

|                |   |  |
|----------------|---|--|
| Project        | <b>IEEE 802.16 Broadband Wireless Access Working Group</b> < <a href="http://ieee802.org/16">http://ieee802.org/16</a> >  |  |
| Title          | <b>Modifications of the proposed 16m channel model</b>  |  |
| Date Submitted | <b>[2007-07-09]</b>   |  |
| Source(s)      | <p><b>Andreas F. Molisch, Phil Orlik, Jinyun Zhang</b><br/> Mitsubishi Electric Research Lab<br/> 201 Broadway<br/> Cambridge, MA 02139 USA</p> <p><b>Toshiyuki Kuze</b><br/> Mitsubishi Electric Corp<br/> 5-1-1 Ofuna Kamakura, Kanagawa<br/> 2478501, Japan</p>  | <p>Voice: 617-621-{7558,7595}<br/> Fax: 617-621-7550<br/> <a href="mailto:{molisch,jzhang}@merl.com">{molisch,jzhang}@merl.com</a></p> <p>Voice: +81-467-41-2885<br/> Fax: +81-467-41-2486<br/> <a href="mailto:Kuze.Toshiyuki@ah.MitsubishiElectric.co.jp">Kuze.Toshiyuki@ah.MitsubishiElectric.co.jp</a></p> |
| Re:            | [Response to the call for comments on the 16m system evaluation methodology]  |  |
| Abstract       | This document proposes some modifications and improvements of the currently discussed version of the IEEE 802.16m channel model. In particular, we suggest that (i) a full description of the temporal Rice factor (which is required to model stationary devices), (ii) a description of the elevation spectrum of the arriving waves for all environments, (iii) taking into account the random nature of the conventional (space-variant) Rice factor.   |  |
| Purpose        | [Description of what <i>specific</i> action is requested of the 802.16 Working Group or subgroup.]  |  |
| Notice         | <i>This document does not represent the agreed views of the IEEE 802.16 Working Group or any of its subgroups. It represents only the views of the participants listed in the "Source(s)" field above. It is offered as a basis for discussion. It is not binding on the contributor(s), who reserve(s) the right to add, amend or withdraw material contained herein.</i>  |  |
| 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  | <p>The contributor is familiar with the IEEE-SA Patent Policy and Procedures:<br/> &lt;<a href="http://standards.ieee.org/guides/bylaws/sect6-7.html#6">http://standards.ieee.org/guides/bylaws/sect6-7.html#6</a>&gt; and<br/> &lt;<a href="http://standards.ieee.org/guides/opman/sect6.html#6.3">http://standards.ieee.org/guides/opman/sect6.html#6.3</a>&gt;.</p> <p>Further information is located at &lt;<a href="http://standards.ieee.org/board/pat/pat-material.html">http://standards.ieee.org/board/pat/pat-material.html</a>&gt; and<br/> &lt;<a href="http://standards.ieee.org/board/pat">http://standards.ieee.org/board/pat</a>&gt;.</p> |  |

# Proposed modifications to the 16m channel model

**Andreas F. Molisch, Phil Orlik, 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

This document proposes some modifications and improvements of the currently discussed version of the IEEE 802.16m channel model. In particular, we suggest that (i) a full description of the temporal Rice factor (which is required to model stationary devices), (ii) a description of the elevation spectrum of the arriving waves for all environments, (iii) taking into account the random nature of the conventional (space-variant) Rice factor.

The following sections first contain a motivation and intuitive description of the changes, followed by the explicit text modifications whose inclusion into the system evaluation methodology we propose.

## 2. Motivation

The channel model as proposed in the current (June 2007) version of the system evaluation methodology gives a good approximation to reality, but there are a number of points where improvements are important.

First and foremost, the current definition of the temporal channel variations of stationary devices is incomplete. A complete specification requires not only the definition of the Doppler spectrum, but also of the “temporal K factor”, which describes the ratio of the energies of temporally variant contributions to the impulse response over that of the temporally invariant contributions. We propose a simple equation for this temporal K factor that is parameterized (based on data from the peer-reviewed literature) for different environments. Without the adoption of an equation for temporal Rice factors, system simulations are not possible (note that all environments include a finite percentage of users with zero mobility).

Next, we note that the current specifications do not contain elevation spectra for all the environments. We therefore propose deterministic elevation spectra, and suggest a simple way of including them in the current simulation procedure. We postulate that the absence of elevation spectra leads to inaccuracies in the

Last, but not least, extensive experiments have shown that the Rice factor is not a fixed value even in deterministic environments, but rather a random variable. We therefore suggest a simple model (lognormal distribution) for a random Rice factor. We furthermore also suggest an explicit model for the probability of line-of-sight.

### 3. Suggested text

The geometry-based stochastic models are created using the parameters listed in the Table 3. The channel realizations are obtained by a step-wise procedure described in the reference [Winner II].

In addition to the procedure described there, the following steps need to be used:

1. Each path is associated with an elevation at both BS and MS. The elevation angles are chosen at random from the distribution specified in Table III.
2. If a LOS component is present, then we first generate the Rice factor at random from a lognormal distribution whose mean and variance is given in Table 3. The total combined power of the LOS component and the diffuse components is normalized to unity power so the coherent LOS component will have a relative amplitude

$$\sqrt{\frac{K}{K+1}}$$

- 3: If the TX and the RX are stationary, and the channel at time  $t$  is to be computed, then each cluster is made of a number of coherent (fixed) rays  $N_c$  and a number of scattered (variable) rays  $N_s$  ( $N_c + N_s =$  total number of rays per clusters).

The variable rays are ascribed a bell-shaped Doppler spectrum as described in [Erceg et al. 2001]:

$$S(f) = \begin{cases} 1 - 1.72f_0^2 + 0.785f_0^4 & f_0 \leq 1 \\ 0 & f_0 > 1 \end{cases} \quad \text{where } f_0 = \frac{f}{f_m}$$

where  $f_m$  is the maximum Doppler rate (suggested value: 2 Hz [Erceg et al. 2001]). The fixed rays within a cluster share the same amplitude and phase, and their Doppler spectrum is a Dirac impulse at  $f = 0$  Hz.

To determine the power of the coherent and scattered rays, we fix  $N_c = N_s = N$ . The  $n^{\text{th}}$  cluster is associated with a temporal K-factor  $K_n$  [dB]. The power in [dB] of each scattered ray is then given by

$$P_n - 10 \log_{10}(N) - K_n$$

while the power of each coherent ray is then given by

$$P_n - 20 \log_{10}(n)$$

All coherent rays within a given cluster are then ascribed equal amplitude (according to the above power) and equal phase, this phase being randomly distributed between clusters over  $[0, 2\pi]$ .

The cluster K-factor is a lognormally distributed variable whose variance is equal to 8 dB and whose mean  $\bar{K}_n$  is computed as follows.

a) in the absence of a LOS:

- **for indoor scenarios**

$$\bar{K}_n [dB] = K_0 - \beta \tau_n [ns]$$

- **for outdoor scenarios**

$$\bar{K}_n [dB] = K_0 - \beta \tau_n$$

where  $\tau_n$  [ns] is the average cluster delay. The values of  $K_0$  and  $\beta$  are given in Table 3 [Oestges et al. 2007, Oestges et al. 2006, Oestges et al. 2005, Ahumada et al. 2005, Erceg et al., 2004].

b) if a LOS is present (both for indoor and outdoor cases), the mean K-factor of the LOS cluster is given by  $K_{LOS} [dB]$ .

$$\bar{K}_1 [dB] = K_{LOS}$$

The other clusters have a mean K-factor as given by the above relationships. The values of  $K_{LOS} [dB]$  are given in Table 3 [Oestges et al. 2007, Oestges et al. 2006, Oestges et al. 2005, Ahumada et al. 2005, Erceg et al., 2004].

c) in bad urban scenarios (outdoor microcells and macrocells), the far scatterer clusters are given a specific mean K-factor  $K_{far} [dB]$

$$\bar{K}_n [dB] = K_{far}$$

The values of  $K_{far} [dB]$  are given in Table 3 [Ahumada et al. 2005].

d) for outdoor scenarios, the above formulas are valid for a TX-RX range  $d [m]$  of 200 m and a UE antenna height  $h [m]$  of 3 m. For alternative ranges and UE antenna heights, all mean K-factors above are modified as follows [Erceg et al. 2001]:

$$\bar{K}_n(d, h) [dB] = \bar{K}_n(d = 200m; h = 3m) - 5 \log_{10}(d[m]/200) + 4.6 \log_{10}(h[m]/3)$$

#### ADDITION IN PARAMETER TABLES: ELEVATION

For all environments, an elevation spectrum is defined, with a deterministic angular spread. Only the elevation spread of the NLOS scenario is given. The elevation spread for the diffuse components in LOS is the same; the presence of the LOS component reduces the elevation spread in an implicit manner

##### \* **A1** Indoor:

BS: Laplacian angular spectrum. Angular spread: 11 degrees. Source [Winner 2007]

MS: Laplacian angular spectrum: Angular spread 13 degrees. Source [Winner 2007]

##### \* **B1** Microcell:

BS: Laplacian angular spectrum. Angular spread:  $5 + 35 \cdot (h_{roof} - h_{BS}) / h_{roof}$  degrees. Linear interpolation between [Toeltsch et al. 2002] (for  $h_{BS} = h_{roof}$ ) and [Laitinen et al.] (for  $h_{BS}$  very small).

MS: Uniform angular spectrum between 0 and 60 degrees [Kalliola et al. 2003], [Kuchar 2000], [Medbo et al. 2005]

##### \* **B2** bad microcell

same as B1

##### \* **B4**: outdoor-to-indoor

BS: same as B1

MS: Laplacian angular spectrum. Angular spread: 7 degrees [Kalliola et al. 2002].

##### \* **C1** suburban:

same as D1

##### \* **C2** urban

BS: Laplacian angular spectrum: Angular spread: 0.5 degrees [Asplund et al. 2006]

MS: uniform angular spectrum between 0 and 60 degrees [Kuchar et al. 2000]

##### \* **C3** bad macrocell urban:

same as C2

##### \* **D1** Highway (rural):

BS: same as BS in macrocell urban

MS: Laplacian angular spectrum, mean 6 degrees, angular spread 8 degrees [Kalliola et al. 2002]

\* **D2**: high-speed

for both BS and MS, we use the values of the MS in D1

### MODIFICATION OF RICE FACTOR

The Rice factor is modeled as a lognormally distributed random variable. It has a mean as suggested in Table 3, and a standard deviation of 6 dB [Asplund et al. 2006].

### MODIFICATION OF TEMPORAL RICE FACTOR

The Rice factor for stationary TX-RX is modelled as a lognormally distributed random variable, whose mean is computed based on the following values of  $K_0$ ,  $\beta$ ,  $K_{far}$ , and  $K_{LOS}$  (see Table 3-next page)

### Clustered Delay Line model

#### Scenario A1: LOS Clustered delay line model, indoor environment.

| Cluster # | Delay [ns] |     |     | Power [dB] |   |   | AoD [°] | AoA [°] | Ray power [dB] |       | Temporal K-factor [dB] | Cluster ASD = 5° | Cluster ASA = 5° |
|-----------|------------|-----|-----|------------|---|---|---------|---------|----------------|-------|------------------------|------------------|------------------|
|           |            |     |     |            |   |   |         |         | -              | -     |                        |                  |                  |
| 1         | 0          |     |     | 0.0        |   |   | 0       | 0       | 0.08*          | 30.2* | 30                     |                  |                  |
| 2         | 20         |     |     | -25.3      |   |   | -160    | 164     | -38.3          | 29.80 |                        |                  |                  |
| 3         | 35         | 40  | 45  | -          | - | - | -113    | -116    | -25.7          | 29.60 |                        |                  |                  |
| 4         | 45         |     |     | -21.0      |   |   | -146    | 149     | -34.0          | 29.55 |                        |                  |                  |
| 5         | 45         |     |     | -19.4      |   |   | 140     | 143     | -32.4          | 29.55 |                        |                  |                  |
| 6         | 90         |     |     | -23.3      |   |   | 153     | 157     | -36.3          | 29.10 |                        |                  |                  |
| 7         | 110        | 115 | 120 | -          | - | - | 148     | 151     | -28.8          | 28.85 |                        |                  |                  |
| 8         | 155        |     |     | -25.2      |   |   | -159    | 163     | -38.2          | 28.45 |                        |                  |                  |
| 9         | 190        |     |     | -21.6      |   |   | 148     | 151     | -34.7          | 28.1  |                        |                  |                  |
| 10        | 245        |     |     | -19.1      |   |   | -139    | -142    | -32.1          | 27.55 |                        |                  |                  |
| 11        | 255        |     |     | -27.9      |   |   | -168    | -172    | -40.9          | 27.45 |                        |                  |                  |
| 12        | 320        |     |     | -30.5      |   |   | 176     | -180    | -43.5          | 26.80 |                        |                  |                  |

\* Power of dominant ray,

\*\* Power of each other ray

**Scenario A1 NLOS Clustered delay line model, indoor environment.**

| Cluster # | Delay [ns] |    |    | Power [dB] |     |     | AoD [°] | AoA [°] | Ray power [dB] | Temporal K-factor [dB] | Cluster ASD = 5° | Cluster ASA = 5° |
|-----------|------------|----|----|------------|-----|-----|---------|---------|----------------|------------------------|------------------|------------------|
|           | -          | -  | -  | -          | -   | -   |         |         |                |                        |                  |                  |
| 1         | 0          | 5  | 10 | 3.0        | 5.2 | 7.0 | 0       | 0       | -13.0          | 20.0                   |                  |                  |
| 2         | 5          |    |    | -4.0       |     |     | 59      | -55     | -17.0          | 19.95                  |                  |                  |
| 3         | 20         |    |    | -4.7       |     |     | -64     | -59     | -17.7          | 19.8                   |                  |                  |
| 4         | 25         |    |    | -9.0       |     |     | 89      | -82     | -22.0          | 19.75                  |                  |                  |
| 5         | 30         |    |    | -8.0       |     |     | 83      | -77     | -21.0          | 19.70                  |                  |                  |
| 6         | 30         | 35 | 40 | 4.0        | 6.2 | 8.0 | -67     | 62      | -14.0          | 19.65                  |                  |                  |
| 7         | 35         |    |    | -1.1       |     |     | 32      | 29      | -14.2          | 19.65                  |                  |                  |
| 8         | 45         |    |    | -5.2       |     |     | -67     | 62      | -18.2          | 19.55                  |                  |                  |
| 9         | 55         |    |    | -9.5       |     |     | -91     | -84     | -22.5          | 19.45                  |                  |                  |
| 10        | 65         |    |    | -7.9       |     |     | -83     | 77      | -20.9          | 19.35                  |                  |                  |
| 11        | 75         |    |    | -6.8       |     |     | -77     | -71     | -19.8          | 19.25                  |                  |                  |
| 12        | 90         |    |    | -14.8      |     |     | -113    | 105     | -27.8          | 19.10                  |                  |                  |
| 13        | 110        |    |    | -12.8      |     |     | -106    | 98      | -25.8          | 18.90                  |                  |                  |
| 14        | 140        |    |    | -14.1      |     |     | 111     | -103    | -27.2          | 18.60                  |                  |                  |
| 15        | 210        |    |    | -26.7      |     |     | -152    | 141     | -39.7          | 17.90                  |                  |                  |
| 16        | 250        |    |    | -32.5      |     |     | -168    | -156    | -45.5          | 17.5                   |                  |                  |

**Scenario B1: NLOS Clustered delay line model.**

| Cluster # | Delay [ns] |     |     | Power [dB] |      |      | AoD [°] | AoA [°] | Ray power [dB] | Temporal K-factor [dB] | Cluster ASD = 10° | Cluster ASD = 22° |
|-----------|------------|-----|-----|------------|------|------|---------|---------|----------------|------------------------|-------------------|-------------------|
|           | -          | -   | -   | -          | -    | -    |         |         |                |                        |                   |                   |
| 1         | 0          |     |     | -1.0       |      |      | 8       | -20     | -14.0          | 21                     |                   |                   |
| 2         | 90         | 95  | 100 | -3.0       | -5.2 | -7.0 | 0       | 0       | -13.0          | 20.05                  |                   |                   |
| 3         | 100        | 105 | 110 | -3.9       | -6.1 | -7.9 | -24     | 57      | -13.9          | 19.95                  |                   |                   |
| 4         | 115        |     |     | -8.1       |      |      | -24     | -55     | -21.1          | 19.85                  |                   |                   |
| 5         | 230        |     |     | -8.6       |      |      | -24     | 57      | -21.6          | 18.7                   |                   |                   |
| 6         | 240        |     |     | -11.7      |      |      | 29      | 67      | -24.7          | 18.6                   |                   |                   |
| 7         | 245        |     |     | -12.0      |      |      | 29      | -68     | -25.0          | 18.55                  |                   |                   |
| 8         | 285        |     |     | -12.9      |      |      | 30      | 70      | -25.9          | 18.15                  |                   |                   |
| 9         | 390        |     |     | -19.6      |      |      | -37     | -86     | -32.6          | 17.1                   |                   |                   |
| 10        | 430        |     |     | -23.9      |      |      | 41      | -95     | -36.9          | 16.7                   |                   |                   |
| 11        | 460        |     |     | -22.1      |      |      | -39     | -92     | -35.1          | 16.4                   |                   |                   |
| 12        | 505        |     |     | -25.6      |      |      | -42     | -99     | -38.6          | 15.95                  |                   |                   |
| 13        | 515        |     |     | -23.3      |      |      | -40     | 94      | -36.4          | 15.85                  |                   |                   |
| 14        | 595        |     |     | -32.2      |      |      | 47      | 111     | -45.2          | 15.05                  |                   |                   |
| 15        | 600        |     |     | -31.7      |      |      | 47      | 110     | -44.7          | 15.00                  |                   |                   |
| 16        | 615        |     |     | -29.9      |      |      | 46      | -107    | -42.9          | 14.85                  |                   |                   |

**Scenario B4: NLOS Clustered delay line model, outdoor to indoor environment**

| Cluster # | Delay [ns] |    |    | Power [dB] |      |      | AoD [°] | AoA [°] | Ray power [dB] | Temporal K-factor [dB] | Cluster ASD = 5° | Cluster ASA = 8° |
|-----------|------------|----|----|------------|------|------|---------|---------|----------------|------------------------|------------------|------------------|
|           |            |    |    |            |      |      |         |         |                |                        |                  |                  |
| 1         | 0          |    |    | -7.7       |      |      | 29      | 102     | -20.8          | 16                     |                  |                  |
| 2         | 10         | 15 | 20 | -3.0       | -5.2 | -7.0 | 0       | 0       | -13.0          | 15.85                  |                  |                  |
| 3         | 20         |    |    | -3.7       |      |      | 20      | 70      | -16.7          | 16                     |                  |                  |
| 4         | 35         |    |    | -3.0       |      |      | -18     | -64     | -16.0          | 15.65                  |                  |                  |
| 5         | 35         |    |    | -3.0       |      |      | 18      | -63     | -16.0          | 15.65                  |                  |                  |
| 6         | 50         |    |    | -3.7       |      |      | 20      | 70      | -16.7          | 15.5                   |                  |                  |
| 7         | 55         | 60 | 65 | -5.4       | -7.6 | -9.4 | 29      | 100     | -15.4          | 15.4                   |                  |                  |
| 8         | 140        |    |    | -5.3       |      |      | 24      | 84      | -18.3          | 14.6                   |                  |                  |
| 9         | 175        |    |    | -7.6       |      |      | 29      | 100     | -20.6          | 14.25                  |                  |                  |
| 10        | 190        |    |    | -4.3       |      |      | -21     | 76      | -17.3          | 14.1                   |                  |                  |
| 11        | 220        |    |    | -12.0      |      |      | 36      | -126    | -25.0          | 13.8                   |                  |                  |
| 12        | 585        |    |    | -20.0      |      |      | 46      | 163     | -33.0          | 10.15                  |                  |                  |

**Scenario C1: LOS Clustered delay line model, suburban environment.**

| Cluster # | Delay [ns] |     |     | Power [dB] |   |   | AoD [°] | AoA [°] | Ray power [dB] |        | Cluster ASD = 5° | Cluster ASD = 5° |
|-----------|------------|-----|-----|------------|---|---|---------|---------|----------------|--------|------------------|------------------|
|           |            |     |     |            |   |   |         |         |                |        |                  |                  |
| 1         | 0          | 5   | 10  | 0.0        | - | - | 0       | 0       | -0.02*         | 33.1** |                  |                  |
| 2         | 85         |     |     | -21.6      |   |   | -29     | -144    | -34.7          |        |                  |                  |
| 3         | 135        |     |     | -26.3      |   |   | -32     | -159    | -39.3          |        |                  |                  |
| 4         | 135        |     |     | -25.1      |   |   | -31     | 155     | -38.1          |        |                  |                  |
| 5         | 170        |     |     | -25.4      |   |   | 31      | 156     | -38.4          |        |                  |                  |
| 6         | 190        |     |     | -22.0      |   |   | 29      | -146    | -35.0          |        |                  |                  |
| 7         | 275        |     |     | -29.2      |   |   | -33     | 168     | -42.2          |        |                  |                  |
| 8         | 290        | 295 | 300 | -          | - | - | 35      | -176    | -34.3          |        |                  |                  |
| 9         | 290        |     |     | -23.2      |   |   | -30     | 149     | -36.2          |        |                  |                  |
| 10        | 410        |     |     | -32.2      |   |   | 35      | -176    | -45.2          |        |                  |                  |
| 11        | 445        |     |     | -26.5      |   |   | -32     | -159    | -39.5          |        |                  |                  |
| 12        | 500        |     |     | -32.1      |   |   | 35      | -176    | -45.1          |        |                  |                  |
| 13        | 620        |     |     | -28.5      |   |   | 33      | -165    | -41.5          |        |                  |                  |
| 14        | 655        |     |     | -30.5      |   |   | 34      | -171    | -43.5          |        |                  |                  |
| 15        | 960        |     |     | -32.6      |   |   | 35      | 177     | -45.6          |        |                  |                  |

\* Power of dominant ray,

\*\* Power of each other ray

**Clustered delay-line model for Scenario C1 NLOS**

| Cluster # | Delay [ns] |   |    | Power [dB] |     |      | AoD [°] | AoA [°] | Ray power [dB] | Cluster ASD = 2° | Cluster ASD = 10° |
|-----------|------------|---|----|------------|-----|------|---------|---------|----------------|------------------|-------------------|
|           |            |   |    |            |     |      |         |         |                |                  |                   |
| 1         | 0          | 5 | 10 | 3.0        | 5.2 | -7.0 | 0       | 0       | -13.0          |                  |                   |
| 2         | 25         |   |    | -7.5       |     |      | 13      | -71     | -20.5          |                  |                   |
| 3         | 35         |   |    | -10.5      |     |      | -15     | -84     | -23.5          |                  |                   |

|    |     |    |    |       |     |      |     |     |       |
|----|-----|----|----|-------|-----|------|-----|-----|-------|
| 4  | 35  |    |    | -3.2  |     |      | -8  | 46  | -16.2 |
| 5  | 45  | 50 | 55 | 6.1   | 8.3 | 10.1 | 12  | -66 | -16.1 |
| 6  | 65  |    |    | -14.0 |     |      | -17 | -97 | -27.0 |
| 7  | 65  |    |    | -6.4  |     |      | 12  | -66 | -19.4 |
| 8  | 75  |    |    | -3.1  |     |      | -8  | -46 | -16.1 |
| 9  | 145 |    |    | -4.6  |     |      | -10 | -56 | -17.6 |
| 10 | 160 |    |    | -8.0  |     |      | -13 | 73  | -21.0 |
| 11 | 195 |    |    | -7.2  |     |      | 12  | 70  | -20.2 |
| 12 | 200 |    |    | -3.1  |     |      | 8   | -46 | -16.1 |
| 13 | 205 |    |    | -9.5  |     |      | 14  | -80 | -22.5 |
| 14 | 770 |    |    | -22.4 |     |      | 22  | 123 | -35.4 |

Scenario C2: NLOS clustered delay line model.

| Cluster # | Delay [ns] |     |     | Power [dB] |      |      | AoD [°] | AoA [°] | Ray power [dB] |
|-----------|------------|-----|-----|------------|------|------|---------|---------|----------------|
| 1         | 0          |     |     | -6.4       |      |      | 11      | 61      | -19.5          |
| 2         | 60         |     |     | -3.4       |      |      | -8      | 44      | -16.4          |
| 3         | 75         |     |     | -2.0       |      |      | -6      | -34     | -15.0          |
| 4         | 145        | 150 | 155 | -3.0       | -5.2 | -7.0 | 0       | 0       | -13.0          |
| 5         | 150        |     |     | -1.9       |      |      | 6       | 33      | -14.9          |
| 6         | 190        |     |     | -3.4       |      |      | 8       | -44     | -16.4          |
| 7         | 220        | 225 | 230 | -3.4       | -5.6 | -7.4 | -12     | -67     | -13.4          |
| 8         | 335        |     |     | -4.6       |      |      | -9      | 52      | -17.7          |
| 9         | 370        |     |     | -7.8       |      |      | -12     | -67     | -20.8          |
| 10        | 430        |     |     | -7.8       |      |      | -12     | -67     | -20.8          |
| 11        | 510        |     |     | -9.3       |      |      | 13      | -73     | -22.3          |
| 12        | 685        |     |     | -12.0      |      |      | 15      | -83     | -25.0          |
| 13        | 725        |     |     | -8.5       |      |      | -12     | -70     | -21.5          |
| 14        | 735        |     |     | -13.2      |      |      | -15     | 87      | -26.2          |
| 15        | 800        |     |     | -11.2      |      |      | -14     | 80      | -24.2          |
| 16        | 960        |     |     | -20.8      |      |      | 19      | 109     | -33.8          |
| 17        | 1020       |     |     | -14.5      |      |      | -16     | 91      | -27.5          |
| 18        | 1100       |     |     | -11.7      |      |      | 15      | -82     | -24.7          |
| 19        | 1210       |     |     | -17.2      |      |      | 18      | 99      | -30.2          |
| 20        | 1845       |     |     | -16.7      |      |      | 17      | 98      | -29.7          |

Cluster ASD = 2°

Cluster ASD = 15°

## References

[Winner II] IST-WINNER II Deliverable D1.1.1 v1.0, “WINNER II Interim Channel Models”, December 2006.

[Ahumada et al. 2005] L. Ahumada, R. Feick, R. A. Valenzuela, and C. Morales, Measurement and



- characterization of the temporal behavior of fixed wireless links, *IEEE Trans. Veh. Techn.*, vol. 54, No. 6, pp. 1913-1922, November 2005.
- [Almers et al. 2007] 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. Ozelik, "Survey of channel and radio propagation models for wireless mimo systems," *Eurasip J. Wireless Comm. Networking*, vol. in press, 2007.
- [Asplund et al. 2006] 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.
- [Calcev et al. 2007] G. Calcev, D. Chizhik, B. Goeransson, S. Howard, H. Huang, A. Kogiantis, A. F. Molisch, A. L. Moustakas, D. Reed and H. Xu, "A Wideband Spatial Channel Model for System-Wide Simulations", *IEEE Trans. Vehicular Techn.*.
- [Chong et al. 2003] Chia-Chin Chong; Laurenson, D.I.; McLaughlin, S. "Spatio-temporal dispersion and correlation properties for the 5.2 GHz WLAN indoor propagation environments", *Proc. Personal, Indoor and Mobile Radio Communications, 2003. PIMRC 2003.* 697-701, 2003.
- [Erceg et al. 2001] V. Erceg, et al., Channel Models for Fixed Wireless Applications (IEEE802.16.3c-01/29r4), IEEE P802.16, Broadband Wireless Working Group, 2001.
- [Erceg et al. 2004] V. Erceg, P. Soma, D.S. Baum, and S. Catreux, "Multiple-input multiple-output fixed wireless radio channel measurements and modeling using dual-polarized antennas at 2.5 GHz," *IEEE Trans. Wireless Comm*, vol. 3, No. 6, pp. 2288 – 2298, Nov. 2004
- [Gudmundson 1991] Gudmundson, M. [7 November, 1991] Correlation Model for Shadow Fading in Mobile Radio Systems. *Electron. Lett.*, Vol. 27, **23**, 2145-2146
- [Kalliola et al. 2002] Kalliola, K.; Sulonen, K.; Laitinen, H.; Kivekas, O.; Krogerus, J.; Vainikainen, P. , "Angular power distribution and mean effective gain of mobile antenna in different propagation environments", *IEEE Trans. Vehicular Techn.* 51, 823-838, 2002.
- [Kivinen et al. 1999] Kivinen J.; Xiongwen Zhao; Vainikainen P , "Wideband indoor radio channel measurements with direction of arrival estimations in the 5 GHz band", *Proc. Vehicular Technology Conference, 1999. VTC 1999 - Fall.* IEEE 2308-2312, 1999
- [Laitinen et al.] Heikki Laitinen(1), Kimmo Kalliola(2), Pertti Vainikainen, "ANGULAR SIGNAL DISTRIBUTION AND CROSS-POLARIZATION POWER RATIO SEEN BY A MOBILE RECEIVER AT 2.15 GHz"
- [Medbo et al. 2005] Medbo, J.; Riback, M.; Asplund, H.; Berg, J. , "MIMO channel characteristics in a small macrocell measured at 5.25 GHz and 200 MHz bandwidth", *Vehicular Technology Conference, 2005. VTC-2005-Fall.* 372-376, 2005.
- [Molisch et al. 2006] 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.
- [Oestges et al. 2004] C. Oestges, and A.J. Paulraj, "Propagation into buildings for Broadband Wireless Access," *IEEE Trans. Veh. Techn.*, vol. 53, No. 2, pp. 521-526, March 2004.
- [Oestges et al. 2005] C. Oestges, D. Vanhoenacker-Janvier, B. Clerckx, Macrocellular directional channel modeling at 1.9 GHz: cluster parameterization and validation, *61<sup>st</sup> IEEE Semi-annual Vehicular Technology Conference Spring, VTC-Spring '05* (Stockholm, Sweden), vol. 1, pp. 121-125, May 2005.
- [Oestges et al. 2006] C. Oestges, D. Vanhoenacker-Janvier, and B. Clerckx, "Channel characterization of indoor wireless personal area networks," *IEEE Trans. Ant. Propagat.* (special issue on wireless communications), vol. 54, No. 11-1, pp. 3143-3150, November 2006.
- [Oestges et al. 2007] C. Oestges, and B. Clerckx, "Modeling outdoor macrocellular clusters based on 1.9-GHz experimental data," *IEEE Trans. Veh. Tech.*, vol. 56, No. 6, November 2007.
- [Shafi et al. 2006] M. Shafi, M. Zhang, A. L. Moustakas, P. J. Smith, A. F. Molisch, F. Tufvesson, and S. H.

Simon, "Polarized MIMO Channels in 3D: Models, Measurements and Mutual Information, IEEE J. Selected Areas Comm., 24, 514-527 (2006).

[Steinbauer et al. 2001] M. Steinbauer, A. F. Molisch, and E. Bonek, "The double-directional radio channel," IEEE Antennas and Propagation Mag., pp. 51–63, August 2001.

[Winner 2007] Winner II interim report, version 1.1.1, 2007