| | | |
|---|---|---|
| Project | **IEEE 802.16m Group** | |
| Title | **Considerations for channel modeling in IEEE 802.16m** | |
| Date | **2007-01-11** | |
| Source(s) | **Andreas F. Molisch, Jinyun Zhang**<br>Mitsubishi Electric Research Lab<br>201 Broadway<br>Cambridge, MA 02139 USA | Voice: 617-621-{7558,7595}<br>Fax: 617-621-7550<br>{molisch, jzhang}@merl.com |
| | **Toshiyuki Kuze**<br>Mitsubishi Electric Corp<br>5-1-1 Ofuna Kamakura, Kanagawa<br>2478501, Japan | Voice: +81-467-41-2885<br>Fax: +81-467-41-2486<br>Kuze.Toshiyuki@ah.MitsubishiElectric.co.jp |
| Re: | Response to the call for technical proposal regarding IEEE Project 802.16m | |
| Abstract | We present some fundamental considerations for channel models in 802.16m. The key points are (i) new channel models are required to allow reasonable comparisons of 802.16m system proposals; (ii) the new models will have to be suitable for MIMO systems operating in at least 100 MHz bandwidth; (iii) while existing standardized models can be used as a partial basis of 802.16m models, none can be adopted without modifications; (iv) the generic model structure should be a double-directional (MIMO) channel model that takes the interdependence of different channel parameters into account. | |
| Purpose | To provide general information on channel modeling to IEEE 802.16m. | |
| Notice | *This document has been prepared to assist IEEE 802.16. It is offered as a basis for discussion and is not binding on the contributing individual(s) or organization(s). The material in this document is subject to change in form and content after further study. The contributor(s) reserve(s) the right to add, amend or withdraw material contained herein.* | |
| Release | *The contributor grants a free, irrevocable license to the IEEE to incorporate material contained in this contribution, and any modifications thereof, in the creation of an IEEE Standards publication; to copyright in the IEEE's name any IEEE Standards publication even though it may include portions of this contribution; and at the IEEE's sole discretion to permit others to reproduce in whole or in part the resulting IEEE Standards publication. The contributor also acknowledges and accepts that this contribution may be made public by IEEE 802.16.* | |
| Patent Policy and Procedures | *The contributor is familiar with the IEEE 802.16 Patent Policy and Procedures <http://ieee802.org/16/ipr/patents/policy.html>, including the statement "IEEE standards may include the known use of patent(s), including patent applications, provided the IEEE receives assurance from the patent holder or applicant with respect to patents essential for compliance with both mandatory and optional portions of the standard." Early disclosure to the Working Group of patent information that might be relevant to the standard is essential to reduce the possibility for delays in the development process and increase the likelihood that the draft publication will be approved for publication. Please notify the Chair <mailto:chair@wirelessman.org> as early as possible, in written or electronic form, if patented technology (or technology under patent application) might be incorporated into a draft standard being developed within the IEEE 802.16 Working Group. The Chair will disclose this notification via the IEEE 802.16 web site <http://ieee802.org/16/ipr/patents/notices>.* | |

# Considerations for channel modeling in IEEE 802.16m

*Andreas F. Molisch, Jinyun Zhang*
Mitsubishi Electric Research Lab
201 Broadway
Cambridge, MA 02139 USA

*Toshiyuki Kuze*
Mitsubishi Electric Corp
5-1-1 Ofuna Kamakura, Kanagawa
2478501, Japan

## 1. Introduction

For the design and testing of wireless communications systems, models of the propagation channel are an absolute necessity. Simulation results of different systems can only be compared if they are based on the same channel models. For this reason, standardized channel models have played an important role in the development of wireless standards. Important standardized channel models include the COST207 channel models [1], which have been used for establishing the GSM standard; the ITU-R channel models, which influenced the development of third-generation cellphones [2]; the HIPERLAN channel models, which were used for 802.11 systems [3], and the COST 231 pathloss models, which have been applied for a number of microcellular systems [4]. Most relevantly for IEEE 802.16, the SUI (Stanford University Interim) models have been used extensively in the development of the 802.16 standard [5].

However, most channel models are tuned to specific system parameters and environments. As the envisioned environments change, and as the underlying techniques become more advanced, new channel models are required. In particular, the SUI channel models have the following restrictions:

- they exist only for a small number of environments, namely 3 terrain types with different types of vegetation density. They do not, for example, include outdoor-to-indoor propagation.
- they have only three taps in the delay domain, limiting the bandwidth to which they are applicable.
- they treat the rms delay spread as fixed. However, extensive studies in the literature (summarized in [6]) have shown the delay spread to be a random variable.
- they prescribe a single antenna correlation coefficient; this coefficient is independent of pathloss, delay spread, etc.
- they have a limited range of Doppler spreads

All those restrictions were not a problem for the simulation of FWA (fixed wireless access) systems with a rather small bandwidth, as were relevant for WiMax. However, the 802.16m system will have quite different requirements. As a system with increased mobility, it will need to operate in different environments, and will see larger Doppler spreads. Meeting the probable IMT-advanced requirements of   Gbit/s peak data rate will require larger bandwidth (probably   MHz), and MIMO operation. For all these reasons, new channel models will be required.

The current document is intended to outline a few basic principles of channel models for 802.16m. It will start out with a description of probable environments in which the system will have to work. Section III then gives an overview of different techniques to model MIMO propagation channels. Next, Section IV gives a summary of all parameters that are needed for a complete channel model. Finally, we describe existing MIMO channel models, and discuss their pros and cons. The document draws from previous papers of one of the authors [7], [8], [9], [10], [11].

## 2. Operation Environments

As a first step, we have to establish in which environments the 16m system will operate. While fixed wireless access will remain an important application, a number of new environments will open up. As a basis for the discussion, it is interesting to consider the environments defined by the European Research Initiative COST 273 [11], since they are the currently most complete list of environments.

## *2.1. Environment definitions of COST 273*

### 2.1.1. Macrocells

Macrocellular environments are generally defined as environments where the base station is placed above the rooftop height of the surrounding buildings. It is the most "conventional" scenario for cellular applications.

1. Small macrocells in city center:
2. Large urban macrocells: this is mainly the same environment as above but with a BS far above rooftop level.
3. Suburban:
4. Fixed wireless access: in urban environments
5. Outdoor to indoor urban:
6. Outdoor to indoor suburban:

No definitions for rural environments are given

### 2.1.2. Microcells

Microcellular environments are defined as environments where the base station height is at or below the level of the surrounding rooftops, but outdoors. The MS can be located either indoor or outdoor. Note that BS at rooftop is sometimes called "minicell"; it is, however, included in our description of the micro cell.

1. City center:
2. Bad city center: includes high-rise buildings that act as far-scatterer clusters
3. Open place: large open space surrounded by buildings
4. BS outdoor – user indoors:
5. Peer-to-peer: both mobiles at street level

### 2.1.3. Picocells

1. Halls: including railway stations, airport halls, factory halls.
2. Tunnels: railway and subway tunnels, car tunnels, and mines.
3. Corridors LOS: tboth the BS and the MS are in a corridor, and LOS exists between the two.
4. Corridors NLOS : BS is in a corridor, while the MS can be either in a different part of the corridor (without LOS), or in a room adjacent to the corridor.
5. Office LOS: Office building is defined to be a concrete/steel/glass building, with a shape and size that is different from a residential environment. It is this building structure that defines the office environment, not the usage (offices put into a residential building are still viewed as ”residential”).
6. Office NLOS: describes offices where the BS and the MS do not have LOS.
7. Home environments LOS:
8. Home environments NLOS:

### 2.1.4. Ad-hoc networks

Ad-hoc network environments are characterized by the following properties: (i) all transceivers are at approximately the same height, (ii) all transceiver stations show nomadic mobility, i.e., remain static for an extended period of time, before being "dropped" to a new location.

1. Office/residential LOS: ad-hoc network in office or residential LOS environment.
2. Office/residential NLOS: ad-hoc network in office or residential NLOS environment.
3. Halls: ad-hoc network in hall environment.

### 2.2. Discussion and suggestion for further environments

The COST 273 definitions have a relatively small number of fixed-wireless access scenarios, namely an urban macrocellular environment. It might be desirable to include a fixed-wireless model for a number of different environments. Such a specification would require to pay special attention to the temporal Rice factor, and entail a modified Doppler spectrum.

We also note that the COST 273 definitions include a large number of picocells. It is doubtful whether 802.16m will see significant deployments in this area, or whether handover to such schemes as 802.11n or WiMedia will be used. This question should be considered in more detail after the application scenarios have been defined by the Task Group.

## 3. Generic MIMO channel modeling methods

The most important change between the SUI models and the new 802.16m model will lie in the modeling o channel aspects that are relevant for MIMO systems. We note again that the SUI models only use a single correlation factor between signals at different antennas. This approach is insufficient in a number of respects for 16m models:

- it does not take into account that the correlation coefficient changes as the mobile station moves over the cell (this is due to the fact that the angular spectrum of the channel changes over the cell)
- it does not allow to compare different antenna configurations
- it does not show the dependence of the correlation coefficient on the Rice factor (the stronger the LOS, the higher the correlation)
- it is difficult to realistically handle systems with more than 2 antennas.

In general, MIMO channels can be modeled either as double-directional channels [12] or as vector (matrix) channels [13]. The former method is more related to the physical propagation effects, while the latter is more centered on the effect of the channel on the system. Still, they must be equivalent, as they describe the same physical channel. Another distinction is whether to treat the channel deterministically or stochastically. In the following, we outline the relations between those description methods.

### 3.1. Double-directional characterization

The *deterministic double-directional channel* is characterized by its double-directional impulse response. It consists of $N$ propagation paths between the transmitter and the receiver sites. Each path is delayed in accordance to its excess-delay $\tau_\ell$, weighted with the proper complex amplitude $a_\ell e^{j\phi_\ell}$. Note that the amplitude is a two-by-two matrix, since it describes the vertical and horizontal polarizations and the cross-polarization; neglecting a third possible polarization direction is admissible in macro- and microcells. Finally, the paths are characterized by their direction-of-departure (DOD) $\Omega_{T,\ell}$ and direction-of-arrival (DOA) $\Omega_{R,\ell}$.[1] The channel impulse response matrix $\underline{h}$, describing horizontal and vertical polarization is then

$$\underline{h}(t,\tau,\Omega_T,\Omega_R) = \sum_{\ell=1}^{N} \underline{h}_\ell(t,\tau,\Omega_T,\Omega_R) = \sum_{\ell=1}^{N} \underline{a}_\ell e^{j\phi_\ell}\delta(\tau-\tau_\ell)\delta(\Omega-\Omega_{T,\ell})\delta(\Psi-\Omega_{R,\ell}) \qquad (1)$$

---

[1] We stress that the (double-directional) channel is reciprocal. While the directions of multipath components at the base station and at the mobile station are different, the directions at one link end for the transmit case and the receive case must be identical. When we talk in the following about DOAs and DODs, we refer to the directions at two different link ends.

The number of paths $N$ can become very large if all possible paths are taken into account; in the limit, the sum has to be replaced by an integral. For practical purposes, paths that are significantly weaker than the considered noise level can be neglected. Furthermore, paths with similar DOAs, DODs, and delays can also be merged into ”effective” paths. Note that the parameters of those paths must be similar enough so that over the distances of interest for the simulation, no fading is created by the superposition of the subpaths.

In general, all multipath parameters in (1), $\tau_\ell, \Omega_{R,\ell}$, $\Omega_{T,\ell}, \underline{a}_\ell$, and $e^{j\phi_\ell}$ will depend on the absolute time $t$; also the set of multipath components (MPCs) contributing to the propagation will vary, $N \rightarrow N(t)$. The variations with time can occur both because of movements of scatterers, and movement of the mobile station MS (the BS is assumed fixed). Without restriction of generality, the reference coordinate (center) of the base station antenna array is chosen to coincide with the origin of the coordinate system. We furthermore assume that the antenna arrays both at the BS and MS are small enough so that the MPC parameters do not change over the size of this array.

The above *double-directional* description seems rather straightforward. However, a straightforward *stochastic* description of the involved parameters involves a multi-dimensional probability density function that could only be described or saved as a huge file. Note that in general, the statistics of MPC delays, DOAs, DODs, amplitudes and phases are not separable, and thus have to be described by their *joint* probability density function. It is thus often preferable to base the MPC parameters (DOA, delay,...) on another set of parameters (see Sec. 4). While the number of parameters in that different set is large, the pdfs of those parameters are more compact.

## 3.2. Channel transfer matrix

The *deterministic* wideband *matrix* channel response describes the channel from a transmit to a receive antenna array. It is characterized by a matrix $\underline{H}$ whose elements $H_{ij}$ are the (nondirectoinal) impulse responses from the $j-$th transmit to the $i$-th receive antenna element. They can be computed for any antenna constellation as

$$H_{i,j} = h(\tau, \vec{x}_{R,i}, \vec{x}_{T,j}) = \sum_{\ell=1}^{N} \vec{g}_R(\Omega_R) \cdot \underline{h}(\tau_\ell, \Omega_{R,\ell}, \Omega_{T,\ell}) \cdot \vec{g}_T(\Omega_T) \cdot e^{j\left\langle \vec{k}(\varphi_{R,\ell})\vec{x}_{R,i} \right\rangle} e^{j\left\langle \vec{k}(\varphi_{T,\ell})\vec{x}_{T,j} \right\rangle}, \qquad (2)$$

where where $\vec{x}_R$ and $\vec{x}_T$ are the vectors of the chosen element-position measured from an arbitrary but fixed reference points $\vec{x}_{R,0}$ and $\vec{x}_{T,0}$ (e.g., the centers of the arrays) and $\vec{k}$ is the wavevector so that

$$\left\langle \vec{k}(\Omega) \cdot \vec{x} \right\rangle = \frac{2\pi}{\lambda}(x \cos\vartheta \cos\varphi + y \cos\vartheta \sin\varphi + z \sin\vartheta). \qquad (3)$$

where $\vartheta$ and $\varphi$ denote elevation and azimuth, respectively.The functions $\vec{g}_R(\Omega_R)$ and $\vec{g}_T(\Omega_T)$ are the antenna patterns at transmitter and receiver, respectively, where the two entries of the vector $\vec{g}$ describe the antenna pattern for horizontal and vertical polarization.

The *stochastic* description of the *matrix channel* also seems simple at first glance. It requires the average powers of the entries of the transfer matrix (from each transmit to each receive antenna), as well as the correlation between the matrix entries. Especially for small antenna array sizes, a description of the $H$-matrix seems desirable. However, we have to keep the following point in mind:

1. The fading at the different antenna elements can be Rayleigh, Rician, or ”double-Rayleigh”. Thus, we have to define those statistics and its associated parameters.
2. The number of involved correlation coefficients increases quadratically with the number of antenna elements. Their number might be reduced in periodic structures, as can be usually found at base stations (BSs) (Toeplitz structure of the correlation matrix for antenna arrays), but not necessarily for diversity arrangements as found at the mobile station (MS). Approximate description methods have been suggested to reduce the number of involved parameters, including the Weichselberger model [14,15],

and the more simplified Kronecker model [16].

3. The whole description is dependent on the used antenna arrangement. Generalizations to larger (or just different) structures are not easily possible.
4. In delay-dispersive environments, we have to define different correlation factors for each delay, because different propagation mechanisms (which induce different correlation factors) have different delays.
5. The correlation matrices change, depending on the realizations of the position (and therefore realization of large-scale fading etc.) of the mobile station in the cell.

### 3.3. Geometry-based stochastic channel models

A alternative stochastic description of MIMO channels is a *geometry-based stochastic channel model* (GSCM). This model is a way of efficiently describing and implementing a double-directional channel characterisation, by stochastically prescribing scatterer locations. The actual channel impulse response is then found by a simplified RT procedure.GSCM were originally devised for channel simulation in systems with multiple antennas at the base station (diversity antennas, smart antennas) [17], [18,19,20,21,22], taking only single-scattering processes into account. The single-scattering assumption makes RT extremely simple: apart of the LoS, all paths consist of two subpaths connecting the scatterer to the Tx and Rx, respectively. These subpaths characterize the DoD, DoA, and propagation time (which in turn determines the overall attenuation, usually according to a power law).

A GSCM has a number of important advantages [23]:

- it has an immediate relation to physical reality; important parameters (like scatterer locations) can often be determined via simple geometrical considerations;
- many effects are implicitly reproduced: small-scale fading is created by the superposition of waves from individual scatterers; DoA and delay drifts caused by MS movement are implicitly included;
- all information is inherent to the distribution of the scatterers; therefore, dependencies of power delay profile (PDP) and angular power spectrum (APS) do not lead to a complication of the model;
- Tx/Rx and scatterer movement as well as shadowing and the (dis)appearance of propagation paths (e.g. due to blocking by obstacles) can be easily implemented.

Using the assumption of single-scattering, the position of a scatterer completely determines DoD, DoA, and delay. However, many environments (e.g., micro- and picocells) feature multiple-bounce scattering for which DoD, DoA, and delay are completely decoupled. If the directional channel properties need to be reproduced only for *one* link end (i.e., multiple antennas only at the Tx or Rx), multiple-bounce scattering can be incorporated into a GSCM via the concept of *equivalent scatterers* - virtual single-bounce scatterers whose position is chosen such that they mimic multiple bounce contributions in terms of their delay and DoA [7]. In a MIMO system, the equivalent scatterer concept fails since the angular channel characteristics are reproduced correctly only for one link end. As a remedy, [9] suggested the use of double scattering where the coupling between the scatterers around the BS and those around the MS is established by means of a so-called illumination function (essentially a DoD spectrum relative to that scatterer). Another approach to incorporate multiple-bounce scattering into GSCM models is the twin-cluster concept pursued within COST 273 [11].

## 4. Parameter set for complete double-directional models

As mentioned in Sec. 3, a direct characterization of the pdfs of the MPC parameters is too complex. Rather, it is preferable to provide an indirect characterization via a set of auxiliary parameters. In this section, we provide a list of such parameters.

It is important to understand that there can be dependencies between the different model parameters. For example, the famous Greenstein model established a correlation between the shadowing and the rms delay spread [6]. Thus, a complete channel model cannot simply take a pathloss/shadowing model and a delay spread model, and put them together into a single model. In the following, we give a list of parameters, adopted from the COST 273 model [11], which in turn is mostly based on the COST 259 model [7], [8].

## 4.1. External parameters

As mentioned above, external parameters are parameters that remain fixed for a simulation run. They might change according to the system that is simulated, and according to geographical regions (for example the average rooftop height in city centers can be different in Northern Europe and in Japan).

### 4.1.1. External parameters for all environments

The following parameters are to be used in all environments:

$f_c$ : *Carrier frequency* [Hz]:

$h_{BS}$ : *Base station height* [m]:

$h_{MS}$ : *Mobile station height* [m]:

$\vec{r}_{BS}$ : *Base station position* [m]:

$\vec{r}_{MS}$ : *Mobile station position* [m]:

*antenna scenarios* (e.g., 4-element ULA) [no of antennas, antenna spacing, array shape]:
*antenna orientation* [pdf]:
*Pathloss model* [dB/m]:

### 4.1.2. Additional external parameters for macro- and microcells

$h_B$ : Average rooftop height [m]:

$w_r$ : Width of roads [m]:

$wb$ : distance between buildings [m]:

$\phi_R$ : Road orientation with respect to direct path [degree]:

### 4.1.3. Additional external parameters for picocells and ad-hoc networks

$l_l$, $l_w$ : size of rooms [m×m]. .

$N_{floor}$ : number of floors between BS and MS [integer]:

Whether there is a building on the opposite side of the building BS and MS are in [yes/no]:

## 4.2. Stochastic parameters

The stochastic parameters describe the variations according to the different locations and radio environments in which the MS might be. Their parameterization is influenced by the external parameters.
Following the concepts of [7], multipath components (MPCs) arrive in clusters. The total DDIR can thus be written as the sum of the cluster DDIRs, which in turn can be formulated as [8]

$$P\left(\tau,\theta_{BS},\varphi_{BS},\theta_{MS},\varphi_{MS}\right)=P_\tau\left(\tau\right)P_\theta^{BS}\left(\theta_{BS}\right)P_\varphi^{BS}\left(\varphi_{BS}\right)P_\theta^{MS}\left(\theta_{MS}\right)P_\varphi^{MS}\left(\varphi_{MS}\right). \tag{4}$$

Note that this model assumes that *within one cluster*, azimuth spread, elevation spread, and delay spread are independent at the BS and the MS. Note that this is *not* the common Kronecker model that assumes the angular statistics to be independent at BS and MS.

### 4.2.1. Visibility region

The concept of visibility regions is explained in [7]. Each cluster of IOs is associated with a visibility region. If the MS is in a visibility region, then a cluster is active and contributes to the impulse response; if the MS is outside the visibility region, the cluster does not contribute. The visibility region is characterized by

$R_\mathrm{C}$ : size of the visibility region [m].

$L_\mathrm{C}$ : size of the transition region [m].

A smooth transition from non-active to active cluster is achieved by scaling the path gain of the cluster by a transition function. Furthermore, the visibility region is characterized by the probability density function of its location which depends on the distance between the visibility region and the BS.

### 4.2.2. Cluster generation

The distribution of the number of clusters $N_\mathrm{C}$ is modeled uniformly $N_\mathrm{C,min}$ (corresponding to the cluster originating from interactions around the MS, plus possible the cluster around the BS) plus a random variable with parameter $N_\mathrm{P}$, which can be, e.g., a Poisson-distributed variable. For the placement of clusters and visibility regions, the COST 259, COST 273, and 3GPP models propose a variety of methods, whose discussion is beyond the scope of the current document.

### 4.2.3. Cluster power model

The power contained in each cluster is a function of the delay (with respect to the LOS or quasi-LOS component). Typically, the longer the delay, the smaller is the power that it carries. However, there is limit to the cluster attenuation (if the attenuation becomes too high, the cluster does not have an impact on the impulse response, and is thus dropped from the considerations. In COST 259 and 273, The power of the $m-$th cluster is

$$P_m = P_0 \max\left\{\exp\left[-k_\tau(\tau_\mathrm{m}-\tau_0)\right], \exp\left[-k_\tau(\tau_\mathrm{B}-\tau_0)\right]\right\} \ . \qquad (5)$$

The parameters describing this equation are

$k_\tau$ : attenuation coefficient given in units of [dB/ $\mu$ s],

$\tau_0$ : delay of the LOS component given in units of [ $\mu$ s],

$\tau_\mathrm{B}$ : cut-off delay given in units of [ $\mu$ s].

### 4.2.4. LOS occurrence

For some environments the occurrence of LOS is modeled stochastically. The modeling approach has a strong similarity to the visibility region for the clusters. The probability for LOS decreases strongly with the distance of the MS from the BS, and is zero after a cutoff distance $d_\mathrm{co}$. The model is thus described by the following parameters:

$d_\mathrm{co}$ [m]: cutoff distance for LOS,

$R_\mathrm{L}$ [m]: radius of visibility region for LOS,

$L_\mathrm{L}$ [m]: size of transition region for LOS visibility region.

Depending on the existence of a LOS connection, the LOS power factor (power of the first component, compared to the power of all other components) varies, and thus is described as a random variable with a certain pdf.

## 4.2.5. Cluster dispersion

The DDDPS (i.e., the squared magnitude of the DDIR, averaged over the small-scale fading) can be characterized for each cluster by its dispersion in the following domains: delay, azimuth at the BS, elevation at the BS, azimuth at the MS, elevation at the MS. In the literature, the most common model for the power delay profile (behavior in the delay domain) is a single-exponential decay, while the power angular spectrum is Laplacian. Mathematically, this means

$$P_\tau\left(\tau\right) = \frac{1}{\sigma_\tau} e^{-(\tau-\tau_m)\sigma_\tau}. \tag{6}$$

The delay spread $\sigma_\tau$ is itself a log-normal random variable, with a mean $m_{\mathrm{S}\tau}$ (given in [ns]) and standard deviation $S_{\mathrm{S}\tau}$ (given in [dB]). Note that the mean increases with increasing distance between BS and MS [6], as

$$m_{\mathrm{S}\tau} = \overset{\square}{m}_{\mathrm{S}\tau} d^{-\varepsilon}. \tag{7}$$

For the angular spectrum

$$P_\varphi\left(\varphi\right) = \frac{1}{\sigma_\varphi \sqrt{2}} e^{-\sqrt{2}\left|\varphi-\varphi_m\right|\sigma_\varphi}, \tag{8}$$

where the azimuthal spread $\sigma_\varphi$ is a log-normal random variable with mean $m_{\mathrm{S}\varphi}$ (given in [degree] and standard deviation $S_{\mathrm{S}\varphi}$ (given in [dB]). Similarly, the elevation power spectrum is given as

$$P_\theta\left(\theta\right) = \frac{1}{\sigma_\theta \sqrt{2}} e^{-\sqrt{2}\left|\theta-\theta_m\right|\sigma_\varphi} \tag{9}$$

where the elevation spread $\sigma_\theta$ is a log-normal random variable with mean $m_{\mathrm{S}\theta}$ and standard deviation $S_{\mathrm{S}\theta}$.

Similarly, the angular parameters are also defined for the MS. It is noteworthy that those parameters might depend on the delay of the cluster.

## 4.2.6. Shadow fading

Following a widely used approach, each cluster undergoes shadow fading, which is modeled log-normally distributed with standard deviation $\sigma_{\mathrm{S}}$ [dB]. The mean of the shadowing variance (see below) is correlated with the pathloss.

## 4.2.7. Autocorrelation distances and crosscorrelations

The shadow fading, delay spreads and angular spreads are correlated random variables, and usually are modeled as lognormal:

$$S_{\mathrm{m}} = 10^{s_{\mathrm{S}} X_{\mathrm{m}} 10} \tag{10}$$

$$\sigma_{\tau,\mathrm{m}} = m_{\mathrm{s}\tau} \left(\frac{d}{1000}\right)^{\varepsilon} 10^{s_{\mathrm{s}\tau} Z_{\mathrm{m}} 10} \tag{11}$$

$$\sigma_{\varphi_{\mathrm{BS}},\mathrm{m}} = m_{\mathrm{s}\varphi_{\mathrm{BS}}} 10^{s_{\mathrm{s}\varphi_{\mathrm{BS}}} Y_{\mathrm{m}} 10} \tag{12}$$

where $X_{\mathrm{m}}$, $Y_{\mathrm{m}}$, and $Z_{\mathrm{m}}$ are correlated normal random variables with zero mean and unit variance. Furthermore, the shadowing as well as the delay and angular spreads change as the MS moves over large distances and are therefore charactized by a spatial autocorrelation function:

$$ACF(x,x') = \exp(-|x-x'|/L_x) \quad (13)$$

### 4.2.8. Polarization

The polarization is characterized by the polarization matrix

$$\begin{pmatrix} P_{VV} & P_{VH} \\ P_{HV} & P_{HH} \end{pmatrix} \quad (14)$$

where the entries characterize the powers, averaged over the small-scale fading.

### 4.2.9. Temporal variations in fixed-wireless systems and nomadic applications

For fixed wireless systems, we need to define the temporal K-factor, which describes the ratio of the power in the time-invariant MPCs to that of the time-variant MPCs. The factor can depend on terrain, vegetation, and season, as well as the distance of the scatterer location to the BS and MS.

### 4.2.10. Diffuse scattering

Diffuse scattering is the part of the measured signal which can not be resolved in the angular domain.

## *5. Standardized Models*

This section presents an overview of some standardized MIMO channel models, which might be useful as a partial basis for a 802.16m model.

## *5.1. COST 259/273*

### 5.1.1. COST 259 Directional Channel Model

The COST 259 directional channel model (DCM) [7,8] gives a model for the delay and angle dispersion at BS and MS, for different radio environments. It was the first model that explicitly took the rather complex relationships between BS-MS-distance, delay dispersion, angular spread, and other parameters into account. It is also general in the sense that it is defined for a 13 different radio environments (e.g., typical urban, bad urban, open square, indoor office, indoor corridor) that include macrocellular, microcellular, and picocellular scenarios.[2] The modeling approaches for macro-, micro- and picocells are different.

Each radio environment is described by external parameters (e.g., BS position, radio frequency, average BS and MS height) and by global parameters, which are sets of probability density functions and/or statistical moments characterizing a specific environment. The determination of the global parameters is partly geometric, and partly stochastic. From random positions of MS and scatterers, we can determine the relative delay and mean angles of the different clusters that make up the double-directional impulse response. The angular spread, delay spread, and shadowing, of each cluster are determined stochastically.

Each radio environment contains a number of propagation environments, which are defined as an area over which the local parameters (which are defined as realizations of the global parameters) are approximately constant. These local parameters are randomly generated realizations of the global parameters and describe the instantaneous channel behavior. The ultimate output of the channel model is the double-directional impulse

---

[2] *Macro-cells* have outdoor BSs above rooftop and either outdoor MSs at street level or indoor MSs. The BS and MS environments are thus quite different. Cell sizes are typically in the kilometer range. *Micro-cells* differ from macro-cells by having outdoor BSs *below* rooftop. The BS and MS environments here are thus more similar than in macro-cells. *Pico-cells* have indoor BSs and much smaller cell size.

response. The COST 259 model can handle the continuous movement of the MS over several propagation environments, and even across different radio environments [7,8].

Note that the COST 259 model assumes all scatterers to be stationary, thus making it difficult to directly apply to FWA applications. On the other hand, simple modifications (introduction of temporal Rice factors) could lift these restriction.

### 5.1.2. COST 273

The COST 273 channel model [11] shows considerable similarity to the COST 259 model, but differs in several key respects:

6. a number of new radio environments is defined,
7. the parameters are partly different
8. the same modeling approach is used for macro-, micro-, and pico-cells.
9. the modeling of the distribution of DOAs and DODs is different, compared to the COST 259 model, based on the twin-cluster concept mentioned in Sec. 3.

## *5.2. 3GPP SCM*

The spatial channel model (SCM) [24] was developed by 3GPP/3GPP2 to be a common reference for evaluating different MIMO concepts in outdoor environments at a center frequency of 2 GHz and a system bandwidth of 5 MHz. The SCM consists of two parts: (i) a calibration model, and (ii) a system-simulation model.

### 5.2.1. Calibration Model

The calibration model is an over-simplified channel model whose purpose is to check the correctness of simulation implementations. In the course of standardization work, it is often necessary to compare the implementations of the *same algorithm by different companies*. Comparing the performance of the algorithm in the "calibration" channels allows to easily assess whether two implementations are equivalent. We stress that the calibration model is *not* intended for performance assessment of algorithms or systems.

The model is a simple spatial extension of the ITU-R channel models [2]. Taps with different delays are independently fading, and each tap is characterized by its own power azimuth spectrum (which is uniform or Laplacian), angular spread (AS), and mean direction, at both the MS and the BS. The parameters (i.e., angular spread, mean direction, etc.), are fixed; thus the model represents stationary channel conditions. The model is double-directional, but also defines a number of antenna configurations that can be used to transform it into an equivalent transfer function matrix.

### 5.2.2. Simulation Model

The SCM intended for performance evaluation is called the simulation model. It is a double-directional model; antenna radiation patterns, antenna geometries, and orientations can be chosen arbitrarily.

The model distinguishes between three different environments: urban macrocell, suburban macrocell, and urban microcell. The model structure and simulation methodology are identical for all these environments, but the parameters, like angular spread, delay spread, etc., are different. The model structure is a simplified version of the COST 259 model. The bulk pathloss is given by the COST 231 - Hata model for macrocells, and the COST 231- Walfish -Ikegami model for microcells. The number of taps with different delays is 6 (as in the ITU-R models), but their delay and average power are chosen stochastically from a probability density function. Each tap shows angular dispersion at the BS and the MS; this dispersion is implemented by representing each tap by a number of 20 sub-paths that all have the same delay, but different DOAs (and DODs). The mean DOA (or DOD) of one tap is chosen at random from a Gaussian distribution that is centered around this total mean. The

20 subpaths have different offsets from this tap-mean; those offsets are fixed and tabulated in the 3GPP standard. Adding up the different subpaths results in Rayleigh or Rice fading.
The SCM has two major restrictions:

- no continuous movement of the MS over large distances can be simulated. The simulation of the system behaviour is carried out as a sequence of "drops", where a "drop" is defined as one simulation run over a certain (short) time period - so short that the only changes are the phase changes of the sub-paths due to the movement of the MS.
- it is assumed that all scatterers are stationary; temporal variations only arise from the movement of the MS

In addition, the simulation model has several optional features: (i) a polarization model, (ii) far scatterer clusters, (iii) a LoS component for the microcellular case, and (iv) a modified distribution of the angular distribution at the MS, which emulates propagation in an urban street canyon.

### *5.3. IEEE 802.11n*

The TGn channel model [25] of IEEE 802.11 was developed for indoor environments in the 2 GHz and 5 GHz bands, with a focus on MIMO WLANs. The TGn channel model specifies a set of six environments (A to F), which mostly correspond to the single antenna WLAN channel models of [3]. The 802.11 TGn model is a double-directional model, using a non-geometric stochastic approach, somewhat similar to the 3GPP/3GPP2 model. The directional impulse response is described as a sum of clusters. Each cluster consists of up to 18 delay taps (separated by at least 10 ns), and to each tap is assigned a DoA and a truncated Laplacian power azimuth spectrum with angular spread ranging from $20^\circ$ to $40^\circ$ (and similar for the DoD). The number of clusters ranges from 2 to 6 (these numbers were found based on measurement data), and the overall RMS delay spread varies between 0 (flat fading) and 150 ns. The impulse response consists of a deterministic (LOS) component, and a random component; the angular spectra at TX and RX are assumed to be independent.
Time-variations in the model are intended to emulate moving "environmental" scatterers. The prescribed Doppler spectrum consists of a "bell shaped" part with low Doppler frequency and an optional additional peak at a larger Doppler frequency that corresponds to vehicles passing by, plus channel time-variations caused by fluorescent lights.

## *6. Summary and conclusions*

We have presented some fundamental considerations for channel models in 802.16m. The key points are

- new channel models are required to allow reasonable comparisons of 802.16m system proposals
- the new models will have to be suitable for MIMO systems operating in at least 100 MHz bandwidth
- while existing standardized models can be used as a partial basis of 802.16m models, none can be adopted without modifications
- the generic model structure should be a double-directional (MIMO) channel model that takes the interdependence of different channel parameters into account.

## 7. References

[1] M. Failli (ed.), Digital Land Mobile Radio Communications—COST 207. ECSC-EEC-EAEC, 1989.
[2] International Telecommunications Union, "Guidelines for Evaluation of Radio Transmission Technologies for IMT-2000," Recommendation ITU-R M.1225, (1997).

[3] J. Medbo and P. Schramm, “Channel models for HIPERLAN/2, ETSI/BRAN document no. 3ERI085B,” tech. rep., European Telecommunications Standards Institute, 2000.
[4] E. Damosso and L. Correia, eds., Digital mobile radio towards future generation systems. Commission of the European Union, 1999.
[5] V. Erceg et al., “Channel models for fixed wireless applications,” 802.16.3c-01/29r4, (2001).
[6] L. Greenstein et al., “A new path-gain/delay-spread propagation model for digital cellular channels.,” IEEE Trans. on Vehicular Techn., vol. 46, May 1997.
[7] A. F. Molisch, H. Asplund, R. Heddergott, M. Steinbauer, and T. Zwick, “The COST259 directional channel model – I. overview and methodology,” IEEE Trans. Wireless Comm., vol. 5, pp. 3421–3433, 2006.
[8] H. Asplund, A. A. Glazunov, A. F. Molisch, K. I. Pedersen, and M. Steinbauer, “The COST259 directional channel model II - macrocells,” IEEE Trans. Wireless Comm., vol. 5, pp. 3434–3450, 2006.
[9] A. F. Molisch, “A generic model for MIMO wireless propagation channels,” IEEE Trans. Signal Processing, vol. 52, pp. 61–71, 2004.
[10] P. Almers, E. Bonek, A. Burr, N. Czink, M. Debbah, V. Degli-Esposti, H. Hofstetter, P. Kyosti, D. Laurenson, G. Matz, A. F. Molisch, C. Oestges, and H. Ozcelik, “Survey of channel and radio propagation models for wireless mimo systems,” Eurasip J. Wireless Comm. Networking, vol. in press, 2007.
[11] A. F. Molisch and H. Hofstetter, “The COST273 Channel Model,” in “Mobile Broadband Multimedia Networks “, (L. Correia, ed.), Academic Press, 2006.
[12] M. Steinbauer, A. F. Molisch, and E. Bonek, “The double-directional radio channel,” IEEE Antennas and Propagation Mag., pp. 51–63, August 2001.
[13] G. J. Foschini and M. J. Gans, “On limits of wireless communications in a fading environment when using multiple antennas,” Wireless Personal Communications, vol. 6, pp. 311–335, Feb. 1998.
[14] W. Weichselberger, M. Herdin, H. Özcelik, and E. Bonek, “A Stochastic MIMO Channel Model with Joint Correlation of Both Link Ends.” IEEE Trans. on Wireless Comm..
[15] W. Weichselberger, Spatial Structure of Multiple Antenna Radio Channels. PhD thesis, Institut für Nachrichtentechnik und Hochfrequenztechnik, Vienna University of Technology, Vienna, Austria, Dec. 2003. downloadable from http://www.nt.tuwien.ac.at/mobile.
[16] C.-N. Chuah, J. Kahn, and D. Tse, “Capacity of Multi-Antenna Array Systems in Indoor Wireless Environment,” in Proc. IEEE Global Telecommunications Conf., vol. 4, (Sidney, Australia), pp. 1894–1899, 1998.
[17] W. Lee, “Effects on Correlations between Two Mobile Base-Station Antennas,” IEEE Trans. Comm., vol. 21, pp. 1214–1224, 1973.
[18] P. Petrus, J. Reed, and T. Rappaport, “Geometrical-based Statistical Macrocell Channel Model for Mobile Environments,” IEEE Trans. Comm., vol. 50, pp. 495–502, Mar. 2002.
[19] J. C. Liberti and T. Rappaport, “A Geometrically Based Model for Line-Of-Sight Multipath Radio Channels,” in Proc. IEEE Vehicular Technology Conf., pp. 844–848, Apr.May 1996.
[20] J. Blanz and P. Jung, “A Flexibly Configurable Spatial Model for Mobile Radio Channels,” IEEE Trans. Comm., vol. 46, pp. 367–371, Mar. 1998.
[21] O. Norklit and J. Andersen, “Diffuse Channel Model and Experimental Results for Array Antennas in Mobile Environments,” IEEE Trans. on Antennas and Propagation, vol. 46, pp. 834–843, June 1998.
[22] J. Fuhl, A. F. Molisch, and E. Bonek, “Unified Channel Model for Mobile Radio Systems with Smart Antennas,” IEEE Proc. - Radar, Sonar and Navigation: Special Issue on Antenna Array Processing Techniques, vol. 145, pp. 32–41, Feb. 1998.
[23] A. F. Molisch, A. Kuchar, J. Laurila, K. Hugl, and R. Schmalenberger, “Geometry-based Directional Model for Mobile Radio Channels – Principles and Implementation,” European Trans. Telecomm., vol. 14, pp. 351–359, 2003.
[24] 3GPP - 3GPP2 Spatial Channel Model Ad-hoc Group3GPP TR 25.996, “Spatial Channel Model for Multiple Input Multiple Output

(MIMO) Simulations," v6.1.0 (2003-09).

[25] V. Erceg, L. Schumacher, P. Kyritsi, A. Molisch, D. S. Baum, A. Y. Gorokhov, C. Oestges, Q. Li, K. Yu, N. Tal, B. D. Dijkstra, A. Jagannatham, C. Lanzl, V. J. Rhodes, J. Medbo, D. Michelson, and M. Webster, "TGn Channel Models," tech. rep., IEEE P802.11 Wireless LANs, May 2004. http://www.802wirelessworld.com:8802/.