The correlated MIMO channel model for IEEE 802.16n

Abstract A more accurate correlated multiple input and multiple output (MIMO) channel model for IEEE 802.16n is presented. On one hand, this MIMO channel model can obtain more precise antenna correlation, which is a key character for MIMO channel and important for the research of IEEE 802.16n and MIMO technologies. On the other hand, it maintains a low complexity of simulation.

Keywords MIMO, channel model, power delay profile, antenna correlation

1 Introduction

As presently defined through IEEE Standard 802.16, a wireless MAN provides network access to buildings through exterior antennas communicating with central radio base stations (BSs) [1]. The wireless MAN offers an alternative to cabled access networks, such as fiber optic links, coaxial systems using cable modems, and digital subscriber line (DSL) links. Because wireless systems have the capacity to address broad geographic areas without the costly infrastructure development required in deploying cable links 1 to individual sites, the technology may prove less expensive to deploy and may lead to more ubiquitous broadband access. Because of the propagation requirements, the use of advanced antenna systems is supported. The research concerning the suitability of certain communication parameters, like modulation, coding, symbol rate, MIMO antenna utilization, and so on, is performed through extensive simulations. The simulation results depend strongly on the radio channel. Hence, the radio channel is a crucial part of the simulation. On one hand, it is very important to use a very accurate and realistic channel model in the simulation to enable reliable simulation results. On the other hand, the complexity of the simulation should be kept low. Therefore, the research challenge is to create a channel model which is realistic and simple.

Many MIMO channel models have been developed and can be generally divided into three classes: ray-tracing, scattering, and correlation model. It is hard to say which one is the best model. Fortunately, Reference [2] has already proposed a MIMO channel model which belongs to the third class for IEEE 802.16. A set of six typical channels was selected for the three terrain types that are typical of the continental US [3]. This article presents an improved correlation MIMO channel model for IEEE 802.16. The theory analysis and simulation results indicate that the new model can describe the antenna correlation much more precisely than that in Ref. [2].

2 IEEE 802.16 wireless channel model

An important requirement for assessing technology for broadband fixed wireless applications is to have an accurate description of the wireless channel. Channel models are heavily dependent on the radio architecture. For example, in first generation systems, a super-cell or “single-stick” architecture is used where the base station (BTS) and the subscriber station are in line-of-sight (LOS) condition and the system uses a single cell with no co-channel interference. For second generation systems, a scalable multi-cell architecture with non-line-of-sight (NLOS) conditions becomes necessary. For IEEE 802.16, a set of propagation models applicable to the multi-cell architecture is presented. Typically, the scenario is as follows [2]:

1) Cells are less than 10 km in radius, variety of terrain and tree density types.
2) Under-the-eave/window or rooftop installed directional antennas (2 – 10 m) at the receiver.
3) 15–40 m BTS antennas.
4) Requirement for high cell coverage (80%–90%).
And the wireless channel is characterized by:
1) Path loss (including shadowing).
2) Spread of multi-path delay.
3) Fading characteristics.
4) Doppler spread.
5) Co-channel and adjacent channel interference.
It is to be noted that these parameters are random and only a statistical characterization is possible. Typically, the mean and variance of the parameters are specified.

The above-mentioned propagation model parameters depend on terrain, tree density, antenna height and beamwidth,
wind speed and season (time of the year).

This article combines and elaborates on contributions [4–6] which were presented at the IEEE 802.16.3 meeting in Tampa, FL, on November 7, 2000.

2.1 Path loss model

The most widely used path loss model for signal strength prediction and simulation in macrocellular environments is the Hata-Okumura model [7, 8]. To correct for certain limitations of that model, Ref. [2] proposes a model presented in Ref. [9]. The model covers the three most common terrain categories found across the United States.

2.2 Multi-path delay spread

Due to the scattering environment, the channel has a multi-path delay profile. For directive antennas, the delay profile can be represented by a spike-plus-exponential shape [10]. It is characterized by \( \tau_{\text{RMS}} \) (RMS delay spread of the entire delay profile) which is defined as:

\[
\tau_{\text{RMS}} = \sqrt{\sum_j P_j \tau_j^2 - (\tau_{\text{avg}})^2}
\]

where, \( \tau_j \) is the delay of the \( j \)th delay component of the profile and \( P_j \) is given by \( P_j = \text{(power in the } j\text{th delay component) / (total power in all components)}. \)

2.3 Doppler spectrum

Following the Ricean power spectral density (PSD) model in COST 207 [11], Ref. [2] defines scatter and fixed Doppler spectrum components. In fixed wireless channels, the Doppler PSD of the scatter (variable) component is mainly distributed around \( f = 0 \) Hz (Fig. 1(a)). The shape of the spectrum is therefore different than the classical Jakes’s spectrum for mobile channels. A rounded shape as shown in Fig. 1(b) can be used as a rough approximation to the Doppler PSD which has the advantage that it is readily available in most existing radio frequency (RF) channel simulators [12]. It can be approximated by:

\[
S(f) = \begin{cases} 
1 - 1.72 f_0^2 + 0.785 f_0^3; & f_0 \leq 1 \\
0; & f_0 > 1
\end{cases}
\]

where \( f_0 = f / f_{\text{max}} \).

The function is parameterized by a maximum Doppler frequency \( f_{\text{max}} \).

These parameters are important for MIMO spatial channel model. The most important parameter is coherence distance. Coherence distance is the minimum distance between points in space for which the signals are mostly uncorrelated. This distance is usually greater than 0.5 wavelengths, depending on antenna beamwidth and angle of arrival distribution. At the BTS, it is common practice to use spacing of about 10 and 20 wavelengths for low-medium and high antenna heights, respectively (120 degree sector antennas).

3 Modified stanford university interim (SUI) model for IEEE 802.16

The above-described channel models provide the basis for specifying channels for a given scenario. It is obvious that there are many possible combinations of parameters to obtain such channel descriptions. A set of six typical channels was selected for the three terrain types that are typical of the continental US [3].

In this section, SUI channel models that Ref. [2] modified to account for 30 degree directional antennas are presented. These models can be used for simulations, design, developments, and testing of technologies suitable for fixed broadband wireless applications. The parameters were selected on the basis of the statistical models described in the earlier sections.

Scenario for modified SUI channels:
1) Cell size: 7 km.
2) BTS antenna height: 30 m.
3) Receive antenna height: 6 m.
4) BTS antenna beamwidth: 120°.
5) Receive antenna beamwidth: omnidirectional (360°) and 30°. For a 30° antenna beamwidth, 2.3 times smaller RMS delay spread is used when compared to an omnidirectional antenna RMS delay spread [10]. Consequently, the second tap power is attenuated additional 6 dB and the third tap power is attenuated additional 12 dB (effect of antenna pattern, delays remain the same). For the omnidirectional receive antenna case, the tap delays and powers are consistent with the COST
4 MIMO channel model for IEEE 802.16

4.1 Generic structure for IEEE 802.16 MIMO channel model

The above-mentioned structure is general for MIMO channels and includes other configurations like single input single output (SISO) and single input multiple output (SIMO) as subsets. The SUI channel structure is the same for the primary and interfering signals.

Input mixing matrix: this part models correlation between input signals if multiple transmitting antennas are used.

Tapped delay line matrix: this part models the multi-path fading of the channel. The multi-path fading is modeled as a tapped-delay line with three taps with nonuniform delays. The gain associated with each tap is characterized by a distribution (Ricean with a K-factor>0, or Rayleigh with K-factor=0) and the maximum Doppler frequency.

Output mixing matrix: this part models the correlation between output signals if multiple receiving antennas are used.

Using the above-mentioned general structure of the SUI channel and assuming the above-mentioned scenario, six SUI channels are constructed which are representative of the real channels.

4.2 Spatial correlation for IEEE 802.16 MIMO channel

The SUI channel models define an antenna correlation, which has to be considered if multiple transmit or receive elements, that is, multiple channels are being simulated. Antenna correlation is commonly defined as the envelope correlation coefficient between signals received at two antenna elements. The received baseband signals are modeled as two complex random processes $X(t)$ and $Y(t)$ with an envelope correlation coefficient of

$$
\rho_{ENV} = \frac{E[(X - E[X])(Y - E[Y])^\ast]}{\sqrt{E[(X - E[X])^2]E[(Y - E[Y])^2]}}
$$

(3)

This is not equal to the correlation coefficient of the envelopes (magnitude) of two signals, a measure that is also used frequently in cases if no complex data is available.

From Ref. [2], it can be seen that the antenna correlation can be related to the individual tap correlations.

To obtain a simple solution for setting these tap correlations depending on the required antenna correlation, all tap correlations need to be equal. Then Ref. [2] states that all the tap correlations have to be set to the antenna correlation. For the simulation of the IEEE 802.16 MIMO channel, it is necessary to set all tap correlations equal to the antenna correlation.

4.3 An improved correlation model for IEEE 802.16 MIMO channel

To generate a sequence of random state vectors with specified first order statistics (mean vector $\mu$ and correlation matrix $R$), the following transformation can be used [14]:

$$
\hat{V} = R^{-1}V + \mu
$$

(4)

where $V$ is a vector of independent sequences of Gaussian-distributed random numbers with zero mean and identical variance. The correlation matrix $R$ is defined and factored as:

$$
R = E \begin{bmatrix}
1 & r_{12} & \cdots \\
0 & 1 & \cdots \\
\vdots & \vdots & \ddots
\end{bmatrix}
$$

(5)

If Eq. (4) is used to correlate complex sequences, not all correlations between real and imaginary parts of the input sequences are set according to the specified envelope correlation coefficient. To correlate complex sequences, each complex sequence was split into real and imaginary part and the real-valued sequences were correlated. For example, to correlate two complex sequences $X$ and $Y$, the input vector $V$ and the correlation matrix $R$ are set as:

$$
\begin{bmatrix}
X \\
Y
\end{bmatrix} R = \begin{bmatrix}
1 & \rho_{ENV} \\
\rho_{ENV} & 1
\end{bmatrix}
$$

(6)

If the real part and image part of complex sequences $X$ and $Y$ are dealt with separately, Ref. [2] recommends that Eq. (6) should be modified as:

$$
\begin{bmatrix}
\text{Re}\{X\} \\
\text{Im}\{X\} \\
\text{Re}\{Y\} \\
\text{Im}\{Y\}
\end{bmatrix} R = \begin{bmatrix}
1 & 0 & \rho_{ENV} & \rho_{ENV} \\
0 & 1 & \rho_{ENV} & \rho_{ENV} \\
\rho_{ENV} & \rho_{ENV} & 1 & 0 \\
\rho_{ENV} & \rho_{ENV} & 0 & 1
\end{bmatrix}
$$

(7)

But according to the theoretical analysis and simulation results, there is a more precise and simpler form than Eq. (7) as:

$$
\begin{bmatrix}
\text{Re}\{X\} \\
\text{Im}\{X\} \\
\text{Re}\{Y\} \\
\text{Im}\{Y\}
\end{bmatrix} R = \begin{bmatrix}
1 & 0 & \rho_{ENV} & 0 \\
0 & 1 & 0 & \rho_{ENV} \\
\rho_{ENV} & 0 & 1 & 0 \\
0 & \rho_{ENV} & 0 & 1
\end{bmatrix}
$$

(8)

In Eq. (8), real part of $X$ is considered to be correlated to the real part of $Y$. This assumption reduces the complexity of MIMO correlation channel simulation because the number of zero element of Eq. (8) is the twice that of Eq. (7) and
improves its accuracy. When the number of complex sequences grows the dimension of $R$ and the complexity of correlation calculation grows simultaneously.

5 Simulation results

5.1 Power delay profile of two methods

The red and blue points in the Figs. 2 and 3 denote power delay profile (PDP) of $2 \times 2$ IEEE 802.16 MIMO channel simulation results and ideal values, respectively. It can be seen that both simulation methods can obtain the same accurate ideal PDP results.

The simulation assumptions are shown in Table 1.

<table>
<thead>
<tr>
<th>BASE Mobile</th>
<th>Antenna type</th>
<th>Array type</th>
<th>K type</th>
<th>Channel type</th>
<th>Number of path</th>
<th>Tx antenna number</th>
<th>Rx antenna number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobile</td>
<td>$30^\circ$ directional</td>
<td>omnibearing</td>
<td>90%</td>
<td>SUI-3</td>
<td>6</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Mobile</td>
<td>omnibearing</td>
<td>ULA</td>
<td>ULA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5.2 Power delay profile of two methods

The red and blue points in the following Figs. 4 and 5 denote the antenna correlation of $2 \times 2$ IEEE 802.16 MIMO channel simulation results and ideal values, respectively. The antenna correlation is defined by Eq. (3). The ideal values are defined by Ref. [2] which are based on the measured results and published reports. In this simulation, the cross-correlation is between the three taps of TX#1-RX#1 channel and three taps of all the other MIMO channels.

The simulated antenna correlation of the new simulation method is much more precise than that of the old simulation method.
6 Conclusions

In this article, an improved correlated MIMO channel model is presented. This new MIMO channel simulation method can obtain more precise antenna correlation which is the key parameter for space-time MIMO channel characters. On the other hand, this novel method does not maintain the high complexity of simulation. The more accurate correlation MIMO channel model is helpful for the research and simulation of IEEE 802.16 technologies. For a more generalized MIMO channel model, several researchers have developed other modeling.

References

4. Hari K V S, Sheikh K P, Bushue C. Interim channel models for G2 MMDS fixed wireless applications. IEEE 802.16.3c–00/49
5. Smith M S, Tappenden C. Additional enhancements to interim channel models for G2 MMDS fixed wireless applications. IEEE 802.16.3c–00/53
6. Erceg V. Channel models for broadband fixed wireless systems. IEEE 802.16.3c–00/53

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