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Channel Models for IEEE 802.20 MBWA System Simulations – Rev 03

This document is a Draft Permanent Document of IEEE Working Group 802.20. Permanent Documents (PD) are used in facilitating the work of the WG and contain information that provides guidance for the development of 802.20 standards. This document is work in progress and is subject to change.

Contents

1 Introduction

This document describes a set of Multiple-Input-Multiple-Output (MIMO) radio channel models based on references [6, 13], as a result of the discussions within IEEE 802.20 Working Group. In specifying these models, we have tried to address various comments and inputs from all the 802.20 participants, who have expressed their opinion on this subject. As a result of this effort, the previous version of 802.20 channel models proposal (Rev 2) has been revised.

[Editor's Note: There have been more than 10 contributions on this topic so far. For MIMO channel modeling, contributions C802.20-03/42 and C802.20-03/50 indicated that correlation model should be adopted due to the simplicity. Efforts have been made to make sure that the MIMO channel models have appropriate delay spread, Doppler spread, and spatial characteristics that are typical of the licensed bands below 3.5GHz. The effort to keep backward compatibility with standardized ITU SISO models has also been made during the selection of channel delay profiles.]

1.1 Purpose

This document specifies a set of mobile broadband wireless channel models in order to facilitate the simulations of MBWA Air Interface schemes at link level, as well as system level.

1.2 Scope

The scope of this document is to define the specifications of mobile broadband wireless channel models.

1.3 Abbreviations and Definitions

AoA	Angle of Arrival
AoD	Angle of Departure
AS	Angle Spread
BS	Base Station
DoT	Direction of Travel
DS	Delay Spread
MEA	Multi-Element Array
MIMO	Multiple-Input Multiple Output
MISO	Multiple-Input Single-Output
MS	Mobile Station
Path	Ray
PAS	Power Azimuth Spectrum
PDP	Power Delay Profile
PL	Path Loss
SISO	Single-Input Single Output
SIMO	Single-Input Multiple-Output
TE	Test Environment
ULA	Uniform Linear Array

2 Link Level MIMO Channel Model Parameters

2.1 Introduction

In this Chapter, a set of spatial channel model parameters are specified that have been developed to characterize the particular features of MIMO radio channels. SISO channel models provide information on the distributions of signal power level and Doppler shifts of received signals. MIMO channel models which are based on the classical understanding of multi-path fading and Doppler spread, incorporate additional concepts such as angular spread, angle of arrival, Power-Azimuth-Spectrum (PAS), and the antenna array correlation matrices at the transmit (Tx) and receiving (Rx) ends.

2.2 Spatial Channel Characteristics

Mobile broadband radio channel is a challenging environment, in which the high mobility causes rapid variations across the time-dimension, multi-path delay spread causes severe frequency-selective fading, and multi-path angular spread causes significant variations in the spatial channel responses. For best performance, the Rx & Tx algorithms must accurately track all dimensions of the channel responses (space, time, and frequency). Therefore, a MIMO channel model must capture all the essential channel characteristics, including

- Spatial characteristics (Angle Spread, Power Azimuth Spectrum, Spatial correlations),
- Temporal characteristics (Power Delay Profile),
- Frequency-domain characteristics (Doppler spectrum).

In MIMO systems, the spatial (or angular) distribution of the multi-path components is important in determining system performance. System capacity can be significantly increased by exploiting rich multi-path scattering environments.

2.3 MIMO Channel Model Classification

There are three main approaches to MIMO channel modeling: the correlation model, the ray-tracing model, and the scattering model. The properties of these models are briefly described as follows:

- **Correlation Model**: This model characterizes spatial correlation by combining independent complex Gaussian channel matrices at the transmitter and receiver. For multipath fading, the ITU model is used to generate the power delay profile and Doppler spectrum. Since this model is based on ITU generalized tap delay line channel model, the model is simple to use and backward compatible with existing ITU channel profiles.

- **Ray-Tracing Model**: In this approach, exact locations of the primary scatterers are assumed known. The resulting channel characteristics are then predicted by summing the contributions from a large number of the paths through the simulated environment from each transmit antenna to each receive antenna. This technique provides fairly accurate channel prediction by using site-specific information, such as building databases of architectural drawings. However, it is too complex to use this approach to modeling outdoor environment because of the difficulty in obtaining detailed terrain and building databases.

- **Scattering Model**: This model assumes a particular statistical distribution of scatterers. Using this distribution, channel models are generated through simulated interaction of scatterers and planar wave-fronts. This model requires a large number of parameters.

2.4 MBWA Channel Environments

The following channel environments will be considered for MBWA system simulations:

1. **Suburban macro-cell**
    a. Large cell radius (approximately 1-6 km distance BS to BS)
    b. High BS antenna positions (above rooftop heights, between 10-80m)
    c. Low delay and angle spreads
    d. High range of mobility (0 – 250 km/h)
2. **Urban macro-cell**
    a. Large cell radius (approximately 1-6 km distance BS to BS)
    b. High BS antenna positions (above rooftop heights, between 10-80m)
    c. Moderate (to high) delay and angle spread
    d. High range of mobility (0 – 250 km/h)
3. **Urban micro-cell**
    a. Small cell radius (approximately 0.3 – 0.5 km distance BS to BS)
    b. BS antenna positions (at rooftop heights or lower)
    c. High angle spread and moderate delay spread
    d. Medium range of mobility (0 – 120 km/h)
    e. The model is sensitive to antenna height and scattering environment (such as street layout, LOS)

2.5 Spatial Parameters for the Base Station

Calibrating MBWA simulators at link level requires the specification of a common set of spatial parameters for the base station.

2.5.1 BS Antenna Topologies

At the BS, three values for reference antenna element spacing are defined as: 0.5λ, 4λ, and 10λ. The 3-sector antenna pattern is used for BS, which is plotted in Figure 2.1 and is specified by

$$A(\theta) = -\min\left[12\left(\frac{\theta}{\theta_{3dB}}\right)^2,\ A_m\right] \quad \text{where} \quad -180 \le \theta \le 180$$

θ is defined as the angle between the direction of interest and the broadside of the antenna array. θ_{3dB} is the 3dB beam-width in degrees, and A_m is the maximum attenuation. For a 3 sector scenario θ_{3dB} is 70 degrees, and A_m = 20dB. The term broadside refers to the direction from which the signal is coming perpendicularly to the MEA. Antenna array shows the maximum gain at its broadside direction. The antenna broadside pointing direction is illustrated by Figure 2.2 for a 3-sector scenario. The antenna gain, as specified by 3GPP document [13], is 14 dBi for a 3-sector scenario.

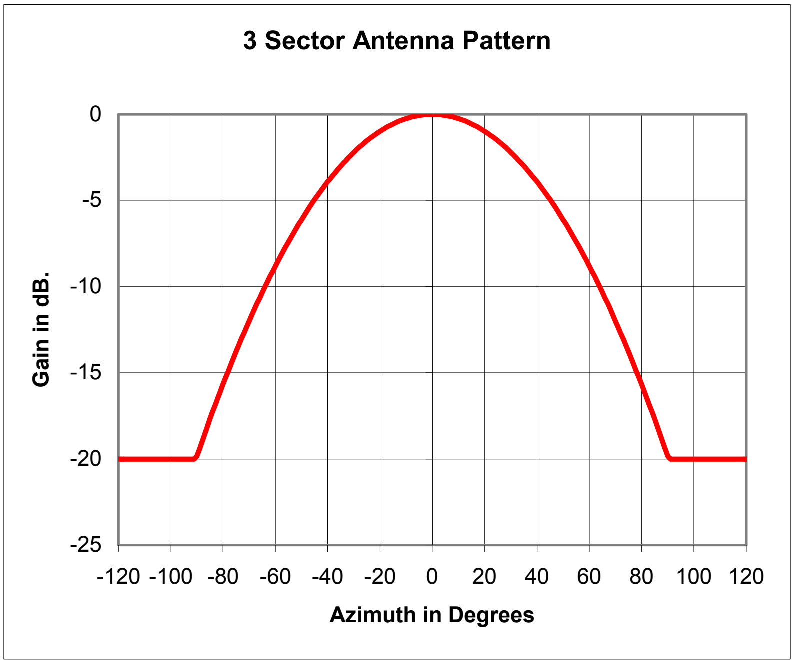

Figure 2.1 Antenna pattern for 3-sector cells

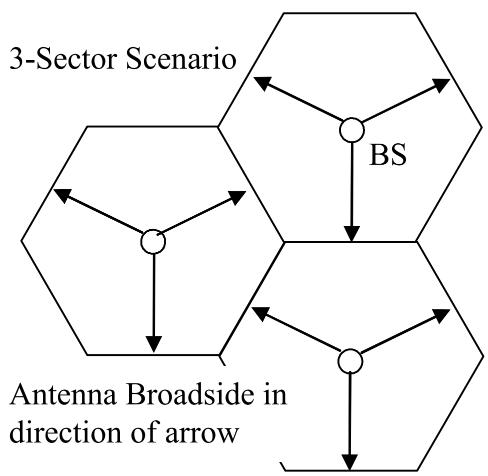

Figure 2.2 Illustration of the broadside pointing direction of antenna array for 3-sector cells

For a 6 sector scenario, θ_{3dB} is 35 degree, A_m =23dB, which results in the antenna pattern shown in the figure below, and the broadside pointing direction illustrated by Figure . The gain specified by 3GPP document [13] is 17dBi for a 6 sector scenario.

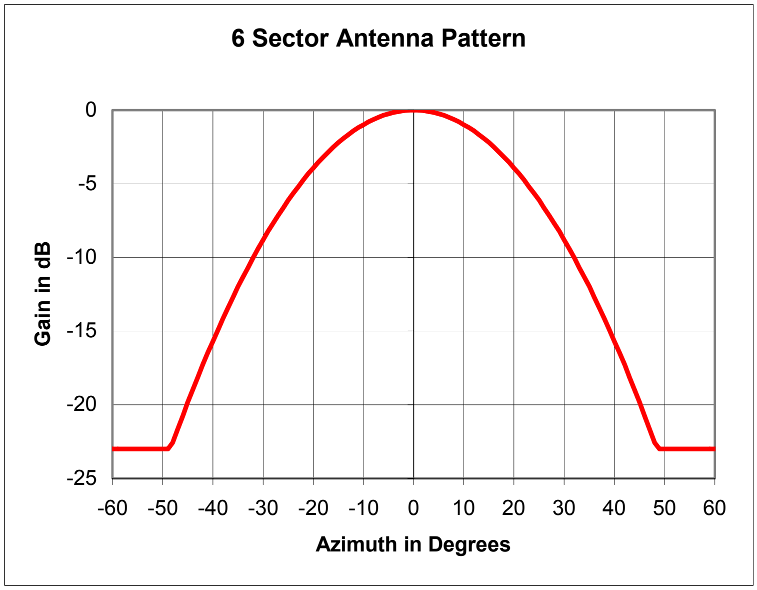

Figure 2.3 Antenna Pattern for 6-sector cells

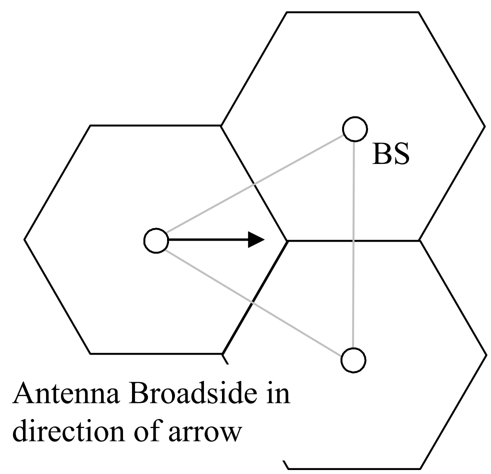

Figure 2.4 Broadside Pointing Direction for 6-sector cells

2.5.2 BS Angle Spread

The base station per-path angle spread (or called narrowband angle spread) is defined as the root mean square (RMS) of angles with which an arriving ray's power is received by the base station MEA. The individual path powers are defined in the temporal ITU SISO channel models. Two values of BS angle spread (each associated with a corresponding mean angle of departure, AoD) are considered in this document:

- AS: 2 degrees at AoD = 50^o

- AS: 5 degrees at AoD = 20^o

Attention should be paid when comparing the link level performance between the two angles spread values since the BS antenna gains for the two corresponding AoDs are different.

2.5.3 BS Angle of Departure

The Angle of Departure (AoD) is defined to be the mean angle with which an arriving or departing ray's power is received or transmitted by the BS array with respect to the broadside. The two values considered are:

- AoD: 50 degrees (associated with the RMS Angle Spread of 2^o)
- AoD: 20 degrees (associated with the RMS Angle Spread of 5^o)

2.5.4 BS Power Azimuth Spectrum

The Power Azimuth Spectrum (PAS) of a ray arriving at the base station MEA exhibits Laplacian distribution. For an AoD $\overline{\theta}$ and RMS angle-spread σ , the BS per path PAS value at an angle θ is given by:

$$P(\theta,\sigma,\overline{\theta}) = N_o \exp\left[\frac{-\sqrt{2}\left|\theta-\overline{\theta}\right|}{\sigma}\right]G(\theta)$$

where both angles $\overline{\theta}$ and θ are given with respect to the broadside of the MEA. It is assumed that all antenna elements' orientations are aligned. Also, P is the average received power and G is the numeric base station antenna gain given by

$$G(\theta) = 10^{0.1A(\theta)}$$

Finally, N_o is the normalization constant:

$$N_o^{-1} = \int_{-\pi+\overline{\theta}}^{\pi+\overline{\theta}} \exp\left[\frac{-\sqrt{2}\left|\theta-\overline{\theta}\right|}{\sigma}\right]G(\theta)\, d\theta$$

In the above equation, θ represents path components (sub-rays) of the path power arriving at an AoD.

2.6 Spatial Parameters for the Mobile Station

Calibrating MBWA simulators at link level requires the specification of a common set of spatial parameters for the mobile station.

2.6.1 MS Antenna Topologies

At the MS, the MEA element spacing is 0.5 λ , where λ is the wavelength of the carrier frequency.
For each antenna element at the MS, the antenna pattern will be assumed omni directional with an antenna gain of -1 dBi.

2.6.2 MS Angle Spread

The MS per-path AS is defined as the root mean square (RMS) of angles of an incident path's power at the MS array. Two values of the path's angle spread are considered:

- AS: 104^o (results from the PAS with a uniform distribution over 360 degree),
- AS: 35^o for a Laplacian PAS with a certain path specific Angle of Arrival (AoA).

2.6.3 MS Angle of Arrival

The per-path Angle of Arrival (AoA) is defined as the mean angle of an incident ray at the MS MEA with respect to the broadside as shown in the figure below,

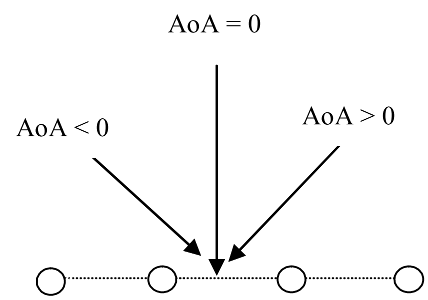

Figure 2.5 Angle of arrival orientation at the MS

The AoA analysis can provide an illustration of the PAS at MS MEA. Three different per-path AoA values at the MS are suggested for the cases of a non-uniform PAS,

- AoA: -67.5 degrees (associated with an RMS Angle Spread of 35^o)
- AoA: +67.5 degrees (associated with an RMS Angle Spread of 35^o)
- AoA: +22.5 degrees (associated with an RMS Angle Spread of 35^o or with an LOS component)

2.6.4 MS Power Azimuth Spectrum

The Power Azimuth Spectrum (PAS) of a ray arriving at the MS is modeled as either Laplacian distribution or uniform distribution over 360^o. Since an omni antenna is assumed at MS, the received per path PAS will remain either Laplacian or uniform. For an incoming AoA $\overline{\theta}$ and RMS angle spread σ, the MS per-path Laplacian PAS value at an angle θ is given by:

$$P(\theta,\sigma,\overline{\theta}) = N_o \exp\left[\frac{-\sqrt{2}\left|\theta-\overline{\theta}\right|}{\sigma}\right],$$

where both angles $\overline{\theta}$ and θ are given with respect to the broadside of the MEA. It is assumed that all antenna elements' orientations are aligned. Also, P is the average received power and N_o is the normalization constant:

$$N_o^{-1} = \int_{-\pi+\bar{\theta}}^{\pi+\bar{\theta}} \exp\left[\frac{-\sqrt{2}\left|\theta-\bar{\theta}\right|}{\sigma}\right] d\theta .$$

In the above equation, θ represents path components (sub-rays) of the path power arriving at an incoming AoA $\overline{\theta}$.

2.6.5 MS Direction of Travel

The mobile station direction of travel is defined with respect to the broadside of the mobile antenna array as shown in the figure below,

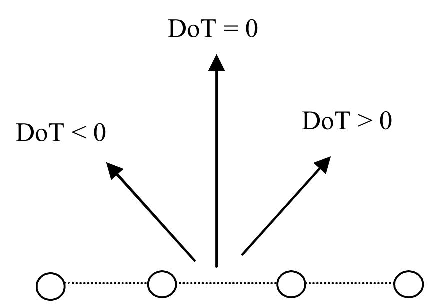

Figure 2.6 Direction of Travel for MS

2.6.6 Doppler Spectrum

The per-path Doppler Spectrum is defined as a function of DoT, per-path PAS, and AoA at MS. Doppler spectrum is affected by the PAS and the Angle of Arrival. Doppler spectrum affects the time-domain behavior of the channel.

2.7 Link Level Spatial Channel Model Parameter Summary and Reference Values

This section describes link-level channel modeling parameters. Link level simulations alone will not be used for the comparison of MBWA technical proposals. Only system level simulations can achieve accurate performance evaluation of different MBWA AI proposals.

2.7.1 Link Level Channel Model Parameter Summary

The following table summarizes the physical parameters to be used for link level modeling.

MODELS		CASE-I		CASE-II		CASE-III		CASE-IV		CASE-V	
PDP		Modified Pedestrian-A		Vehicular-A		Pedestrian-B		Typical Urban (optional)		Vehicular-B (optional)	
Doppler Spectrum		Classical; Optional: Path#1 = Rician (K=6)		Classical;		Classical		Classical		Classical	
Number of Paths		1) 4+1 (LOS on, K = 6dB) 2) 4 (LOS off)		6		6		11		6	
Relative Path power (dB)	Delay (ns)	1) 0, 2) -∞ ,	0	0	0	0	0	-4.0	0	-2.5	0
		1) -6.51, 2) 0,	0	-1.0	310	-0.9	200	-3.0	100	0	300
		1) -16.21, 2) -9.7	110	-9.0	710	-4.9	800	0	300	-12.8	8900
		1) -25.71, 2) –19.2	190	-10.0	1090	-8.0	1200	-2.6	500	-10.0	12900
		1) -29.31, 2) -22.8	410	-15.0	1730	-7.8	2300	-3.0	800	-25.2	17100
				-20.0	2510	-23.9	3700	-5.0	1100	-16.0	20000
								-7.0	1300		
								-5.0	1700		
								-6.5	2300		
								-8.6	3100		
								-11.0	3200		
Speed (km/h)		1) 3 2) 30, 120		30, 120, 250		3, 30, 120,		3, 30, 120		30, 120	
Mobile Station	Topology	0.5λ		0.5λ		0.5λ		0.5λ		0.5λ	
	PAS	1) LOS on: Fixed AoA for LOS component, remaining power has 360 degree uniform PAS. 2) LOS off: PAS with a Laplacian distribution, RMS angle spread of 35 degrees per path		RMS angle spread of 35 degrees per path with a Laplacian distribution Or 360 degree uniform PAS		RMS angle spread of 35 degrees per path with a Laplacian distribution		RMS angle spread of 35 degrees per path with a Laplacian distribution Or 360 degree uniform PAS		RMS angle spread of 35 degrees per path with a Laplacian distribution Or 360 degree uniform PAS	
	DoT (degrees)	0		22.5		-22.5		22.5		22.5	

<table>
<tr><td></td><td>AoA (degrees)</td><td>22.5 (LOS component)
67.5 (all other paths)</td><td>67.5 (all paths)</td><td>67.5 (all paths)</td><td>22.5 (odd number paths),
-67.5 (even number paths)</td><td>67.5 (all paths)</td></tr>
<tr><td rowspan="3">Base Station</td><td>Topology</td><td colspan="5">Reference: ULA with
0.5λ-spacing or 4λ-spacing or 10λ-spacing</td></tr>
<tr><td>PAS</td><td colspan="5">Laplacian distribution with RMS angle spread of
2 degrees or 5 degrees,
per path depending on AoA/AoD</td></tr>
<tr><td>AoD/AoA
(degrees)</td><td colspan="5">50° for 2° RMS angle spread per path
20° for 5° RMS angle spread per path</td></tr>
</table>

Table 1 Summary of Link Level Channel Model Parameters

2.7.2 Reference Values for Spatial Channel Model Parameters

[Editor's note: Each resolvable path is characterized by its own spatial channel parameters (angle spread, angle of arrival, power azimuth spectrum). All paths are assumed independent. These assumptions apply to both BS and MS. The above assumptions are in effect only for the Link Level channel model. For the purpose of calibrating software simulator and link level simulations, reference values of the average complex correlation values and its magnitude are needed.]

3 MIMO Channel Model for System Level Simulations

3.1 Introduction

The spatial channel model for MBWA system-level simulations is described in this chapter. As in the link level simulations, the description is in the context of a downlink system where BS transmits to a MS; however the material described here can be applied to the uplink as well. The goal of this chapter is to define the methodology and parameters for generating the spatial and temporal MIMO channel model coefficients for MBWA system simulations.

As opposed to link level simulations where only considering the case of a single BS transmitting to a single MS, the system level simulations typically consist of multiple cells/sectors, BSs, and MSs. Performance metrics such as data throughputs are collected over D drops, where a "drop" is defined as a simulation run for a given number of cells/sectors, BSs, and MSs, over a specified number of frames.

During a drop, the channel undergoes fading according to the speed of MSs. Channel state information is fed back from the MSs to the BSs, and the BSs use schedulers to determine which user(s) to transmit to.

Typically, over a series of drops, the cell layout is fixed, but the locations of the MSs are still random variables at the beginning of each drop.

For an ***S*** element BS array and a ***U*** element MS array (See Figure 3.1), the channel coefficients for one of ***N*** multi-path components are given by an $U \times S$ matrix of complex amplitudes. We denote the channel transfer matrix for the ***n***th multi-path component as $\mathbf{H}_n(t)$, where ***n*** = 1,…, ***N***. It is a function of time t because the complex amplitudes are undergoing fast fading governed by the movement of the MS. The overall procedure for generating the channel matrices consists of three basic steps:

1. Specify an environment, i.e., suburban macro, urban macro, or urban micro.
2. Obtain the parameters to be used in simulations, associated with that environment.
3. Generate the channel coefficients based on the parameters.

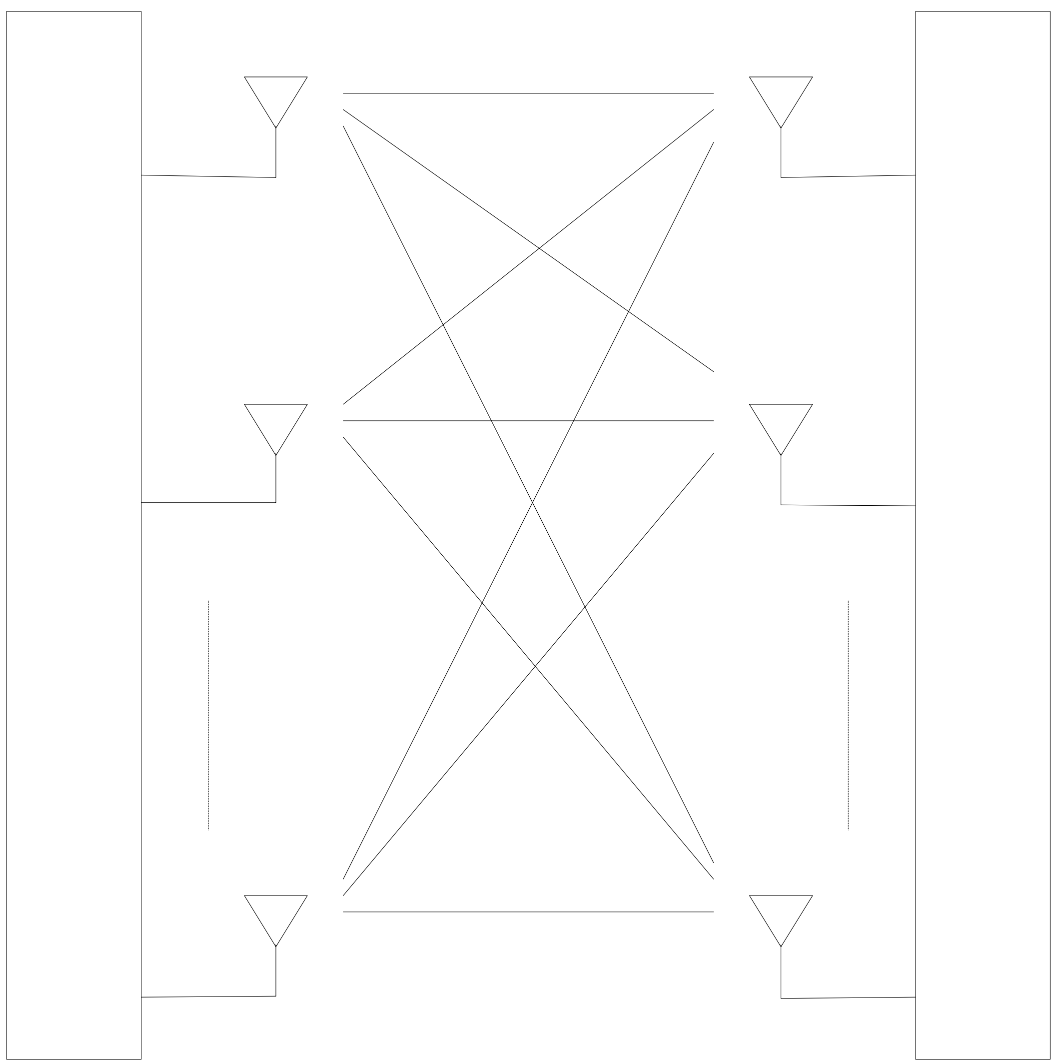

Figure 3.1 MIMO Model with ***S*** Transmit Antennas and ***U*** Receive Antenna

The following sections describe the details of overall procedure. The figure below provides a flow chart for generating channel coefficients.

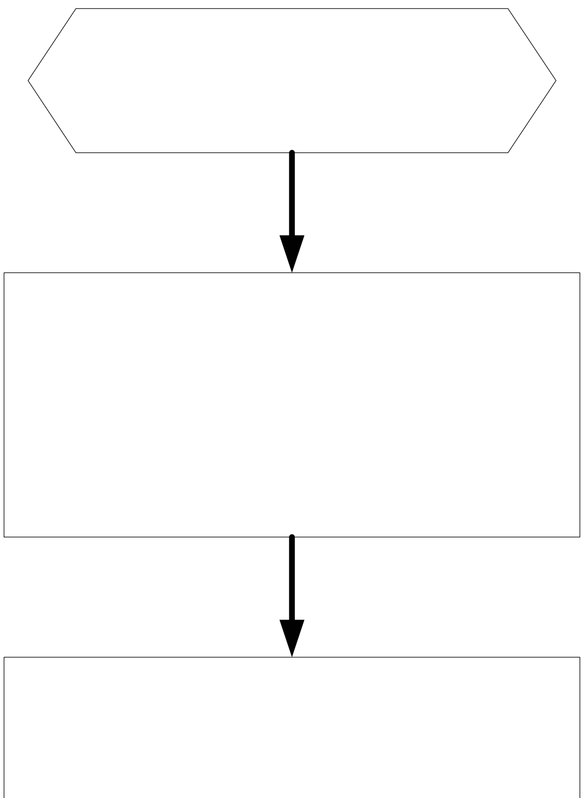

Figure 3.2 The flow chart for the generation of MIMO channel model coefficients

3.2 Definitions, Parameters, and Assumptions

The received signal at MS consists of ***N*** time-delayed multi-path replicas of the transmitted signal. These ***N*** paths are defined by the channel PDP, and are chosen randomly according to the channel generation procedure. Each path consists of M sub-paths. Figure 3.2 shows the angular parameters used in the model. The following definitions are used:

Ω_{BS} BS antenna array orientation, defined as the angle between the broadside of BS MEA and the absolute North (N) reference direction.

θ_{BS} The angle between LOS direction and the broadside of BS array.

$\delta_{n,AoD}$ AoD for the ***n***th ray with respect to the LOS, where (n = 1 … N).

$\Delta_{n,m,AoD}$ Offset for the ***m***th subpath of the ***n***th ray with respect to, where (m = 1 … M).

$\theta_{n,m,AoD}$ Absolute AoD for the ***m***th subpath of the nth ray at the BS with respect to the BS broadside.

Ω_{MS} MS antenna array orientation, defined as the angle between the broadside of the MS MEA and the absolute North reference direction.

θ_{MS} Angle between the BS-MS LOS and the MS broadside

$\delta_{n,AoA}$ AoA of the ***n***th ray with respect to LOS

$\Delta_{n,m,AoA}$ Offset for the ***m***th subpath of the ***n***th ray with respect to $\delta_{n,AoA}$.

$\theta_{n,m,AoA}$ Absolute AoA for the ***m***th subpath of the ***n***th ray at the MS w.r.t. the MS broadside

V MS velocity vector

θ_v Angle of the velocity vector with respect to the MS broadside: $\theta_v = \arg(V)$

Note: The angle measured in a clockwise direction is assumed to be negative value.

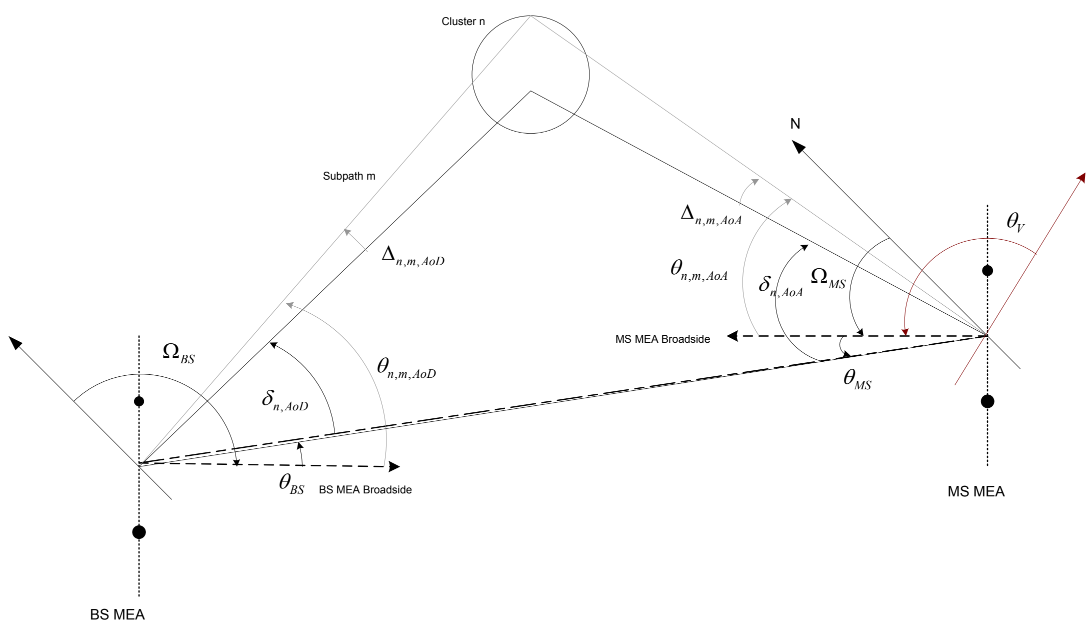

Figure 3.2 The MIMO channel model angle parameters at both BS and MS

For the purpose of system level simulation, the fast fading per-path will be evolved in time, although bulk parameters including angle spread, delay spread, log normal shadowing, and MS location will remain fixed during its evaluation at one drop.

The following assumptions are made for all simulations, independent of environment:

1. Uplink-Downlink Reciprocity: The AoD/AoA values are identical between the uplink and downlink.

2. For FDD systems, random subpath phases between UL, DL are uncorrelated. (For TDD systems, the phases will be fully correlated.)

3. Shadowing among different mobiles is uncorrelated. In practice, this assumption would not hold if mobiles are very close to each other, but we make this assumption just to simplify the model.

4. The spatial channel model should allow any type of antenna configuration to be selected. In order to compare algorithms, reference antenna configurations based on Uniform Linear Array (ULA) configurations with 0.5, 4, and 10 wavelength inter-element spacing will be used.

5. The composite AS, DS, and SF shadow fading, which may be correlated parameters depending on the channel scenario, are applied to all the sectors or antennas of a given base. Sub-path phases are random between sectors. The AS is composed of N x 20 sub-paths, and each sub-path has a precise AoD. The SF is a bulk parameter and is common among all the BS antennas or sectors.

6. The elevation spread is not modeled here.

7. To allow comparisons of different antenna scenarios, the transmit power of a single antenna case shall be the same as the total transmit power of a multiple antenna case.

8. The generation of the channel coefficients assumes linear arrays. The procedure can be generalized for other array configurations.

3.3 MIMO Channel Environments

The following channel environments will be considered for system level simulations.

- Suburban macro-cell
- Urban macro-cell
- Urban micro-cell

The table below describes the parameters used in each of the environments.

Channel Scenario	**Suburban Macro**	**Urban Macro**	**Urban Micro**
Number of paths (*N*)	6	6, 11	6, 11
Number of sub-paths (*M*) per-path	20	20	20
Mean AS at BS	$E[\sigma_{AS}] = 5^0$	$E[\sigma_{AS}] = 8^0, 15^0$	NLOS: $E[\sigma_{AS}] = 19^0$
AS at BS as a lognormal RV $\sigma_{AS} = 10^\wedge(\varepsilon_{AS} x + \mu_{AS}),\ x \sim \eta(0,1)$	$\mu_{AS} = 0.69$ $\varepsilon_{AS} = 0.13$	8^0 $\mu_{AS} = 0.810$ $\varepsilon_{AS} = 0.34$ 15^0 $\mu_{AS} = 1.18$ $\varepsilon_{AS} = 0.210$	N/A
$r_{AS} = \sigma_{AoD} / \sigma_{AS}$	1.2	1.3	N/A
Per-path AS at BS (Fixed)	2^0	2^0	5^0 (LOS and NLOS)

BS per-path AoD Distribution standard distribution	$\eta(0,\sigma^2_{AoD})$ where $\sigma_{AoD} = r_{AS}\sigma_{AS}$	$\eta(0,\sigma^2_{AoD})$ where $\sigma_{AoD} = r_{AS}\sigma_{AS}$	U(-40°, 40°)
Mean AS at MS	$E[\sigma_{AS, MS}] = 68^0$	$E[\sigma_{AS, MS}] = 68^0$	$E[\sigma_{AS, MS}] = 68^0$
Per-path AS at MS (fixed)	35^0	35^0	35^0
MS Per-path AoA Distribution	$\eta(0,\sigma^2_{AoA}(\mathrm{Pr}))$	$\eta(0,\sigma^2_{AoA}(\mathrm{Pr}))$	$\eta(0,\sigma^2_{AoA}(\mathrm{Pr}))$
Delay spread as a lognormal RV $\sigma_{DS} = 10\,\hat{}\,(\varepsilon_{DS}x + \mu_{DS}),\ x \sim \eta(0,1)$	μ_{DS} = - 6.80 ε_{DS} = 0.288	μ_{DS} = -6.18 ε_{DS} = 0.18	N/A
Mean total RMS Delay Spread	$E[\sigma_{DS}] = 0.17\ \mu s$	$E[\sigma_{DS}] = 0.65\ \mu s$	$E[\sigma_{DS}] = 0.251\mu s$
$r_{DS} = \sigma_{delays} / \sigma_{DS}$	1.4	1.7	N/A
Distribution for path delays			*U*(0, 1.2μs)
Lognormal shadowing standard deviation	8dB	8dB	NLOS: 10dB LOS: 4dB
Pathloss model (dB), *d* is in meters	$31.5 + 35\log_{10}(d)$	$34.5 + 35\log_{10}(d)$	NLOS: $34.53 + 38\log_{10}(d)$ LOS: $30.18 + 26*\log_{10}(d)$

Table 3.1 Environment Parameters

The following assumptions are made for the suburban macro-cell and urban macro-cell environments.

1. The macrocell pathloss is based on the modified COST231 Hata urban propagation model:

$$PL[dB] = \left(44.9 - 6.55\log_{10} h_{bs}\right)\log_{10}\left(\frac{d}{1000}\right) + 45.5 + \left(35.46 - 1.1h_{ms}\right)\log_{10}(f_c) - 13.82\log_{10}(h_{bs}) + 0.7h_{ms} + C$$

   where h_{bs} is the BS antenna height in meters, h_{ms} the MS antenna height in meters, f_c is the carrier frequency in MHz, *d* is the distance between the BS and MS in meters, and *C* is a constant factor (*C* = 0dB for suburban macro and *C* = 3dB for urban macro). Setting these parameters to h_{bs} = 32m, h_{ms} = 1.5m, and f_c =1900MHz, the path-losses for suburban and urban macro environments become, respectively, $PL = 31.5 + 35\log_{10}(d)$ and $PL = 34.5 + 35\log_{10}(d)$. The distance *d* is required to be at least 35m.

2. Antenna patterns at the BS are the same as those used in the link simulations.

3. Site-to-site SF correlation is $\zeta = 0.5$.

4. The hexagonal cell repeats will be the assumed layout.

The following assumptions are made for the micro-cell environment.

1. The microcell NLOS pathloss is based on the COST 231 Walfish-Ikegami NLOS model with the following parameters: BS antenna height 12.5m, building height 12m, building to building distance 50m, street width 25m, MS antenna height 1.5m, orientation 30deg for all paths, and selection of metropolitan center. With these parameters, the equation simplifies to:

$$PL(dB) = -55.9 + 38*\log10(d) + (24.5 + 1.5*f_c/925)*\log10(f_c).$$

The resulting pathloss at 1900 MHz is: $PL(dB) = 34.53 + 38*\log10(d)$, where d is in meters. The distance d is at least 20m. A bulk log normal shadowing applying to all sub-paths has a standard deviation of 10dB.

The microcell LOS pathloss is based on the COST 231 Walfish-Ikegami street canyon model with the same parameters as in the NLOS case. The pathloss is

$$PL(dB) = -35.4 + 26*\log10(d) + 20*\log10(f_c)$$

The resulting pathloss at 1900 MHz is $PL(dB) = 30.18 + 26*\log10(d)$, where d is in meters. The distance d is at least 20m. A bulk log normal shadowing applying to all sub-paths has a standard deviation of 4dB.

2. Antenna patterns at the BS are the same as those used in the link simulations.

3. Site-to-site correlation is $\zeta = 0.5$.

4. The hexagonal cell repeats will be the assumed layout.

3.4 Generating Channel Model Parameters

[For a given scenario and a set of parameters, realizations of each channel model parameters such as the path delays, powers, and sub-path AoD and AoA can be derived.]

3.4.1 Generating Model Parameters for Urban and Suburban Macrocell Environments

Step 1: *Choose either an urban macrocell or suburban macrocell environment.*

Step 2: *Determine various distance and orientation parameters.*

Step 3: *Determine the DS, AS, and SF.*

Step 4: *Determine random delays for each of the* ***N*** *multipath components*.

Step 5: *Determine random average powers for each of the N multipath components*.

Step 6: *Determine AoDs for each of the N multipath components*.

Step 7: *Associate the multipath delays with AoDs.*

Step 8: *Determine the powers, phases and offset AoDs of the* ***M*** *= 20 sub-paths for each of the* ***N*** *paths at the BS.*

Step 9: *Determine the AoAs for each of the multipath components.*

Step 10: *Determine the offset AoAs at the UE of the M = 20 sub-paths for each of the N paths at the MS.*

Step 11: *Associate the BS and MS paths and sub-paths.*

Step 12: *Determine the antenna gains of the BS and MS sub-paths as a function of their respective sub-path AoDs and AoAs.*

Step 13: *Apply the path loss based on the BS to MS distance from Step 2, and the log normal shadow fading determined in step 3 as bulk parameters to each of the sub-path powers of the channel model.*

3.4.2 Generating Model Parameters for Urban Microcell Environments

[Urban microcell environments differ from the macrocell environments in that the individual multipaths are independently shadowed.]

Step 1: *Choose the urban microcell environment.*

Step 2: *Determine various distance and orientation parameters.*

Step 3: *Determine the bulk path loss and log normal shadow fading parameters.*

Step 4: *Determine the random delays for each of the N multipath components*.

Step 5: *Determine random average powers for each of the N multipath components*.

Step 6: *Determine AoDs for each of the N multipath components*.

Step 7: *Randomly associate the multipath delays with AoDs.*

Step 8: *Determine the powers, phases, and offset AoDs of the M = 20 sub-paths for each of the N paths at the BS.*

Step 9: *Determine the AoAs for each of the multipath components.*

Step 10: *Determine the offset AoAs of the M = 20 sub-paths for each of the N paths at the MS.*

Step 11: *Associate the BS and MS paths and sub-paths. Sub-paths are randomly paired for each path, and the sub-path phases defined at the BS and MS are maintained.*

Step 12: *Determine the antenna gains of the BS and MS sub-paths as a function of their respective sub-path AoDs and AoAs.*

Step 13: *Apply the path loss based on the BS to MS distance and the log normal shadow fading determined in Step 3 as bulk parameters to each of the sub-path powers of the channel model.*

3.5 Generating Channel Coefficients

Given the user parameters generated in Section 3.4, we use them to generate the channel coefficients. For an ***S*** element linear BS array and a ***U*** element linear MS array, the channel coefficients for one of ***N*** multipath components are given by a $U \times S$ matrix of complex amplitudes. We denote the channel matrix for the *n*th multipath component (*n* = 1,…,*N*) as $\mathbf{H}_n(t)$. The (*u,s*)th component (*s* = 1,…,*S*; *u* = 1,…,*U*) of $\mathbf{H}_n(t)$ is given by

$$h_{u,s,n}(t) = \sqrt{\frac{P_n \sigma_{SF}}{M}} \sum_{m=1}^{M} \begin{pmatrix} \sqrt{G_{BS}(\theta_{n,m,AoD})} \exp\left(j\left[kd_s \sin(\theta_{n,m,AoD}) + \Phi_{n,m}\right]\right) \times \\ \sqrt{G_{MS}(\theta_{n,m,AoA})} \exp\left(jkd_u \sin(\theta_{n,m,AoA})\right) \times \\ \exp\left(jk\|\mathbf{v}\| \cos(\theta_{n,m,AoA} - \theta_v)t\right) \end{pmatrix}$$

where

P_n	is the power of the *n*th path (Step 5).
σ_{SF}	is the lognormal shadow fading (Step 3), applied as a bulk parameter to the n paths for a given drop.
M	is the number of subpaths per-path.
$\theta_{n,m,AoD}$	is the the AoD for the *m*th subpath of the *n*th path (Step 12).
$\theta_{n,m,AoA}$	is the the AoA for the *m*th subpath of the *n*th path (Step 12).
$G_{BS}(\theta_{n,m,AoD})$	is the BS antenna gain of each array element (Step 12).
$G_{MS}(\theta_{n,m,AoA})$	is the MS antenna gain of each array element (Step 12).
j	is the square root of -1.
k	is the wave number $2\pi/\lambda$ where λ is the carrier wavelength in meters.
d_s	is the distance in meters from BS antenna element *s* from the reference (*s* = 1) antenna. For the reference antenna *s* = 1, d_1=0.
d_u	is the distance in meters from MS antenna element *u* from the reference (*u* = 1) antenna. For the reference antenna *u* = 1, d_1=0.
$\Phi_{n,m}$	is the phase of the *m*th subpath of the *n*th path (Step 8).
$\|\mathbf{v}\|$	is the magnitude of the MS velocity vector (Step 2).
θ_v	is the angle of the MS velocity vector (Step 2).

The path loss and the log normal shadowing is applied as bulk parameters to each of the sub-path components of the n path components of the channel.

3.6 Correlation between Channel Parameters

[In [23], the author presents a model for correlating delay spread (DS) with log normal shadow fading (SF). Since both are shown to be log-normal distributed, DS and SF are generally correlated.

The result of the negative correlation between log normal shadowing and delay spread is significant because it indicates that for a larger SF, the DS is reduced, and for a smaller SF, the DS is increased.]

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