A Study on 2 D and 3D Channel Models for Multiple Input Multiple Output Systems

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Abstract- Multiple Input Multiple Output Technology promises higher data rates with increased spectral efficiency. MIMO and multiple antenna technology have been adopted in IEEE 802.16e-based Mobile WiMAX systems and Long-Term Evolution Mobile wireless systems recently. The channel model is a key factor considered in the network performance evaluation. As the channel model influences network performance its characteristic (modeling) should be well defined; but as in practical case it is not possible because of its random characteristics. That is why various channel models have been proposed for different environments. This paper enlightens about the influence of correlation in channel model and the characteristics of different channel models. Different 2D and 3D Channel models have been studied and discussed.

I. Introduction

During the past decade, MIMO techniques have experienced a great interest in wireless communication systems. In MIMO the transmitter sends multiple streams by multiple transmit antennae. The transmit streams go through a matrix channel which consists of all $N_t N_r$ paths between the N_t transmit antenna at transmitter and N_r receive antenna. While MIMO offers the potential for increased signal robustness and capacity improvement when operating in rich scattered environments, developing and testing MIMO components and systems requires advanced channel model that can provide an accurate representation of realistic wireless channel conditions. A narrowband flat fading MIMO system is modeled as,

$$y=Hx+n; \qquad (1)$$

Where, y and x are receiving and transmit vectors; H and n are channel matrix and noise vectors.

II. Channel Model

Channel modeling is a fundamental step that allows performance evaluation. Channel plays most important role in communication system, as it is used to carry information from one point to another point in the form of electromagnetic signal. Generally we classify the MIMO channel model as follow (ref fig 1):

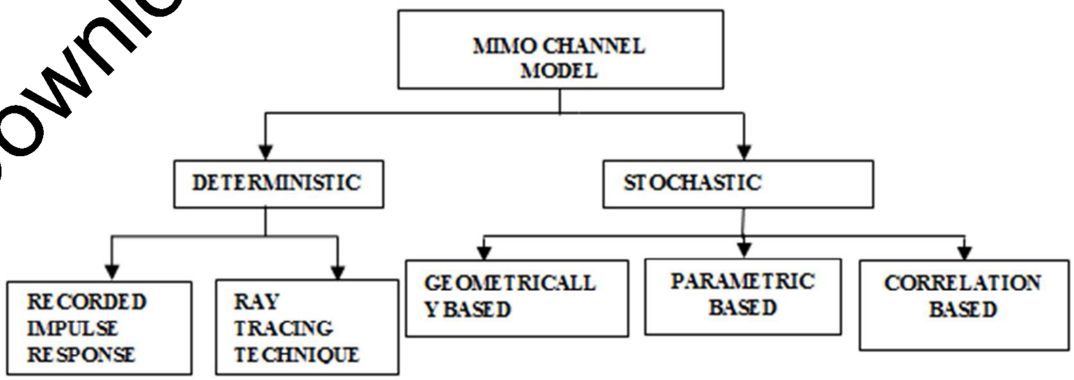

Figure 1: Classification of MIMO channel model

A. 2D channel Model

A simple channel model should describe the *spatial* and *temporal* characteristics of the received signal in order to evaluate, analyze, and design advanced wireless communication systems. However this 2D channel model fails to afford precise information about basic characteristic of the received signals. This type of channel model is mostly preferred in Terrestrial communication application where loss is considered to be negligible. When applying this type of model in satellite communication we face some issues especially when the satellite reaches the line of sight (LOS), the parameter which is preferred to perform channel model itself will act as a noise. This model is based on the assumption that the scatterers are distributed according to Von Mises density function and includes various parameter of interest such as the angular spread at the base station and mobile station, the distance between the BS and MS, mean directions of the signal arrivals, array configurations, and Doppler spread.

B. 3D channel Model

The modeling of MIMO channel needs to be accurate and practical. The well-known 3D geometrical scattering channel modeling technique describes the statistical distributions of the received multipath signals in various types of wireless communication environment. This 3D statistical distribution information of the received multipath signals can provide accurate channel impulse response. This enables wireless system designers to create wireless communication systems more efficiently in terms of some wireless physical channel parameters, such as: receiver SNR, BER performance, capacity, channel access, co-channel interference cancellation, equalization, diversity, modulation performance tradeoffs, and costs. This model can also be used to describe the *angular* and *temporal* statistical distributions of the received multipath signals as seen from both the transmitter and receiver sides, as well as, the spatial correlation functions. For MIMO channel modeling applications, a new 3D spatial correlation function has been developed. This function is based on extending the new 3D ellipsoidal model to obtain the correlation coefficients between various transmit and receive fading signals.

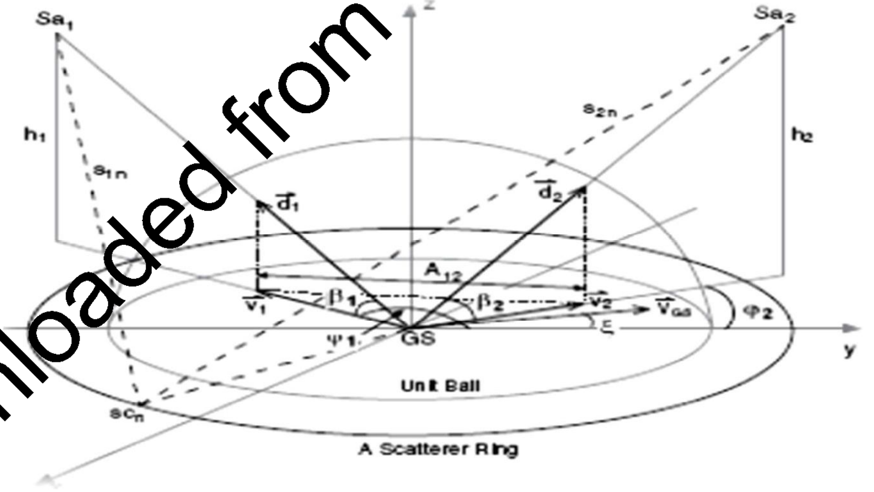

Figure 2: The 3-D channel model for the channel between satellite Antennas and ground station antennas with the projected distance A_{ij}

III. SISO and MIMO Channel Models

A. SISO Channel Model

In Narrowband transmissions, the channel with emitted wave is given by [7]

$$h(t) = 10^{-\frac{\sigma sf + PL}{10}} \exp(\vec{k} \cdot \vec{r}_{UE}(t)) \quad (2)$$

Where $\vec{r}_{UE}(t)$ denotes the position of the mobile station at time t in the coordinate system corresponding to UE and $\vec{k}$ is the wave vector. If the UE is moving with a constant velocity v_o then, $\vec{r}_{UE}(t) = \vec{v}_o t + \vec{r}_{UE,0}$ and $\vec{r}_{UE,0}$ being the position of UE at time 0 and the resulting channel is equal to,

$$h(t) = 10^{-\frac{\sigma sf + PL}{10}} \exp(\vec{k} \cdot \vec{v}_0(t)) \quad (3)$$

In wide band channel modeling, the propagation delay cannot be neglected and the channel impulse response is given by summing all the possible paths [7]

$$h(t) = 10^{-\frac{\sigma_{SF} + PL}{10}} \sum_{l=1}^{Nc} \alpha_l(t) \delta(t - n) \quad (4)$$

Where, $\alpha_l(t)$ represents additional attenuation corresponding to the l-th path.

B. MIMO Channel Models

i) Double Directional MIMO Channel

MIMO channels can be useful to distinguish between the radio channel and the propagation channel which only depends on the environment and excludes as such the effect of antenna responses. This propagation channel is referred to as double directional channel model. It does not depend on the number of antennas at the receiver or the transmitter. Actually, it is a scalar or a 2x2 matrix if dual-polarization is considered. In addition to the delays, the double directional model depends on the directions of departure and the directions of arrival. The double directional impulse function corresponding to the l^{th} multipath component (MPC) is thus given by [7] as

$$h_l(t, \tau, \Omega, \psi) = \alpha_l \delta(\tau - \tau_l) \delta(\Omega - \Omega_l) \delta(\psi - \psi_l) \exp(j \vec{k}_{l,r} \cdot \vec{r}) \quad (5)$$

Where, τ is the delay variable and Ω, ψ stand for the spatial angles respectively at the transmitter and receiver. ie.,Ω=(ϕ, θ) and Ψ , where Φ and ϕ are the departure and arrival azimuth angles whereas θ and υ are the departure and arrival elevation angles. The double directional impulse response is the sum of the Nc multi path components and is given by [7] as,

$$h_l(t, \tau, \Omega, \psi) = \sum_{l=1}^{Nc} \alpha_l \delta(\tau - \tau_l) \delta(\Omega - \Omega_l) \delta(\psi - \psi_l) \exp(j \vec{k}_{l,r} \cdot \vec{r}) \quad (6)$$

If polarization is taken into account and thus $h_l(t, \tau, \Omega, \psi)$ are 2x2 matrices which describe the coupling between horizontal and vertical polarizations [8].

$$h_l(t,\tau,\Omega,\psi) = \begin{bmatrix} h^{VV}(t,\tau,\Omega,\psi) & h^{VH}(t,\tau,\Omega,\psi) \\ h^{HV}(t,\tau,\Omega,\psi) & h^{HH}(t,\tau,\Omega,\psi) \end{bmatrix} \quad (7)$$

The elements $h^{VV}(t,\tau,\Omega,\Psi)$ and $h^{VH}(t,\tau,\Omega,\Psi)$ represent a scalar what would be obtained by a receiver in the vertical and horizontal directions, if the transmitted wave is vertically polarized.

ii) Radio channel

The radio channel is obtained by incorporating the effect of the antennas. This can be modeled at the reception or the transmission side as a coherent sum over all directions. Let N_T and N_R denote the number of the transmitting and receiving antennas. The radio channel is a N_R x N_T matrix given by:

$$H(t,\tau) = \int \vec{g}_r(\psi)^T h(t,\tau,\Omega,\Psi)\, \vec{g}_T(\Omega)\, \vec{a}_R(\Psi)(\vec{a}_T(\Omega))^T\, d\Omega d\Psi \qquad (8)$$

There is a complex SISO channel impulse response of length L+1 between each transmitting antenna m and each receive antenna n of a MIMO system.

$$h_{n,m}(t) = \sum_{\tau=0}^{.l} h_{n,m,\tau}(t) \qquad (9)$$

The linear time invariant MIMO channel is represented by the MIMO channel matrix of dimension N_R X N_T .

$$H(t) = \begin{bmatrix} h_{11}(t) & .... & h_{1,NT}(t) \\ .... & ...... & ..... \\ h_{n_r,1}(t) & ...... & h_{N_R,N_T}(t) \end{bmatrix} \qquad (10)$$

With $h_{n,m}(t) = \mathrm{Re}\{h_{n,m}(t)\} + j\,\mathrm{Im}\{h_{n,m}(t)\}$ (11)

In downlink case, the satellite antennas are referred as transmit antennas and the ground station antennas are referred as receive antennas. Both LOS and multi path components are considered here. Consider n_t transmit antennas and n_r receive antennas which belongs to one ground station. The 3d channel model for the channel between satellite antennas and ground station antennas with the projected distance Aij is shown in fig. 2.

A. Line of Sight (LOS) Component

The LOS components of the channel coefficient between the kth transmit antenna and the pth receive antenna c_{pk} (LOS) (t) is given below. The distance between the antennas is

$$d_{pk} = \sqrt{h^2{}_k + \left(\frac{h_k}{\tan \beta_k}\right)^2 + \rho_p{}^2 - 2\frac{h_k}{\tan \beta_k}\rho_p \cos\left(\varphi_k - \theta_p\right)}$$

$$= \frac{h_k}{\sin \beta_k} - \rho_p \cos \beta_k \cos(\varphi_k - \theta_p) \qquad (12)$$

Where the approximation is based on the fact that the distance from the transmit antenna to the center of the scatter ring is far greater than the distance from the receive antennas to the center of the scatter ring. The corresponding channel matrix entry is,

$$c_{pk}{}^{(LOS)}(t) = e^{j2\Pi\left[f_D t \cos(\xi - \varphi_k)\cos\beta_k + f_d\right]} \qquad (13)$$

The received signal at each ground station antenna has the same unitary power strength and only differs in phase caused by different length of propagation path,[10] because the relative antennas are close to each other, and the attenuation of the signal from different satellites can be normalized into their transmit powers.

B. Multipath Signal Component

The multi path component of the channel coefficient between the kth transmit antenna and the p th receive antenna is [10],

$$c_{pk}(t) = \frac{1}{\sqrt{N}} e^{j 2 \Pi f_{d_k} t} \sum_{n=1}^{N} e^{j[2 \Pi f_d t \cos(\xi - \alpha_n) + \phi_n + \phi^{(sa)}_{kn} + \phi^{gs}_{pn}} \tag{14}$$

Where, N is the number of scatters, and

$$\phi^{sa}_{kn} = -2 \pi s_{kn} / \lambda \tag{15}$$

Where s_{kn} is the distance between pth receive antenna and nth scattered

$$\phi^{gs}_{pm} = -2\pi L_{pn} / \lambda \tag{16}$$

L_{pn} is the distance between pth receive antenna and nth scattered.

C. MIMO Channel Capacity

Channel capacity is a significant parameter for the characterization of a MIMO system. The standard formula for the Shannon capacity expressed in bits per second and hertz can be written as [11]

$$C = \log_2 \left(\det \left[I_{N_R} + \frac{P_T}{N_T \sigma^2_n} . H_F H_F^H \right] \right) \tag{17}$$

Where I am the unit matrix, P is the overall transmit power and σ^2_n is the noise power. For frequency selective MIMO channels, the channel capacity can be obtained by integrating over the non-frequency selective sub-channels. For the discrete case, capacity estimation can be determined by averaging the non-frequency selective sub-channels. The resulting channel capacity is given as

$$C = \frac{1}{N_F} \sum_{L=0}^{N_F - 1} \log_2 \left(\det \left[I_{N_R} + \frac{P_T}{N_T \sigma^2_n} . H_F(l) H_F(l)^H \right] \right) \tag{18}$$

For the comparison of different MIMO channels, the power of the single channels has to be normalized.

$$\sum_{\tau=0}^{L} E\left\{ \left| h_{n,m,\tau}(t) \right|^2 \right\} = 1 \to \sum_{l=0}^{N_F - 1} E\left\{ \left| H_{F_{N,M}}(l)^2 \right| \right\} = N_F \tag{19}$$

However, the estimated channel capacity is calculated for every single MIMO channel, which does not necessarily fulfill condition (eqn) when the system has been normalized with equation (eqn)[11]. This causes additional noise for each MIMO channel, resulting in different signal-to-noise-ratios. It is not possible to fulfill both normalization conditions at the same time, therefore the system can either be normalized for a comparison based on the same SNR (eqn) or for a comparison based on the same path loss (eqn).

IV. Performance Evaluation

The following figure depicts the BER performance of both 3D and 2D Channel models. It is evident that the BER performance of 3Dchannel model is better than the conventional 2D channel model. In this simulation Raleigh and Rician channel environments have been utilized. Among the different 3D channel models, the geometry channel model provides good performance to enhance the capacity by taking into account of angular spread information [6].

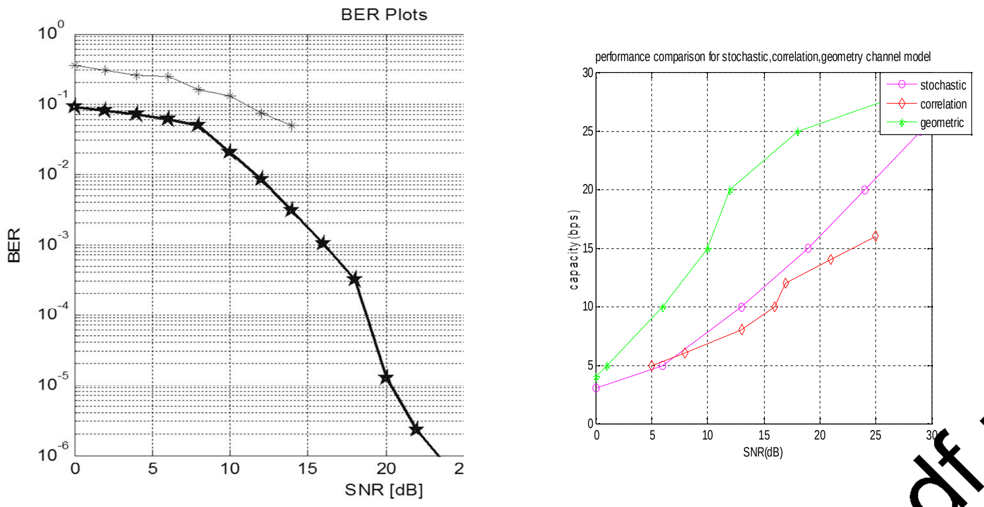

Figure 3: Comparison between 3D and 2D Channel Model

V. Conclusion

In MIMO system, when transmit antennas are at different location (direction), the rate gain is considerably good even without rich scattering in 3D channel model. Since the 3D channel model includes most significant parameters (projected distance) required to perform analytical correlation, the performance of the communication systems will be improved if the three dimensional channel model is adopted.

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