An Adaptive Algorithm for MU-MIMO using Spatial Channel Model

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Abstract

In this paper, Multi User Multiple Input Multiple Output (MU-MIMO) spatial channel model has been implemented for different outdoor environments – Urban Micro, and Urban Macro using MATLAB for finding various parameters like angle of arrival of the user, user direction and the distance between user and access point (AP).

Keywords: MIMO, MU-MIMO, MATLAB, SCM, Urban Micro, Urban Macro.

1. INTRODUCTION

Single User Multiple Input Multiple Output (SU-MIMO) technology was standardized in 2004 for3G mobile phone networks to achieve higher data rates [1]. Later, in order to increase the data rates even further, Paulraj et. Elproposed Orthogonal Frequency Division Multiplexing MIMO known as (MIMO-OFDM) for WiMAX as an alternative to cellular standards [2].WiMAX is based on the 802.16e standard and uses MIMO-OFDM to deliver speeds up to 138 Mbit/s. The more advanced 802.16m standard enables download speeds up to 1 Gbit/s [3].

Recently, Multi User Multiple Input Multiple Output (MU-MIMO) has been widely accepted as the primary means to improve mobile broadband services and to support wider transmission bandwidths [4]. In theory, MU-MIMO can provide throughput gains that scale linearly with the number of antennas [5].MU-MIMO is already supported in LTE Release 8 via transmission mode 5 (TM5). In LTE, specifications provide downlink rates up to 300 Mbit/s and uplink rates up to 75 Mbit/s [6].

Therefore, MIMO processing techniques - such as spatial multiplexing, space-time coding and diversity schemes -have gained much attention. Spatial multiplexing can be used for the improvement of data rates [7-9]. Whereas space-time coding and MIMO diversity techniques can be used for improvement of Signal to Noise Ratio (SNR) while keeping the data rate high [10-11]. Overall, MIMO processing techniques appear very promising for future wireless systems. MU-MIMO and Massive MIMO is already a candidate for future mobile communication networks like 5G network [12]. Experimental evaluation has been started to check either antenna inter element spacing for MU-MIMO is beneficial for outdoor environments or not [13-15]. In this paper, we implement (MU-MIMO) spatial channel model for different outdoor environments: urban, micro, and urban macro. Simulations are carried in MATLAB for finding various parameters like angle of arrival, user direction and the distance between user and access point (AP).

2. DEVELOPMENT OF SPATIAL CHANNEL MODEL

For simulation and design of smart antenna systems, spatial channel model is needed that reflects the measured characteristics of a mobile radio channel. There should be a specific propagation channel model which plays a role as a performance evaluator and comparator. Spatial channel model (SCM) is called geometric or ray based model which is based on stochastic modeling of scatterers. In Spatial Channel Model these environments such as, urban micro and urban macro are considered. Urban micro is also further defined into LOS and NLOS propagation.

Every scenario is being given fixed number of paths which can be modified in channel parameter configuration function and every path has further separated with twenty (20) spatially sub paths. This channel model is used to generate the matrices for desired number of links by using different parameters in the input structures, Such as channel configuration parameters, antenna-parameters and link-parameters. This SCM channel model gives output the MU-MIMO channel matrices while having the input of link-parameter, antenna-parameter and channel configuration-parameter. Channel impulse response for pre-defined number of links is given by a multi-dimensional array output.

3. ENVIRONMENTS CONSIDERED FOR MU-MIMO SCM

Four environments considered in MU-MIMO spatial channel model are as under.

3.1 Urban Environments

An urban area is described as heavily built up area within a city. Tall buildings along streets act as reflectors of radio waves and LOS path normally does not exist because of shadowing of nearby buildings. Both the base station and mobile antennas presumably use an Omni-directional antenna.

3.2 Sub-Urban Environments

A sub-urban area is described as a less built up outskirts of a city. These areas may be open farmlands and there may also be some visible mountains off in the distance. In sub-urban areas nearby buildings cause most of the multi-path with small time delays, but the large scatterers such as large buildings and mountains, generate significant multi-path components with large time delays.

3.3 Macro Cell Environments

In case of macro cell environment, scatterers surrounding MS are at same height or higher than MS, hence BS antenna is placed above scatterers.

3.4 Micro Cell Environment

In micro cell environment, BS antenna may be at same height as surrounding objects. In this case the scattering spread of received signal at BS is greater than that of macro cell environment and delay spread is less due to smaller coverage area.

4. SYNTAX FOR THE USE OF SPATIAL CHANNEL MODEL (SCM)

The full syntax for SCM is given as [CHAN, OUTCOME, DELAY CALCULATION] = Spatial_channel (CHANPARSET, ANTPARSET, LINKPARSET) whereas,

a. CHANPARSET, ANTPARSET, LINKPARSET are generated as MATLAB structures.
b. The first output CHANPARSET is a FIVE Dimensional (5D) array containing the Multi Input Multi Output Spatial Channel matrices for all links over a specified number of time samples.

c. The second output argument is a MATLAB structure and elements of this structure [OUTCOME] contains the information of delays, power of each path, angle of departure, angle of arrival of all twenty (20) spatially separated sub paths and its phases, path losses, shadow fading and time difference (delta-t), a vector which defines time sampling interval for all links.
d. The third output DELAY CALCULATION defines delays of multipath for every link. These delays are given in seconds.

5. SIMULATION OF MU-MIMO SPATIAL CHANNEL MODEL

An Uplink case is being simulated using Multi-User Multi Input Multi Output (MU-MIMO) spatial channel model (SCM) for calculating angle of arrival (AoA) at AP from user which is indicated by a broad beam in the direction of user. During each simulation run the channel undergoes fast fading according to motion of user. The channel state information (CSI) is fed back from user to AP and AP uses the schedulers to determine the direction of user where to transmit. The channel matrix co-efficient are being generated by using Spatial_channel.m which are then gives us the information of angle of arrival (AoA) of the user. To set the parameters for input structures like links, antenna and SCM model we use LINKPARSET, ANTPARSET and CHANPARSET respectively.

5.1 Spatial Channel Model (SCM) Parameter Set

This is an input structure used to define various parameters.Main fields of this structure are defined in Table 1.

NumAPElements	Number of antenna array elements used in access point (AP)
NumUserElements	Number of antenna array elements used in user station.
Environment	Scenarios which could be, urban micro or urban macro.
Sample density Value	It states the number of samples per half wavelength. Also defined as sampling interval of channel. As the Doppler analysis is required so a value greater than one '1' i.e 3 in this case is selected.
APUrban-MacroAS	Average Angle Spread (Mean) of User: 80^{o} and 150^{o} are selected which are only possible values for Urban-macro environment.
No_Paths	Total number of paths available which can be changeable according to scenario.
S_paths_per_path	Total number of sub paths available in each path which are fixed to 20 as it is only value supported by Spatial Channel Model (SCM). Table 2 is given for the offset AoD/AoA for every sub path.
CF	Central frequency (2.0 GHz) which can affects the time sampling interval and path loss.
Chan-Options	SCM channel Options which can be urban canyon, polarized, LOS or none. All of these are mutually exclusive options.

TABLE 1: SCM Parameter Set.

S-path No. (*n*)	**2° Angle Spread at AP (Urban-Macro cell)** $\Delta_{t,n,AoD}$ **(degrees)**	**5° Angle Spread at AP (Urban-Microcell)** $\Delta_{t,n,AoD}$ **(degrees)**	**35° Angle Spread at user station** $\Delta_{t,n,AoA}$ **(degrees)**
1&2	± 0.0784	± 0.3012	± 1.4985
3&4	± 0.3197	± 0.7573	± 5.1425
5&6	± 0.5013	± 1.1989	± 9.0190
7&8	± 0.8014	± 1.9147	± 12.8045
9&10	± 1.1348	± 2.6524	± 15.8562
11&12	± 1.2945	± 3.4572	± 22.8766
13&14	± 1.8541	± 4.5142	± 31.0487
15&16	± 2.3416	± 5.6942	± 39.5124
17&18	± 2.9984	± 7.4265	± 51.2375
19&20	± 4.2132	± 10.8754	± 74.5423

TABLE 2: S-path offsets of AoA and AoD.

5.2 Antenna Parameter Set (ANTPARSET)

This is also being used for defining the input antenna parameter configuration for MU-MIMO SCM. The identical behavior of antenna pattern is not necessary; it only supports the linear arrays in this case. The main fields of the antenna parameter set (ANTPARSET) are given in Table 3.

AP-G-Pattern	This is an argument which defines Access Point gain pattern. All the elements have uniform and identical gain so the value is set to ‘1’.
AP-Azimuth-angles	This input argument is a vector which contains the information of Azimuth angles for the field pattern values of Access Point (AP). Its value is set in the range of –π (-180) to +π (+180).
AP-Elem-Pos	It defines the Access Point’s position of linear antenna array in wavelength, 0.5 is selected as a uniform spacing between the elements.
User-G-Pattern	This is an argument which defines User (Mobile station) gain pattern. All the elements have uniform and identical gain so the value is set to ‘1’.
User-Elem-Pos	It defines the User’s position of linear antenna array in wavelength, 0.5 is selected as a uniform spacing between the elements.
User-Azimuth-Angles	This input argument is a vector which contains the information of Azimuth angles for the field pattern values of User. Its value is set in the range of –π (-180) to +π (+180).

TABLE 3: Antenna Parameter Set.

5.3 Link Parameter Set (LINKPARSET)

This is also being used for defining the input Link parameter configuration for MU-MIMO SCM. Every parameter is a vector of length 'N', where N is the no. of links. The main fields of the antenna parameter set (LINKPARSET) are given in Table 4.

AP-USER-Distance	This input argument is a vector which contains the information of the distance between User and AP, as the users are uniformly distributed in a circular cell so every user is 35 to 500 m away from the AP.
$\boldsymbol{\Theta_{AP}}$	It contains the angle of arrival of the signals for AP in degree.
$\boldsymbol{\Theta_{User}}$	It contains the angles of User in degree.
$\boldsymbol{V_{User}}$	Velocity of the user in meter/sec. (m/s)
User-Direct	It contains the information of direction of the User with respect to Broadside of User antenna array.
User-Height	Height of the user from the ground surface, it is set to 1.5m.
AP-Height	Height of AP from the ground surface, it is set to 32m.
User-No	It is a vector of 1….N, where N is the number of links available. It defines the number of users available in each simulation run.

TABLE 4: Link Parameter Set.

5.4 Output Argument

The output argument ''W'' is a FIVE DIMENSIONAL (5D) array and is defined as under.

Size (W) = [L M N K S]

Whereas,

L = Number of antenna elements available for Access Point (AP).

M = Number of antenna elements available for User.

N = Number of links

K = Total number of paths available for transmission.

S = Total number of time samples are generated per path.

These parameters are used for the generation of the channel co-efficient. For an ''L'' elements linear AP antenna array and ''M'' elements linear User antenna array, LxM matrix of complex amplitudes will give the information of channel co-efficient for 'K' no. of paths. The channel matrix for kth path (n = 1………k) is denoted as $W_k(t)$. Movement of User can cause fast fading in complex amplitudes so it becomes the function of time't'.

6. GENERATION OF CHANNEL MATRIX

It takes three simple steps for the generation of Channel Matrix.

i. In first step it is required to define the environment as described above.

ii. In second step, need to acquire the parameters for particular environment

iii. In third step, Generation of the channel co-efficient based on the parameters calculated in second step.

The (l,m)th component (l = 1……….L; m =1……..M) of $W_k(t)$ is given by:

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

Whereas,

P_n = Power of n^{th} path.

S = Total number of sub_paths available per path

σ_{SF} = lognormal shadow fading.

$\theta_{t,n,AoD}$ = Angle of departure for m^{th} sub_path of n^{th} path.

$\theta_{t,n,AoA}$ = Angle of arrival for m^{th} sub_path of n^{th} path.

$G_{BS}(\theta_{t,n,AoD})$ = is the BS antenna gain of each array element

$G_{MS}(\theta_{t,n,AoA})$ = is the MS antenna gain of each array element

j = it is the square root of –1

k = $2\Pi/\lambda$, where λ is the wavelength in meters

d_l = distance between AP antenna element from reference element. Distance is in meters.

d_m = distance between User antenna element from reference element. Distance is in meters.

$\phi_{n,m}$ = phase of m^{th} sub_path of the n^{th} path.

||v|| = Magnitude of User velocity vector

θ_v = Angle of User velocity vector

7. SIMULATION RESULTS

MU-MIMO Spatial channel model has been used to indicate the angle of different users operating from different locations in addition to following:

a. Angle of Arrival of signal

b. Direction of movement of User.

c. Distance between Userand AP.

7.1 Case-01

A model of a simple 1xtransmitter and 1xreceiver in urban-microenvironment using the SCM model considering design parameters defined in Table 5 is implemented in MATLAB. The resultant value of angle of arrival in Linear, Polar and MUSIC plots are shown in figure-1.

Links (number of links/users)	1
Paths (number of Paths)	1
n_max (number of channel samples generated per Link) (impulse response matrices)	10
scmpar.NumAPElements (antenna elements in the AP antenna array)	8
scmpar.NumUserElements (antenna elements in the User antenna array)	2
scmpar.ScmOptions (Switches on the line of sight option)	“LOS”
User Velocity (Velocity of mobile)	5m/sec
User Height (Height of user antenna elements)	1.5m
AP Height (Height of AP antenna elements)	32m
UserNumber (Number of Mobile Users)	1
D (inter-element spacing)	0.5m
λ (wave length)	d/2

TABLE 5: Case-01 Design Parameters.

7.2 Case-02

A model of a simple 1xtransmitter and 3x receivers in 'urban-micro' environment using the SCM model considering design parameters define in Table 6 is implemented in MATLAB. The resultant values of AoAusing both Linear and Polar plot is shown in Figure1.

Links (number of links/users)	3
Paths (number of Paths)	3
n_max **(number of channel samples generated per Link)** **(impulse response matrices)**	10

scmpar.NumAPElements (total antenna elements in the AP antenna array)	8
scmpar.NumUserElements (total antenna elements in the User antenna array)	2
scmpar.ScmOptions (Switches on the line of sight option)	“LOS”
UserVelocity (Velocity of mobile)	5m/sec
UserHeight (Height of User antenna elements)	1.5m
AP-Height (Height of AP antenna elements)	32m
User-No (Number of Mobile Users)	[1 2 3]
d (inter-element spacing)	0.5m
λ (wave length)	d/2

TABLE 6: Case-02 Design Parameters.

The resultant output values calculated in the link-parameter structure are as under:

User-AP Distance = 349.2884m, 422.5138m and 422.8360m respectively for all users.

Angles of Arrival = -40^{o}, 20^{o} and 40^{o}

User-Direction = 109.7538^{o}, 147.0231^{o} and -96.5180^{o} all users

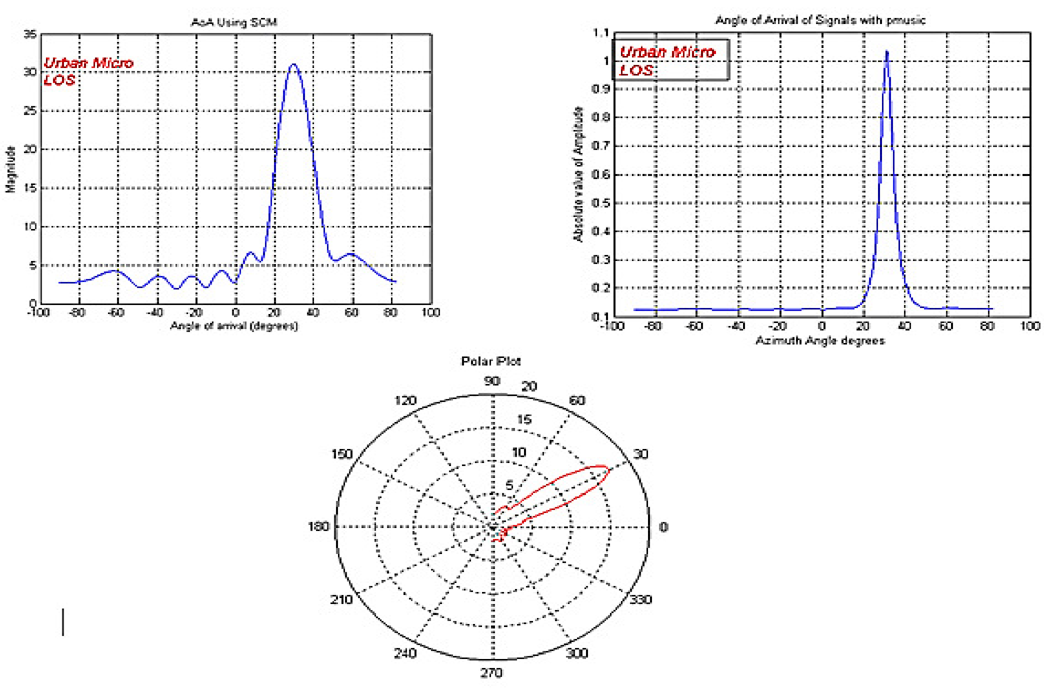

FIGURE 1: AOA of 1x Mobile User.

7.3 Case-03

A model of a simple 1x transmitter and 2x receivers in urban-macro environment using the SCM model considering design parameters defined in Tabl3 7 is implemented in MATLAB. The resultant values of Angles of Arrival using both Linear and Polar plot is shown in Figure 2 and 3.

Links (number of links/users)	2
Paths (number of Paths)	2
n_max **(number of channel samples generated per Link)** **(impulse response matrices)**	10
scmpar.NumAPElements (total antenna elements in the AP antenna array)	8
scmpar.NumUserElements (total antenna elements in the User antenna array)	2
scmpar.ScmOptions (Switches on the line of sight option)	"LOS"
User-Velocity (Velocity of mobile)	5m/sec
User-Height (Height of User antenna elements)	1.5m
AP-Height (Height of AP antenna elements)	32m
User-No (Number of Mobile Users)	[1 2]
D (inter-element spacing)	0.5m
λ (wave length)	d/2

TABLE 7: Case-03 Design Parameters.

The resultant output values calculated in the Link-parameter structure are as under:

User-APDistance=498.5580m and 374.4319m all users.

Angles of Arrival = -40° and 40°

User-Direction = 104.8044° and 113.3827° all users

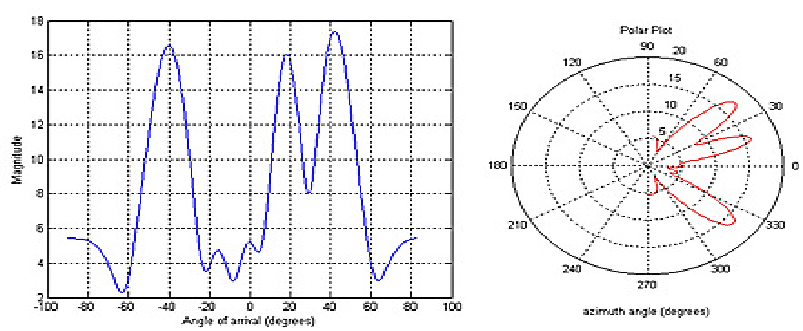

FIGURE 2: AoA of 3x Mobile Users.

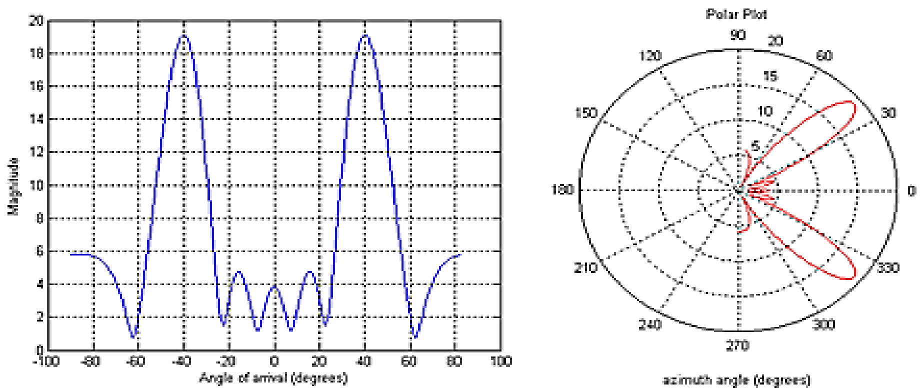

FIGURE 3: AoA's of 2x mobile Users.

Complete simulation results of simulation are given in Table 8. In this table a complete comparison of Angle of Arrival of the user, distance between User and Access Point (AP) and User direction of the movements are given for every user.

Input Parameters											Output Results								
	antenna elements		Scenarios			Option					AoAs (degrees)			MS-BS Distance (meters)			MS Direction (degrees)		
No of Users	BS	MS	S-urbanmacro	Urbanmacro	Urban-micro	LOS	None	Urbancanyon	MS velocity	Cha-nnel samples/link	1	2	3	1	2	3	1	2	3
1	8	1	-	-	Y	Y	-	-	5	10	30	-	-	174.33	-	-	-157.3	-	-
2	8	1	-	Y	-	Y	-	-	5	10	-40	40	-	498	375	-	105.00	113.0	
3	8	1	-	-	Y	Y	-	-	5	10	-40	20	40	349	422	423	109.0	147.0	-96.0

TABLE 8: Simulation Results.

8. CONCOLUSION

In this paper, a simulation environment for outdoor channel model for MU-MIMO was created in MATLAB. Three different scenarios were considered: urban, micro, and urban macro. Simulation results were obtained for these scenarios for input link, antenna, and SCM parameters. Simulation results demonstrate that user parameters – AoA, user direction and distance between user and AP - in a MU-MIMO system in an outdoor environment that may fall in any of above scenarios can be accurately extracted using the proposed adaptive algorithm.

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