independently for the desired signal and for the interferers: 0,1,2,3 and 4 interferers will be simulated.

3.4.3 COST 259 Channel Models

COST259 directional channel model (COST259-DCM) [15] has been defined according to Figure 2. Different environments may have several different propagation scenarios (different parameter sets). These models are directional, geometrically based stochastic models, where mobile stations has single antenna and base station multiple antennas. Multi-path components are assumed to arrive in clusters.

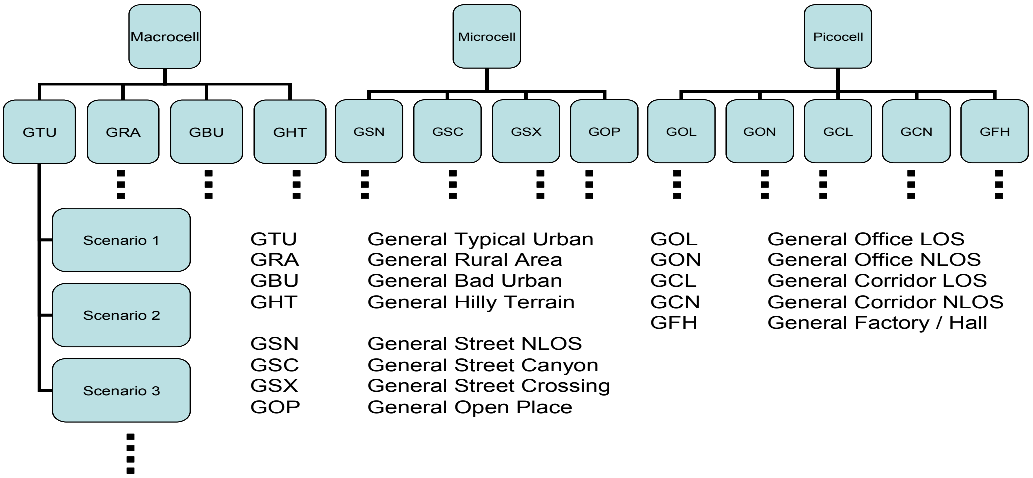

Figure 2. Structure of COST259 Directional Channel Model.

3.4.4 GSM Channel Models

GSM channel models are specified in the 3GPP specifications [9]. Models are intended to be used in GSM/EDGE testing in frequency ranges of around 400, 850, 900, 1800, and 1900 MHz. Maximum continuous frequency band is 75 MHz, but typically one operator uses much less bandwidth. GSM signal bandwidth without Frequency Hopping (FH) is about 200 kHz. Ideal FH case assumes perfect decorrelation between bursts. This case may only be tested if such a decorrelation is ensured in the test. For TU50 (ideal FH), sufficient decorrelation may be achieved with 4 frequencies spaced over 5 MHz. It means that all standard GSM tests can be performed in 20 MHz bandwidth. Other consideration for the bandwidth is the tap spacing. In GSM models, 100 ns tap spacing is used. Then model bandwidth can be assumed to be 1/100 ns = 10 MHz. The propagation conditions of the GSM-models have been listed in the appendix 3.

3.4.5 3GPP Channel Models

In the 3GPP 25.101 specification [10], the following channel models are specified.

- Static propagation condition (AWGN)
- Multi-path fading propagation conditions
    - Cases 1 to 6 (3…583 km/h), 4 taps
    - Case 7 for higher layer signalling, Sector and Beam, (50 and 118 km/h), 6 taps
    - ITU Pedestrian A, B, Vehicular A, B, for HSDPA, (3…282 km/h), 6 taps

  - Case 8 for CQI tests, (30 km/h), 2 taps
- Moving propagation conditions
  - Two taps, first tap fixed, second tap sinusoidally sliding between 1 and 6 µs.
- Birth-death propagation conditions
  - Two randomly hopping taps

3GPP Channel models are listed in the appendix 3.

3.4.6 JTC Channel Models

These models were recommended by the Joint Technical Committee (JTC) for PCS Air Interface Standards [12]. JTC models are relatively narrowband since minimum tap spacing is 50 ns. The various categories of communication environments are listed in the Appendix 3.

3.4.7 IEEE 802.20 MBWA Channel Models

The IEEE 802.20 MBWA models [22] are based on 3GPP-3GPP2 SCM Ad hoc working group and they support also MIMO modeling. Channel modeling is ongoing work in the IEEE 802.20 working group and the parameters are not fixed yet. Due to the incompleteness of the models, they were not considered for selection evaluation to WINNER. However, the work in 802.20 might be followed to see, if some of the WINNER models could be harmonized with the IEEE 802.20 -models. Key parameters of the 802.20 channel models are shown in Table 4.

Table 4. Propagation conditions for the IEEE 802.20 Channel Models.

Channel	# of taps	Max. excess delay [ns]	Mobility [km/h]
Case-I (modified Pedestrian-A)	5	410	3 … 120
Case-ii (Vehicular-A)	6	2510	30 … 250
Case-iii (Pedestrian-B)	6	3700	3 … 120
Case-iv (Typical Urban)	11	3200	3 … 120
Case-v (Vehicular-B)	6	20000	30 … 120

3.4.8 UMTS 30.03 Channel Models

UMTS 30.03 models [23] are interesting for the WINNER WP5 therefore that they include a mobility model that was planned to be taken into use in the WINNER WP3 [17]. However, in connection of the initial models the mobility is not considered as specified in the UMTS 30.03 models.

Models are restricted to ETSI members.

4. Comparison of the models

4.1 General

The generality requirement suggests the use of ray-based (geometry-based) models. The only ray-based model available is the SCM-model. The SCM-model cannot as such be applied in WLAN type sub-systems, because its bandwidth is considered too small. The link-level SCM model is considered so restricted that it is not proposed for the WINNER initial link-level model, but just for comparison purposes.

When using the stochastic models IEEE 802.11n and METRA, it should be noted that the Kronecker product principle has been assumed in both of the models. This makes the models over-simplified, as has been shown in the paragraph 4.1.1.

The comparison of the models is based on the following characteristics:
-suitability for the anticipated frequency ranges and bandwidths,
-applicability for the most important propagation scenarios,
-generality of the modeling principle,
-suitability of the model to support link-level and system-level simulations,
-upgradability of the model.

The frequency and bandwidth matters have been discussed in the paragraph 4.1.2. The propagation scenarios considered have been described in the paragraph 4.1.3.

4.1.1 Limitations of the Kronecker product principle

In the single Kronecker product model, the spatial correlation of the antenna arrays is defined by two correlation matrices, namely R_{MS} and R_{BS}, which characterize the mobile and the base station, respectively.

The basic assumption for this approach is that the correlation properties of the two link ends can be treated separately, i.e., the BS and the MS are not spatially correlated. Separability offers independent optimization of transmit and receive arrays, leading to a reduced complexity and simplicity of the model. As a result of this assumption, the joint spatial correlation matrix R is approximated as the Kronecker product of the R_{MS} and the R_{BS}. The resulting matrix is then properly normalized, multiplying by the inverse of the total channel energy.

In [4] and [13] it was shown that the ‘Kronecker’ assumption does not hold, in general, for realistic MIMO channels. The Kronecker model fits well only in a scenario where the scatterers are assumed to be uniformly distributed around the antenna arrays at both links. When using the Kronecker product principle the receiver is not affected by any kind of spatial filtering of the transmitter. Whatever the transmitter is doing, the Rx array experiences always the same spatial distribution of signal energy. Due to the assumed separability, all directions of departure (DoD) are coupled to the same directions of arrival (DoA) at the receiver.

The Kronecker model mostly underestimates correlation between the paths. The reason is that the basic assumption neglects the interdependence of DoAs and DoDs. For more information on the Kronecker model and extensions thereof see [14].

4.1.2 Frequency ranges and bandwidths

All the models have been defined either in the vicinity of 2 GHz or 5 GHz. IEEE 802.11n model has been defined for both of them [1]. Therefore it is assumed that all the models can be used in the frequency range 2 GHz to 5 GHz, or even up to 6 GHz. It seems that there will be no major difference in the models in this respect. The difference in path-loss has naturally to be taken into account.

All the considered models are meant for systems with considerably lower bandwidth than needed for the WINNER. The IEEE802.11n has been planned for the bandwidth of c.a. 20 MHz. The SCM and METRA models have been planned for the UMTS bandwidth of c.a. 5 MHz. This fact makes that the models probably are not automatically proper for the 100 MHz bandwidth.

The IEEE802.11n model uses mostly more than 10 taps (14 to 18) with minimum tap spacing of 10 ns. From these figures it can be assumed that it would support the 100 MHz bandwidth, at least quite nearly. The SCM-model uses only six path delays. It is also planned for the 5 MHz bandwidth only. For this reason the model is probably too narrowband for the widest WINNER bandwidth required. In the METRA-model the tap numbers and spacings have not been defined explicitly.

4.1.3 Propagation scenarios considered

The propagation environments considered in the comparison of the initial models are shown in the table below. In addition the suitability of the candidate models for those environments is indicated in the table. For the SCM model the environments are defined in system-level, for the other two models in link-level. Propagation scenario is defined by fixing the parameters of the model for each environment.

Table 5. Propagation environments

Scenario		3GPP SCM[1]	METRA	IEEE802.11n
Wide-Area	Rural	N	Y[2]	N
	Suburban	Y	Y[2]	N
	Urban	Y	Y[2]	N
	Outdoor to indoor	N	Y[2]	N
Short-Range	Urban (outdoor to outdoor)	N	N	Y
	Indoor (indoor to indoor)	N	Y[2]	Y
	Infostations	N	N	N
Multiple-link	Relay to MS	N	N	N
	Ad Hoc	N	N	N
Transition scenarios		N	N	N

1) For the SCM two urban environments have been defined: urban macro-cell and urban micro-cell.
2) METRA doesn't include detailed parameter set.

4.2 Comparison Tables

Table 6. Model characteristics

	Unit	3GPP SCM	METRA	IEEE802.11n
Frequency Range	GHz	2	2	2&5
Bandwidth	MHz	5	Not stated	100
Number of taps		≤ 6	Input parameter	≤ 18
Tap spacing (min)	ns	16.28 (default)	Input parameter	10
Suitability for beam forming	Y/N	Y	Y	Y
Suitability for MIMO	Y/N	Y	Y	Y
Restricted to Kronecker approximation	Y/N	N	Y	Y
Ray based / correlation based	R/C	R	C[1]	C[1]
Polarization	Y/N	Y	Y	N
Shadowing	Y/N	Y	N	Y
Path loss	Y/N	Y	N	Y
Antenna pattern	Y/N	Y	Y	N
Spatial Correlation		Implicit	Explicit	Explicit
Doppler		Implicit	Explicit	Explicit

Frequency Correlation		Implicit	Implicit	Implicit

1) Correlation matrix is calculated from the geometry-based model (AoA, AoD).

Table 7. General characteristics of the models

		3GPP SCM	METRA	IEEE802.11n
Suitability to	LL-modeling	Y	Y	Y
	SL-modeling	Y	N	N
SW implementation	Matlab©	N	Y	Y
	Other		COSSAP®	
Multiple-link	Relay to MS	N	N	N
	Ad Hoc	N	N	N
Expandability		Y	Y	N

4.3 Pros and cons of the models

The Pros and Cons of the different models have been listed below.

a) The IEEE802.11n model

PROS

1. The model is an extension in spatial domain to BRAN channel model which is adopted by ETSI that are based on measurements and cover many indoor scenarios.
2. It is in good agreement with the intended WINNER short-range scenarios. It covers a wide range of indoor scenarios from small offices and residential homes to large offices and open spaces.
3. The tap spacing is 10 ns (the bandwidth might be close 100 MHz), which is of interest in WINNER project.
4. The model is directional and the dispersion in time, frequency and space are included.
5. The model operates at 2 GHz and 5GHz bands.
6. Calculation of the channel coefficients is probably computationally efficient. For example correlation matrices for fixed antenna array geometry need to be calculated only once for each model.
7. Most of the parameters are fixed and only few of them, e.g. shadow fading effect and interferer to carrier power ratio of fluorescent light effect, are drawn randomly for every realization.
8. Cross-polarization discrimination (XPD) for LOS and NLOS conditions are defined.
9. Characteristics of the models (i.e., clusters' angular distribution, etc) are taken from several measurement results.
10. Doppler components due to fluorescent lights are included.

CONS

1. The model is a link level channel model. System level features are not supported in the model. Temporal correlation is modeled independently from the spatial correlations and the joint statistics may not be preserved.
2. Correlation matrices at the two ends of the link are combined to MIMO channel correlation matrix using Kronecker product, which is not generally valid, see section 4.1.1.
3. Elevation spread is neglected, which is quite important in indoor environment.
4. The model is antenna dependent. Isotropic antenna pattern is assumed.
5. No antenna correlation model for cross-polarized antennas is given.
6. Assumes the channel impulse response as a function of delay and angle as a separable function, which is not always true especially in indoor environments.
7. The parameters A, B, and α have clear influence in Doppler component due to a moving vehicle, for instance, no clear justification of proposing value $\alpha=0.02$ is given. It might be necessary to tune these parameters by measurement.
8. No correlation between shadowing (or path loss) and delay spread is considered, which might be important.

9. No smooth transition from LOS to NLOS in path loss model.

b) The 3GPP SCM model

PROS

1. It models wide-area propagation scenarios that are of interest in WINNER project, namely: urban macro, urban micro, and suburban scenarios.
2. Modeling principles are based on characteristics obtained from measurements
3. Both link level and system level channel models are included, however, the system level is emphasized.
4. The system level channel model is not based on fixed temporal profiles but rather statistically changing spatial and temporal domains (drop concept, see the paragraph 3.2.2.2),
5. The model is an antenna independent channel model. The model allows any antenna geometry and patterns in azimuth plane.
6. The model is based on simultaneous correlation behavior of the AS, DS, and log normal shadowing parameters, including site-to-site correlation.
7. A key feature of the modeling principle is the parameters (i.e., r_{DS}, ad r_{AS}) that describe the power distribution in delay and angular domains.
8. Clear generation steps for user parameters are given.
9. The model is defined for FDD systems and it can be used in TDD systems
10. The model is scalable in terms of adding more feature if needed, e.g., polarized arrays, far scatterer clusters, urban canyon.
11. A sort of "shadowing" per path is modeled to vary the powers with respect to the average envelope to reproduce the variations experienced in the actual channel.
12. Inclusion of LOS and NLOS is based on some defined probability that depends on distance.
13. The adopted narrow AS per path is closer to reality for wide bandwidth as it has clear influence on correlation properties.
14. The model is applicable to both forward and reverse links in terms of physical parameters.
15. An approach for modeling of the intercell interference is provided based on the strength of the interference.

CONS

1. Suburban outdoor-to-indoor and indoor scenarios are not considered.
2. The model is based on six rays at carrier frequency of 2 GHz and bandwidth of 5 MHz, it is unlikely to be anymore accurate for larger bandwidths and higher frequency.
3. Elevation spread is not considered.
4. Defined values of delay spread and azimuth spread and their distribution may not be accurate for WINNER propagation scenarios.
5. The correlation properties between delay spread and shadow are based on Greenstein work which was for long distance between the BS and MS, the validity of this relation may not be valid for WINNER which is much shorter distances.
6. The assumption of all paths arriving/departing from the same angle in the link level channel model is non-physical. This indicates that the scatterers for the different taps are in the same direction.
7. Far scatterer clusters (FSC) are limited selectable to use with the urban macro-cell. FSC may also appear in urban micro-cell and suburban scenarios.
8. No shadow correlation between different mobile stations, even those having similar obstructions.
9. No shadowing correlation distance is defined, which is important for time evolution of shadowing loss and also is important for determining the span of the array configurations considered, which should be within the shadowing correlation distance of the channels.
10. Same shadow fading loss is assumed in all sectors and cells during simulation. It is not clear if this assumption has measurement background.
11. The delay spread does not depend on distance, which it may as measurements indicate.
12. Path loss model, the Walfish-Ikegami model, for urban microcell may not be valid when the both antennas are below the surrounding building as it is derived for macrocell and the BS antenna above/at rooftop.
13. Due to random realizations in spatial and temporal domains, large amount of simulations are needed to get enough and accurate statistics. The complete randomization of the channel modeling makes the generation procedure tedious, thus increasing the computational load tremendously.

14. The correlation properties at antenna elements are implicitly given.
15. Model is based on snapshot and it doesn't model large scale dynamic changes in radio channel characteristics as a function of time, which would be needed in e.g. reconfigurability and handover algorithm testing.

c) The METRA model

PROS

1. The model is stochastic in nature, which means that it does not require site-specific description.
2. Simplicity of the model is an advantage.
3. The model might be good for link level simulations.
4. It adopts correlation based modeling approach. The spatial correlation properties are derived from a Kronecker product of the transmit and receive correlation matrices. This is an advantage when the Kronecker product assumption is valid, as it is in some scenarios.
5. The model relies on a small set of parameters, extracted from measurements, to characterize the communication scenario, namely:
    a. Power gain of the MIMO channel matrix
    b. Two correlation matrices describing correlation properties at both ends of the transmission link.
    c. The associated Doppler spectrum of the channel paths.
6. The model supports arbitrary antenna geometries.
7. In principle, it can model any scenario, given the proper correlation matrices at the receiver and transmitter and the description of the channel behavior in time and frequency.
8. The model is validated with measurement data collected in picocell, microcell and macrocell environments.

CONS

1. The model is based heavily on Kronecker product approach which enforces separable correlation properties at transmit and receive side, which is not always valid. This approach ignores the dependence of the AoA on the AoD. The spatial structure of the MIMO channel at the two ends has, in general, to be described jointly due to the double direction nature.
2. The model does not support system-level simulation.
3. Temporal correlation is modeled separately from the spatial correlations and the joint statistics may not be preserved.
4. The model may not be valid for algorithm testing that needs parameters of each path (AOD, DOA, etc).
5. Currently supports mostly only picocell scenarios.
6. Parameters have not been fixed.

4.4 Comparison of the suitability

4.4.1 Link versus System Level Simulations

All three models support link level simulations. However, only 3GPP SCM can also support system level simulations, which is its main goal. In fact, the link level models of the 3GPP SCM are meant to be used only for calibration purposes [5].

The authors assume that in the WINNER project the link-level models are used also for other purposes than just calibration. It is assumed that the models should support also link-level algorithm evaluation, like receiver algorithm simulation in SW and HW. Therefore it is proposed to adopt the concept calibration models, in the WINNER context, for the SCM link-level models. It is also proposed that WINNER link-level models corresponding 3GPP SCM are left open or defined in the initial phase, or defined as simplifications of system-level models.

None of the models supports Ad hoc or multi-hop networks.

4.4.2 Short-range Communications

While the METRA and IEEE802.11n channel models support short-range scenarios, the 3GPP SCM model does not.

The IEEE802.11n channel model is especially suited for indoor MIMO WLAN systems. The supported environments are: residential, residential/small office, typical office, large office, and large space. Every environment can be with or without the line of sight component. Additionally it supports outdoor hot-spot scenarios. The modeled value for the mobile speed passing by is 40 km/h.

The METRA channel model also supports different environments: small office, typical office, large space, modern open office.

4.4.3 Wide-area Communications

Wide-area propagation scenarios that are of interest to WINNER project are rural, suburban, urban and outdoor to indoor scenarios. The IEEE802.11n is intended for indoor and short-range outdoor environments with small delay spreads, i.e. picocells and small microcells. Thus, it is clear that it is not a candidate for wide-area communications.

The METRA model, in principle, can be used for any scenario if the proper correlation matrices are found or given. However, the model itself is for link level simulation. It has no system level features. As a result, it should be excluded since MIMO system level simulations are very important for WINNER. It is the one which is used in algorithm comparison and system design

The third candidate is the 3GPP-3GPP2 SCM model, which is intended for outdoor propagation. The SCM model is defined for urban macro and urban micro as well as the suburban scenarios. It is not defined for suburban outdoor to indoor scenarios. The SCM has both link level and system level channel model features. If the parameters required for SCM for undefined outdoor scenarios, e.g., suburban outdoor to indoor are known, then, the model can also be considered for this scenario. Of the three candidates, the most suitable model for wide-area communications for immediate usage of the WINNER project is the 3GPP-3GPP2 SCM model. It is the only model which specifies model parameters for a wide range of outdoor environments for both link level and system level.

5. Selection of the WINNER channel models for immediate use

5.1 Proposed parent models

5.1.1 Models

WP5 proposes that two models are selected for the simulations in the initial phase of the WINNER project. They are:

1. IEEE 802.11n for short-range (hot spot, indoor-to-indoor) scenarios.
2. 3GPP SCM for wide-area outdoor scenarios.

It is also proposed that the models are selected as such for the propagation scenarios supported by the original models. The models can also be modified, if desired, for some other propagation scenarios. This should allow the proposed models to be compatible with the original models and at the same time cope for the more stringent requirements of the WINNER system compared to the original environments.

The IEEE 802.11n model is based on geometry, but is stochastic in nature: The geometric starting point is used to calculate the correlation matrices for the BS and MS, from which the total correlation matrix is calculated by assuming a Kronecker decomposition. It is meant for link-level simulations.

The 3GPP SCM model is ray-based. In the model both the link-level and system-level models are defined. The focus of the model is on the system-level simulations, as understood in the 3GPP and 3GPP2 joint Ad Hoc group. For the purposes of the WINNER project the link-level propagation model is probably too simplified. The system-level propagation model is quite near link-level allowing the simulation of several physical level characteristics, like antenna radiation pattern and antenna array geometry. It seems to have all the relevant parameters included.

As such the propagation model is restricted to 2 GHz, and probably too narrowband for the simulations in the widest specified WINNER bandwidth. If desired, these drawbacks can be overcome by redefining the model so that the center-frequency and/or bandwidth are increased to the required values. However, further study is needed to evaluate the accuracy in such cases.

5.1.2 Reasoning for selection

The reasoning of the selection is the following. IEEE 802.11n is the only existing well-defined MIMO channel model having the required bandwidth. However, IEEE 802.11n is suitable only for short-range communications. Another model is needed for wide-area applications. The 3GPP-3GPP2 SCM is the only existing model having the system-level models included. It is ray-based and includes the most important characteristics needed for thorough simulations.

Together the models cover the short-range and wide-area environments as well as the outdoor and indoor cases.

The METRA model was considered as unsuitable for WINNER initial channel model due to the narrow bandwidth compared to the corresponding IEEE 802.11n model, as well as the limited center-frequency of 2 GHz.

5.1.3 Proposed immediate extension

Only limited improvements can be done immediately. During the WINNER project, more advanced models will be developed.

5.1.3.1 IEEE 802.11n

No immediate improvement is proposed. IEEE 802.11n covers the desired frequency ranges from 2 GHz to 5 GHz and the bandwidth of (almost) 100 MHz. The extension from 5 GHz to 6 GHz should have marginal effect. It should be noted, that the channel transfer function is periodic with a period of 100 MHz in the frequency domain. The effect of this to the simulations is a matter of further study. It is assumed that this can be tolerated in the initial phase of the simulations.

System level simulations could be done by following the FITNESS approach.

5.1.3.2 3GPP SCM

For practical reasons the default value for the delay resolution (minimum tap interval) of the CIR used in the 3GPP SCM model should be changed to 10 ns. In the future this value can be changed, if needed, but in this initial phase it could be the same as for the IEEE 802.11n model.

Currently the model parameters have been specified for the center frequency of the 3GPP system, i.e. for 2 GHz. The supported bandwidth is nominally 5 MHz. For the WINNER project the range should cover at least the frequencies 2 GHz to 6 GHz. In addition the bandwidth of the models should be 100 MHz in some cases. For accurate modeling of radio propagation in bandwidths larger than 5MHz, or center frequencies other than 2 GHz, the model environment parameters may need to be re-determined and validated. Note that it is easy to increase the number of paths which correspond to bandwidth increase. However, one must remember that the parameters of the SCM model (number of paths, subpaths, rms delay spread, pdf, etc) have been tailored for 2GHz/5MHz scenarios and hence may not accurately model radio propagation in other radio environments. On the other hand, for many practical simulation purposes minor mismodelling may not be a key issue, and with sensible interpretation of the simulation results, it is probably possible to use SCM in other environments with minimal parameter tuning. For example, it is possible to modify the SCM path loss model and shadowing to accommodate the 5 GHz center frequency. However, proper adaptation of the model for the higher bandwidths and different center frequencies is a topic for further study.

In the initial phase the only proposed modification for the SCM model is the change of the delay resolution. The next steps in the future would then be the updating of the center frequency and the bandwidth of the model.

5.2 Proposed WINNER initial short-range models

5.2.1 Basic model

The proposed WINNER initial model for the short-range simulations is the IEEE 802.11n model as such. The models are defined for link-level. The authors assume that the short-range scenarios are mostly applied in connection of the WLAN-type systems. Then the different networks can probably be simulated separately in the initial simulations.

5.2.2 Use in link-level simulations

The IEEE 802.11n models are defined for link-level simulations. Therefore they are directly applicable for the link-level simulations. The applied scenarios have been defined in the paragraph 5.2.4.

5.2.3 Use in system-level simulations

The IEEE 802.11n models cannot be used as such in system level simulations, because the model does not include system-level. However, a simple approach for system level simulation, all (or part of) models of the IEEE 802.11n (see Sec. 3.1.3) can be simulated with different percentages of the whole system simulation run. So, different channel conditions with different characteristics in different domains are simulated for system level. One possibility might be to use the IEEE 802.11n model to generate the individual channels of the links considered in system-level simulations. The model might be also used to simulate interferences in system-level simulations.

5.2.4 Initial short-range scenarios

The proposed initial WINNER short-range scenarios are listed in Table 8.

Table 8. IEEE 802.11n suitability for short-range scenarios

Scenario		IEEE802.11n
Short-Range	Urban (outdoor to outdoor)	F
	Indoor (indoor to indoor)	A, B, C, D, E, F
	Infostations	Not available

5.3 Proposed WINNER initial wide-area models

5.3.1 Basic model

The proposed WINNER initial model for the wide-area simulations is the 3GPP SCM model, more specifically the system-level part of the model. The model is proposed to be applied as such for the narrowband models (5 MHz bandwidth). Except for the change of the default delay resolution. The use of the link-level model of the 3GPP SCM model is restricted to comparison purposes between different simulations. (Calibration in 3GPP terminology.)

The wide-area systems are assumed to be mainly of cellular-type. The basic WINNER initial model is proposed to be specified in the system-level. It is proposed that the link-level part of the model is either left open in the initial phase or defined as an implementation of the SL-model for single BS and single MS.

The system-level simulations with the proposed model are assumed to be restricted to a limited number of base stations and mobile stations. If extensive numbers of base-stations and terminals should be simulated, the simulation should use higher abstraction level, somehow based on the WINNER initial model.

5.3.2 Use in link-level simulations

The 3GPP SCM model is defined for system-level simulations. The link-level part of the model is probably too restricted. Therefore the link level model is defined as an implementation of the SL-model for one link. (See paragraph 5.3.3.)

5.3.3 Use in system-level simulations

The 3GPP SCM models can be directly used in the system-level simulations at 2 GHz with the 5 MHz bandwidth. The applied scenarios have been defined in the paragraph 5.3.4. The upgrading of the model is needed in the future, as discussed in the paragraph 5.1.3.2.

5.3.4 Initial wide-area scenarios

The proposed initial WINNER wide-area environments are shown in Table 9. The bandwidth of the proposed models is 5 MHz and center frequency is c.a. 2 GHz (from the 3GPP bandwidth). It is recommended that the models should be used with these parameters in the initial simulations. The path-loss can be calculated also for other center-frequencies with the formulas in the specification [5]. The model can then not be guaranteed to comply with measurements. The compliance shall be validated by measurements in the future. This should be taken into account in the initial simulations, if center-frequencies other than 2 GHz are used.

Table 9. WINNER initial wide-area propagation environments.

Scenario		Original center frequency GHz	Other desired center frequencies GHz	Original bandwidth MHz	Desired bandwidth MHz
		2	5	5	Up to 100
Wide-Area	Suburban	Y	N	Y	N
	Urban macro-cell	Y	N	Y	N
	Urban micro-cell	Y	N	Y	N

5.3.5 Proposed fixed parameter set for 3GPP SCM channel models

It should be decided, if the link-level models should use a fixed parameter set or not.

5.3.6 3GPP SCM channel models for calibration

The link-level models of the original 3GPP SCM model can be used as calibration models for the WINNER system-level simulations.

5.4 Mobility

Mobility is defined in the models via Doppler. Proposed mobile velocities have been defined in initial assumptions [18]. The exact values shall be fixed for the different scenarios supported by the initial models, after the WINNER assumptions have been unified.

5.5 Interference

Interference can be modelled in the wide-area model in system-level simulations, as specified in [5]. The short-range models do not include model for interference.

5.6 Limitations of the initial models

The proposed initial WINNER channel models are not very good for WINNER simulations, but they are currently the most suitable models. The models have the following limitations compared to the needs of the WINNER project.

IEEE 802.11n

- Kronecker approximation
- No model for infostation scenario
- Limited outdoor models
- The channel transfer function is periodic with a period of 100 MHz
- No model for system level simulations
- No smooth transitions/evolution
- No birth/death
- No mobility
- Isotropic antenna pattern assumed
- No polarizations
- No interference model
- Limited evaluation of accuracy

3GPP SCM

- Bandwidth, frequency correlation

- Frequency range (defined currently only for 2 GHz)
- Limited model for link level simulations
- No smooth transitions/evolution
- No birth/death
- No outdoor to indoor scenario
- No rural scenario
- Parameters of the model are heavily environment dependent
- Limited evaluation of accuracy

5.7 Upgrading of the models

The implementation of the propagation models in the WINNER project is assumed to take place by evolution from the initial channel models. Both IEEE 802.11n and 3GPP SCM models are geometry-based stochastic models. Thus the models developed within WINNER will likely be an evolution/extension of these models to include further relevant effects, like transitions, birth-death processes, polarization, etc.

6. Conclusions

In the previous sections the initial channel models for the WINNER project are selected. The selection is performed among three candidates: 3GPP SCM, IEEE 802.11n and METRA models. The 3GPP SCM model is ray-based and the other two are stochastic. It has been found out that no one model as such can cover the requirements of the WINNER project. Therefore two models were selected to be proposed for the WINNER initial channel models: the 3GPP SCM model and the IEEE 802.11n model.

The SCM model is ray-based, which is the preferred foundation principle of the WINNER model. However, it is narrowband, the bandwidth should be increased by modifying the model. The modification work needs some further study. In addition it has been defined only for the 2 GHz frequency range. It is assumed that the modification of the model to the 5GHz center frequency can be performed with the path-loss formulas given in the specification [5]. However, this modification should be justified by further investigations. The IEEE 802.11n is stochastic, and its bandwidth is close to 100 MHz. The channel transfer function is periodic with a period of 100 MHz. If this can be tolerated in the initial simulations, is a matter of further study.

Because of their characteristics, the 3GPP SCM model is proposed for wide-area environments and the IEEE 802.11n is proposed for short-range environments. 3GPP SCM model has to be updated to cope for the 5 GHz center frequency. In future it should also be modified to cover the desired bandwidth of 100 MHz. The SCM model could be used as a starting point for the actual WINNER propagation models.

IEEE 802.11n model can be applied as such in the specified WLAN-type environments. 3GPP SCM model can also, in principle, be applied as such for the cellular-type narrowband simulations. However, it is practical to redefine the default minimum delay difference of the paths to 10 ns, the same as for the IEEE 802.11n model.

It is obvious that the WINNER initial channel models do not cover all the required environments, nor do they fulfill all the requirements posed for the WINNER channel models. The actual channel models will be defined during the Phase I of the WINNER project and after.

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Appendix 1.

Table 10. Common summary table for the compared models.

MODEL SURVEY			
MODEL NAME:	**IEEE P802.11 Wireless LANs, TGn Channel Models**	**3GPP-3GPP2 SCM model**	METRA
Latest version (number)	IEEE 802.11-03/940r2	3GPP TR25.996 V6.1.1	Version 1.1
Latest version (date)	9.1.2004	2003-10	31.10. 2002.
Was it developed in a project or stand alone?	Developed in IEEE standardization	Joint work between 3GPP and 3GPP2. The scope of the 3GPP-3GPP2 SCM AHG is to develop and specify parameters and methods associated with the spatial channel model (SCM) that are common to the needs of the 3GPP and 3GPP2 organizations.	Projects IST-METRA and I-METRA
Distribution agreements	Free to use - legal agreement only for SW	Technical part available to public	Free to use - legal agreement only for SW
Main application	Indoor MIMO WLAN applications	The goal is to develop a model as a common reference for evaluating different MIMO concepts concepts for outdoor environments.	MIMO stochastic model for the third generation mobile communication systems UMTS
Basic principle	Clustered structure, correlation matrix based spatial properties	Ray based model. Consists of two "submodels": a) link level channel model and b) system level channel model. The system level part is based on modeling correlated parameters of different domains and modeling directional information with randomly generated cluster positions.	Kronecker product of the correlation matrices at the MS and BS. The Power Doppler profile and the Power Delay profile define time and frequency.
Scenarios supported	Indoor/Limited outdoor.	Outdoor scenarios. Supports urban macro, urban micro, suburban but not indoor or suburban outdoor to indoor or	No restriction except for pin-hole scenarios
Scenarios investigated	Indoor	Urban macro, urban micro, suburban outdoor	Picocell, microcell, macrocell
Is the model antenna independent	**No**. Antenna geometry is definable, radiation patterns are not	**Yes**. Some antenna pattern is given in the technical description of the model but it can be changed	The spatial properties of the array are included in the correlation matrices. Specific antenna patterns can be additionally integrated**.**
Validation	**Yes**. Capacity analysis	**No**. The model is based on parameters extracted from measurements but no validation of the whole model is given.	**Yes**, eigenanalysis-both in spatial and polarization domains
SW implementation available	Matlab© implementation from L. Schumacher is free with agreements.	**No**.	COSSAP® and MATLAB® SW implementations exist, free with agreements

How does it characterize different scenarios	Different indoor environments, rms delay spread	Via large scale parameters. Different values of large scale parameters (i.e., angle spread, delay spread, shadowing) are assigned to different scenarios. The generation of channel parameters and realizations are heavily dependent on these values.	different Power Doppler and Power Delay spectra, Rms, Rbs
Is it true MIMO	**Yes**	**Yes**. Linear array is presented but other antennas configurations can be used	**Yes**
How is correlation in space, time and frequency treated?	Given delay and azimuth spreads are correlated. Doppler spectrums are defined.	Implicitly. Having different distributions in different domains implies the correlation within different domains.	The Kronecker product of the correlation matrices at the MS and BS defines space. The Power Doppler profile and the Power Delay profile define time and frequency, respectively.
Are Rx and Tx treated separately?	**Yes**	**Yes**. AoD and AoA are generated separately and the pairing between different rays takes place randomly. This way avoids Kronecker product.	**Yes**
Is it based on some known models?	Kronecker model	Yes. COST 259. The principle adopts many of COST 259 recommendations	Kronecker model, pdfs (Laplacian, Gaussian, Uniform)
Which parameters can be set	Antenna geometries, distance between Rx and Tx, carrier frequency, correlation coefficient type (complex/real)	Distance between MS and BS, orientation of antennas and speed of MS, Delay spread and angular spread and shadow fading are given for different scenarios but different values can be set in the model.	Correlation matrices at the MS and BS, shape of the Doppler Spectrum, Power Delay Spectrum, shape of the Power Azimuth Spectrum, distance between antenna elements, velocity of the mobile, carrier frequency.
Antenna array geometries included	**Yes**. Basically only ULA, but also others in horizontal plane are possible	**Yes**. Linear array. LA geometry is discussed but not enforced. Othergeometries can be included.	**No,** only ULAs with omnidirectional elements are supported in the software implementations
Radiation patterns included	**No**	**Yes**. Proposal of antenna pattern is given but it can be replaced with others if needed	**Yes**, patterns can be defined
Polarizations	**No**	**Yes**. Polarized antennas array are included as an option.	**Yes**
Realistic antenna descriptions	**No**	**No**	**No**, considered only in the validation
How is the frequency selectiveness treated?	**Tapped delay line model**	**By multipaths in delay domain**. The model is based on generation of 6 rays each of 20 subrays with some delay spread value. Depending on the chip frequency 6 or less resolvable components appear on the power delay profile	**With the power delay profile**
Natural domain of the model (freq, time) (delay,time) (freq Doppler) or (delay Doppler)	**Delay, time**	**Delay domain**. The model starts with generation of delay components. Doppler domain information is generated implicitly.	**Delay, Doppler**
Intercell interference (multiuser?)	**No**	**Yes**. Interference from other cells is included. The weak interferers are considered spatially white, while the strong interferers are modeled spatially	**No**

How does the model evolve in time	Only evolution is due to Doppler	Link level: Evolution due to Doppler. System level: Random generation of power delay profile. Different PDP are generated statistically from some distribution, every realization (drop) is independent from the others.	Not explicitly stated
How the time is treated (mobility modelling)	Only evolution is due to Doppler	Fixed values for LL and as input parameter in SL. In system level, the velocity of MS can be defined every drop	Simply from the speed of the mobile the Doppler spectrum is calculated
Are references included on higher levels? (such as modulation - beamforming etc)	**No**	**No**.	**No**
Scalability (how to go from LL to SL simulations)	**No**	The LL channel parameters are for calibration purposes. Only SL model can be used in for algorithm testing and system design.	**No**, there were no SL simulations
Multi-hop support	**No**	**No**. The model is intended for cellular type systems	**No**
Near-far capability	**No.** Includes path loss	**Yes**.	**No**, model is not even multiuser=>no near-far problem
Suggestion for improvements		Finding proper channel parameters at different frequencies and bandwidths and increasing number of paths. Also, other models for path loss and shadowing.	Avoid the Kronecker approximation - include multi-user
Other notes		The SCM modeling approach can be adopted for developing new models at different frequencies and bandwidths.	SL interface was not considered at all

Appendix 2.

Table 11 Summary SCM link level parameters for calibration purposes

Model		Case I		Case II		Case III		Case IV	
Corresponding 3GPP Designator*		Case B		Case C		Case D		Case A	
Corresponding 3GPP2 Designator*		Model A, D, E		Model C		Model B		Model F	
PDP		Modified Pedestrian A		Vehicular A		Pedestrian B		Single Path	
# of Paths		1) 4+1 (LOS on, K = 6dB) 2) 4 (LOS off)		6		6		1	
Relative Path Power (dB)	Delay (ns)	1) 0.0 2) -Inf	0	0,0	0	0.0	0	0	0
		1) -6.51 2) 0.0	0	-1.0	310	-0.9	200		
		1) -16.21 2) -9.7	1 10	-9.0	710	-4.9	800		
		1) -25.71 2) -19.2	1 90	-10.0	1090	-8.0	1200		
		1) -29.31 2) -22.8	4 10	-15.0	1730	-7.8	2300		
				-20.0	2510	-23.9	3700		
Speed (km/h)		1) 3 2) 30, 120		3, 30, 120		3, 30, 120		3	
UE/Mobile Station	Topology	Reference 0.5λ		Reference 0.5λ		Reference 0.5λ		N/A	
	PAS	1) LOS on: Fixed AoA for LOS component, remaining power has 360 degree uniform PAS. 2) LOS off: PAS with a Laplacian distribution, RMS angle spread of 35 degrees per path		RMS angle spread of 35 degrees per path with a Laplacian distribution Or 360 degree uniform PAS.		RMS angle spread of 35 degrees per path with a Laplacian distribution		N/A	
	DoT (degrees)	0		22.5		-22.5		N/A	
	AoA (degrees)	22.5 (LOS component) 67.5 (all other paths)		67.5 (all paths)		22.5 (odd numbered paths), -67.5 (even numbered paths)		N/A	
Node B/ Base Station	Topology	Reference: ULA with 0.5λ-spacing or 4λ-spacing or 10λ-spacing						N/A	
	PAS	Laplacian distribution with RMS angle spread of 2 degrees or 5 degrees, per path depending on AoA/AoD						N/A	
	AoD/AoA (degrees)	50^o for 2^o RMS angle spread per path 20^o for 5^o RMS angle spread per path						N/A	

Table 12 Environment parameters for SCM model

Channel Scenario	Suburban Macro	Urban Macro	Urban Micro
Number of paths (*N*)	6	6	6
Number of sub-paths (*M*) per-path	20	20	20
Mean AS at BS AS at BS as a lognormal RV $\sigma_{AS} = 10\,\hat{}\,(\varepsilon_{AS}x+\mu_{AS}),\ x \sim \eta(0,1)$	E(σ_{AS})=5^0 μ_{AS} = 0.69 ε_{AS} = 0.13	E(σ_{AS})=8^0, 15^0 8^0 μ_{AS} = 0.810 ε_{AS} = 0.34 15^0 μ_{AS} = 1.18 ε_{AS} = 0.210	NLOS: E(σ_{AS})=19^0 N/A
$r_{AS} = \sigma_{AoD} / \sigma_{AS}$	1.2	1.3	N/A
Per-path AS at BS (Fixed)	2 deg	2 deg	5 deg (LOS and NLOS)
BS per-path AoD Distribution standard distribution	$\eta(0,\sigma_{AoD}^2)$ where $\sigma_{AoD} = r_{AS}\sigma_{AS}$	$\eta(0,\sigma_{AoD}^2)$ where $\sigma_{AoD} = r_{AS}\sigma_{AS}$	U(-40deg, 40deg)
Mean AS at MS	E($\sigma_{AS,\,MS}$)=68^0	E($\sigma_{AS,\,MS}$)=68^0	E($\sigma_{AS,\,MS}$)=68^0
Per-path AS at MS (fixed)	35^0	35^0	35^0
MS Per-path AoA Distribution	$\eta(0,\sigma_{AoA}^2(\mathrm{Pr}))$	$\eta(0,\sigma_{AoA}^2(\mathrm{Pr}))$	$\eta(0,\sigma_{AoA}^2(\mathrm{Pr}))$
Delay spread as a lognormal RV $\sigma_{DS} = 10\,\hat{}\,(\varepsilon_{DS}x+\mu_{DS}),\ x \sim \eta(0,1)$	μ_{DS} = - 6.80 ε_{DS} = 0.288	μ_{DS} = -6.18 ε_{DS} = 0.18	N/A
Mean total RMS Delay Spread	E(σ_{DS})=0.17 μs	E(σ_{DS})=0.65 μs	E(σ_{DS})=0.251μs (output)
$r_{DS} = \sigma_{delays} / \sigma_{DS}$	1.4	1.7	N/A
Distribution for path delays			*U*(0, 1.2μs)
Lognormal shadowing standard deviation, σ_{SF}	8dB	8dB	NLOS: 10dB LOS: 4dB
Pathloss model (dB), *d* is in meters	$31.5 + 35\log_{10}(d)$	$34.5 + 35\log_{10}(d)$	NLOS: $34.53 + 38\log_{10}(d)$ LOS: $30.18 + 26*\log_{10}(d)$

Appendix 3.

Table 13. Propagation conditions for the GSM channel models

Channel	# of taps	Max. excess delay [ns]	Mobility [km/h]
Rural Area (RA)	6	600	130 … 250
Hilly Terrain (HT)	12	20000	100
Typical Urban (TU)	12	5000	1.5 … 50
Equalization Test (EQ)	6	16000	
Very Small Cells (TI)	2	400	

HT and TU models have also reduced configurations of 6 taps.

Table 14. 3GPP Channel Models

Channel	# of taps	Max. excess delay [ns]	Mobility [km/h]
Case 1	2	976	3…7
Case 2	3	20000	3…7
Case 3	4	781	120…282
Case 4	2	976	3…7
Case 5	2	976	50…118
Case 6	4	781	250…583
Case 7	6	14580	50…118
Case 8	2	976	30
Pedestrian A	4	410	3…7
Pedestrian B	6	3700	3…7
Vehicular A	6	2510	30…71
Vehicular B	6	2510	120…282
Moving	2	6000	N/A
Birth-Death	2	11000	N/A

In addition, so called 3GPP deployment models were specified in [11]. Those models have been defined for the three environments as shown in Table 15.

Table 15. 3GPP Deployment Models

Channel	# of taps	Max. excess delay [ns]	Mobility [km/h]
Typical Urban	20	2140	3…120
Rural Area	10	528	120…250
Hilly Terrain	20	18016	120

Table 16. JTC Channel Models.

Channel	# of taps	Maximum excess delay [ns]
Indoor Office – A	3	100
Indoor Office – B	6	700
Indoor Office – C	8	2375
Indoor Commercial – A	5	200
Indoor Commercial – B	7	750

Indoor Commercial – C	8	2675
Outdoor Urban High-Rice, Low Antenna – A	6	700
Outdoor Urban High-Rice, Low Antenna – B	8	3750
Outdoor Urban High-Rice, Low Antenna – C	10	10000
Outdoor Urban Low-Rice, Low Antenna – A	6	700
Outdoor Urban Low-Rice, Low Antenna – B	10	5100
Outdoor Urban Low-Rice, Low Antenna – C	10	10000
Outdoor Residential, Low Antenna – A	8	350
Outdoor Residential, Low Antenna – B	8	2675
Outdoor Residential, Low Antenna – C	10	5100
Outdoor Urban High-Rice, High Antenna – A	8	2675
Outdoor Urban High-Rice, High Antenna – B	10	20000
Outdoor Urban High-Rice, High Antenna – C	10	50000
Outdoor Urban / Suburban Low-Rice, High Antenna – A	7	1750
Outdoor Urban / Suburban Low-Rice, High Antenna – B	10	25000
Outdoor Urban / Suburban Low-Rice, High Antenna – C	10	55000
Outdoor Residential, High Antenna – A	7	1750
Outdoor Residential, High Antenna – B	10	15000
Outdoor Residential, High Antenna – C	10	50000

Table 17. IST-FITNESS

Channel for UMTS	**PDP**	**Speed (Km/h)**	**Doppler**	**PAS at the BTS**	**PAS at the terminal**
Case 1a: Independent channels (reference case)	Flat	3, 40, 120	Classical	N/A	N/A
Case 1b: Independent multipath channels	Ped A, Veh A	3, 40, 120	Classical	N/A	N/A
Case 2: Rural/Suburban (macro)	ITU Pedestrian A, ITU Vehicular A	3, 40, 120	Classical (other Doppler spectra according to PAS at terminal)	Laplacian	Uniform 360 (smaller ang. spread at a later stage)
Case 3: City Centre (micro)	ITU Pedestrian B	3 and 40	Classical (other Doppler spectra according to PAS at terminal)	Laplacian	Uniform 360 (smaller ang. spread at a later stage)
Case 4: Public (micro/pico)	ETSI BRAN channel model E	3	Classical (other Doppler spectra according to PAS at terminal)	Laplacian	Uniform 360 (smaller ang. spread at a later stage)

Scenarios for WLAN	**Channel Model**	**PDP**	**Spatial correlation**
Home/Small Office	GM1	based on GM1, with RMS Delay Spread= 10ns	Classical
Office	GM1- extension of the home environment: the RMS Delay Spread is higher	based on GM1, with RMS Delay Spread= 50ns (consistent with H2 model A)	TBD
Public (Indoor)	GM2	based on GM2, with RMS Delay Spread=250ns (consistent with H2 model E)	TBD and to be harmonised with UMTS