Modeling and Evaluation on Multi Antenna Characteristics of Mobile Terminal

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***Abstract*—An evaluation model with respect to the effect of antenna characteristics on the performance of multiple-input multiple-output (MIMO) systems is proposed in this paper. The influence of antenna characteristics in terms of antenna gain imbalance (AGI), envelope correlation coefficient (ECC) and isolation can be easily obtained. Since the elevation components of the angle of arrival (AOA) and angle of departure (AOD) of the electromagnetic rays typically cannot be neglected in real propagation environment, a three-dimensional (3D) channel model is presented. The 3D channel model developed from the WINNER II 2D channel model by adding parameters related to elevation angles in addition to azimuth angles. Lastly, simulation result with respect to the influence of AGI and isolation on system throughput is illustrated.**

***Index Terms*—antenna characteristics, 3D channel model, AGI, isolation, throughput.**

I. INTRODUCTION

It is widely known that MIMO technology significantly improves the spectral efficiency by utilizing multi-antennas both at the transmitter and receiver [1]. Thus MIMO becomes a key technology in wireless communication systems and has been investigated extensively. The performance of MIMO system is mainly dependent on the characteristics of antenna and real propagation environment. The spatial characteristics of radio signals transmitted from antennas can be described and analyzed through appropriate channel model. There are two common channel models, including the spatial channel model (SCM) proposed by 3GPP [2] and the WINNER II channel model proposed by the WINNER project [3], both of which are two-dimensional, only assuming that rays transmitted in the horizontal plane, without considering the vertical dimension. In order to fully investigate the channel characteristics, it is important to exploit a more accurate 3D channel model. Recently, extensive research on this subject has been carried out by institute and standardization organizations, and much more different modeling approach was proposed [4]. Base on the ITU 2D channel model, a 3D channel model presented in [5] was proposed through adding the distance-dependent elevation angles. In [6], the common MIMO channel models were classified. It mainly describes the geometry-based stochastic channel model (GSCM) and explains the impact of the propagation environment, such as impact of the distribution of scatters.

In addition to channel model, the performance of antenna is another important factor on the MIMO system capacity. To some extent, the characteristics of antenna also affect channel characteristics, for instance, the correlation among antenna elements usually leads to channel fading correlation. The correlation of the terminal antennas was studied in [7], and also its impact on MIMO channel capacity was investigated. The correlation of antennas could deteriorate the performance of MIMO systems. Therefore in the procedure of designing an antenna array for mobile terminals, the envelope correlation coefficient of antennas should be reduced as much as possible. The authors in [8] proposed a designing method for mobile terminal antennas which can reduce the ECC effectively. The other parameters of antenna, for instance, antenna gain imbalance, antenna isolation, may also have significant effect on the performance of MIMO systems. Therefore proposing an evaluation model or investigating the effect of antenna characteristics on MIMO performance is necessary.

In this paper, we present the evaluation model of antenna characteristics on MIMO performance, simply taking antenna parameters as the input variables and MIMO channel capacity as the output variables. The rest of this paper is arranged as follows, section II describes the 3D channel model and presents the evaluation method through channel capacity. Section III illustrates the simulation results of the effect of AGI on system throughput. Section IV is the conclusion.

II. PROPOSED MODEL

A. 3D Channel Model

Based on the previous WINNER II channel model, the 3D channel model could be derived from adding elevation component of AOA and AOD of radio rays. As shown in Fig.1, the generation procedure of elevation and azimuth is the same, as was already proposed in Step7b of section 4 in [3]. Vertical angle related large scale parameters, such as the distribution of vertical angle extension, are inferred by actual test statistical data. This method is the same as the generation procedure of azimuth angle extension. It should be pointed out that the horizontal AOA and AOD are randomly coupled in 2D channel model. However, in 3D channel model, due to the azimuth and elevation are generally not independent each other. The proposed method is divided into the following three steps.

Firstly, coupling randomly the horizontal departure angle $\varphi_{n,m}$ with the vertical departure angle $\theta_{n,m}$, then the 3D departure angles $(\varphi_{n,m}, \theta_{n,m})$ is obtained. Secondly, coupling randomly the horizontal arrival angle $\phi_{n,m}$ with the vertical arrival angle $\psi_{n,m}$, also the 3D arrival angle $(\phi_{n,m}, \psi_{n,m})$ is obtained. Finally, the 3D departure angle $(\varphi_{n,m}, \theta_{n,m})$ and the arrival angle $(\phi_{n,m}, \psi_{n,m})$ should be coupled randomly.

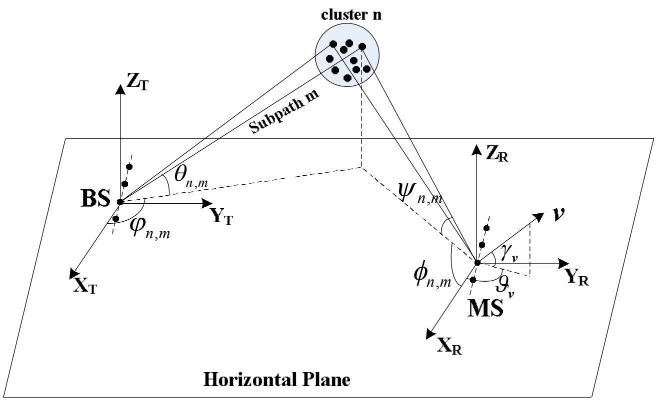

Fig.1 3D Channel Model

When obtaining the large-scale parameters associated with the vertical angle and the cross-correlations among these parameters, then the 3D channel coefficients can be quickly obtained. In this channel model, the generate procedure of channel coefficients is the same as the WINNER II channel model. Assuming that the propagation environment is NLOS case, then the channel coefficient between the s^{th} transmitting antenna and the u^{th} receiving antenna can be expressed as,

$$
\begin{aligned}
h_{u,s,n}(t) = \sqrt{P_n} \sum_{m=1}^{M} & \begin{bmatrix} E_{rx,u,v}(\phi_{n,m}, \psi_{n,m}) \\ E_{rx,u,h}(\phi_{n,m}, \psi_{n,m}) \end{bmatrix}^{T} \\
& \begin{bmatrix} exp(j\Phi_{n,m}^{vv}) & \sqrt{\chi_{n,m}}\, exp(j\Phi_{n,m}^{vh}) \\ \sqrt{\chi_{n,m}}\, exp(j\Phi_{n,m}^{hv}) & exp(j\Phi_{n,m}^{hh}) \end{bmatrix} \\
& \begin{bmatrix} E_{tx,s,v}(\varphi_{n,m}, \theta_{n,m}) \\ E_{tx,s,h}(\varphi_{n,m}, \theta_{n,m}) \end{bmatrix} \bullet exp(j2\pi\lambda_0^{-1} \boldsymbol{r}_s \bullet \boldsymbol{e}_{n,m}^{AOD}) \\
& \bullet exp(j2\pi\lambda_0^{-1} \boldsymbol{r}_u \bullet \boldsymbol{e}_{n,m}^{AOA}) \bullet exp(j2\pi f_{n,m} t)
\end{aligned}
\tag{1}
$$

Where P_n denotes the average power of the ray cluster n. M is the number of rays per cluster. $E_{rx,u,v}(\phi_{n,m}, \psi_{n,m})$ and $E_{rx,u,h}(\phi_{n,m}, \psi_{n,m})$ are field patterns of vertical and horizontal polarizations for the u^{th} receiving antenna element respectively. $\phi_{n,m}$, $\psi_{n,m}$ are azimuth angle and elevation angle of the arrival rays respectively. $\Phi_{n,m}^{vv}$, $\Phi_{n,m}^{vh}$, $\Phi_{n,m}^{hv}$ and $\Phi_{n,m}^{hh}$ are the phase shift of polarizations components respectively. $\chi_{n,m}$ is the cross polarization power ratios in linear scale. $E_{tx,s,v}(\varphi_{n,m}, \theta_{n,m})$ and $E_{tx,s,h}(\varphi_{n,m}, \theta_{n,m})$ are field patterns of the s^{th} transmitting antenna element for vertical and horizontal polarizations respectively. $\varphi_{n,m}$ $\theta_{n,m}$ are the azimuth angle and the elevation angle of the departure rays. λ_0 is wavelength. r_s and r_u are the s^{th} transmitting antenna position vector and the u^{th} receiving antenna position vector respectively. $e_{n,m}^{AOD}$ is the departure angle unit vector, and $e_{n,m}^{AOA}$ is the arrival angle unit vector. $f_{n,m}$ denotes Doppler shift that can be expressed as,

$$
f_{n,m} = \frac{\begin{pmatrix} |\boldsymbol{v}| \cos\psi_{n,m} \cos\phi_{n,m} \cos\gamma_v \cos\vartheta_v + \\ |\boldsymbol{v}| \cos\psi_{n,m} \sin\phi_{n,m} \cos\gamma_v \sin\vartheta_v + \\ |\boldsymbol{v}| \sin\psi_{n,m} \sin\gamma_v \end{pmatrix}}{\lambda_0} \tag{2}
$$

Where $|v|$ is the velocity of mobile station, γ_v, ϑ_v denote the travelling direction in vertical and horizontal plane respectively. Assuming that the mobile station only moves in the horizontal plane, that means $\gamma_v = 0$. Then the expression in (2) can be rewritten as,

$$
f_{n,m} = \frac{|\boldsymbol{v}| \cos\psi_{n,m} \cos(\phi_{n,m} - \vartheta_v)}{\lambda_0} \tag{3}
$$

B. Channel Capacity

Considering the point-to-point MIMO system, in which the transmitter was employed by N_t transmitting antennas and the receiver was employed by N_r receiving antennas. It is assumed that the transmitted signal experiences the flat-fading channel, and the input-output relationship can be described as,

$$
\mathbf{y} = \mathbf{Hx} + \mathbf{n} \tag{4}
$$

Where y is the received signal vector, x is the transmitted signal vector, n is the noise vector, and the channel can be represented by the complex matrix-H. Assuming that channel state information has not been acquired at the transmitter, which means that the transmitting power is divided on the transmitting antennas equally, and the channel capacity can be expressed as [1],

$$
\mathrm{C} = \log_2 \left[\det \left(\mathbf{I}_{N_r} + \frac{\rho}{N_t} \mathbf{H}\mathbf{H}^{\mathrm{H}} \right) \right] \tag{5}
$$

Where ρ is the average signal noise power ratio (SNR), I_{N_r} is an $N_r \times N_r$ identity matrix. As shown in formula (5), the relationship between system channel capacity and antenna parameters can be demonstrated through the channel coefficients. The antenna parameters, for instance, antenna gain imbalance and antenna isolation, affect the MIMO system capacity by altering field pattern of the antennas. In order to analyze the effect of the scatter-parameters on MIMO system capacity, the channel matrix H in formula (5) can be modified as follows,

$$\mathbf{H} = \mathbf{\Lambda}\mathbf{H}_{eff} \tag{6}$$

Where H_{eff} is the actual channel matrix, the element h_{ij} is the channel coefficient between the transmitting antenna j and the receiving antenna i, which can be calculated by the formula (1). Λ is a diagonal matrix that can be expressed as,

$$\mathbf{\Lambda} = diag\left(\eta_{tol,1}, \eta_{tol,2}, \cdots, \eta_{tol,N_r}\right) \tag{7}$$

The elements of the diagonal matrix are the total efficiency of each receiving antenna. The total antenna efficiency of the k^{th} receiving antenna can be calculated by the following expression [9],

$$\eta_{tol,k} = \eta_{r,k}\left(1 - \sum_{l=1}^{N_r} \left|S_{lk}\right|^2\right), \forall k \in \{1, 2, \cdots, N_t\} \tag{8}$$

Where $\eta_{r,k}$ is the radiation efficiency of the k^{th} antenna. Since antenna correlation usually affects the characteristics of spatial channel, the impact of antenna correlation on MIMO system capacity can be investigated from the perspective of channel spatial correlation properties. The spatial correlation of the channel can be completely described by a correlation matrix of the spatial channel that can be calculated from the following procedure.

At first, assuming the channel matrix $\widetilde{H}$ is generated by the 3D channel model and can be expressed as,

$$\begin{aligned}\widetilde{\mathbf{H}} &= (\mathbf{H}_1, \mathbf{H}_2, \ldots, \mathbf{H}_{N_t}) \\ &= \begin{pmatrix} h_{11}(t) & h_{12}(t) & \cdots & h_{1N_t}(t) \\ h_{21}(t) & h_{22}(t) & \cdots & h_{2N_t}(t) \\ \vdots & \vdots & \cdots & \vdots \\ h_{N_r1}(t) & h_{N_r2}(t) & \cdots & h_{N_rN_t}(t) \end{pmatrix}\end{aligned} \tag{9}$$

Where $H_i (i = 1,2,\cdots,N_t)$ is a $N_r \times 1$ column vector, and $vec(\widetilde{H})$ is defined as,

$$vec\left(\widetilde{\mathbf{H}}\right) = \left(\mathbf{H}_1^T, \mathbf{H}_2^T, \ldots, \mathbf{H}_{N_t}^T\right)^T \tag{10}$$

Then the spatial channel correlation matrix R can be computed through $vec(\widetilde{H})$ by the following expression,

$$\mathbf{R} = cov\left(vec\left(\widetilde{\mathbf{H}}\right)\right) = E\left\{vec\left(\widetilde{\mathbf{H}}\right) vec^H\left(\widetilde{\mathbf{H}}\right)\right\} \tag{11}$$

Where $vec^H(\cdot)$ denotes conjugate transpose of $vec(\cdot)$. Assuming that $h_{mp}(t)$ and $h_{nq}(t)$ are elements of $\widetilde{H}$. $h_{mp}(t)$ denotes the channel coefficient of the p^{th} transmitting antenna with the m^{th} receiving antenna, and $h_{nq}(t)$denotes the channel coefficient of the q^{th} transmitting antenna with the n^{th} receiving antenna. Then the cross correlation between $h_{mp}(t)$ and $h_{nq}(t)$ can be expressed as,

$$r_{mp,nq}(t) = E\left\{h_{mp}(t) h_{nq}^*(t)\right\} \tag{12}$$

Where $r_{mp,nq}(t)$ is the element of R. According to formula (11)-(12), the spatial channel correlation matrix R can be obtained. Therefore the real channel matrix that takes the antenna correlation into account can be expressed as,

$$\mathbf{H}_{eff} = vec^{-1}\left(\mathbf{R}^{\frac{1}{2}} vec\left(\mathbf{H}_w\right)\right) \tag{13}$$

Where $H_w \in C^{N_rN_t\times 1}$, and its elements are independent identically distributed with complex gaussian distribution. $vec^{-1}(\cdot)$ denotes inverse operation of $vec(\cdot)$. When H_{eff} is obtained, then the modified channel matrix H can be computed according to formula (6). Substituting H into formula (5), then the effect of antenna characteristics on the performance of MIMO systems can be analyzed.

III. SIMULATION RESULTS

In this section, the proposed evaluation model was verified through a link-level simulation. The propagation scenario was set to urban macro-cell (UMa). Two antenna elements were utilized in the base station (BS) and mobile station (MS) respectively, and the electromagnetic wave signal was transmitted from the BS to the MS. Type of dipole antenna was adopted at the transmitter. In the simulation, system bandwidth was set to 10MHz, and 16QAM was used as the signal modulation scheme. We analyzed thirteen groups of receiving antenna corresponding to different AGI.

Fig.2 illustrates the effect of AGI on system throughput. AGI herein refers to increase the amplitude of field pattern for one of the receiving antennas, and the second one has not change. As shown in Fig.2, 1dB, 2dB, 3dB, 4dB, 5dB and 6dB mean that the amplitude of field pattern for one antenna element increases gradually. Similarly, -1dB, -2dB, -3dB, -4dB, -5dB and -6dB mean that the amplitude of field pattern decreases in the same way. The abscissa in the figure is the reference signal receiving power (RSRP). When decreasing the amplitude of field pattern for one antenna element, and another one has not change, the curves continuously shift to the right. That is to say, the system throughput drops as the amplitude of field pattern decreases, and as the AGI increases. When increasing the amplitude of field pattern, the curves asymptotically shift to the left. It is because that the system throughput increases as the antenna amplitude increases, however, the increasing of AGI leads to the system throughput decreases at the same time, therefore the curves gradually converge.

Fig.3 illustrates the effect of antenna isolation on system throughput. The antenna S-parameters S_{21} was used in the simulation. There are three groups of receiving antenna with different isolation, and the value of antenna isolation is -3dB, -9.4dB, and -14.9dB respectively. As shown in Fig.3, the curves shift to the left with the isolation increases. It is because that the correlation between the antenna elements decreases due to the increasing of antenna isolation, therefore, the performance of MIMO system is improved.

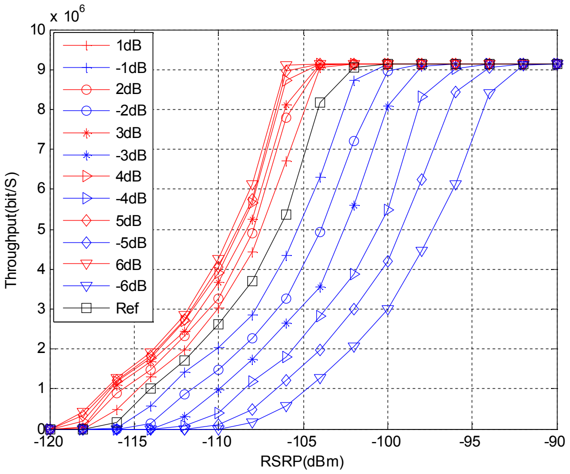

Fig.2 Effect of AGI on system throughput with RSRP

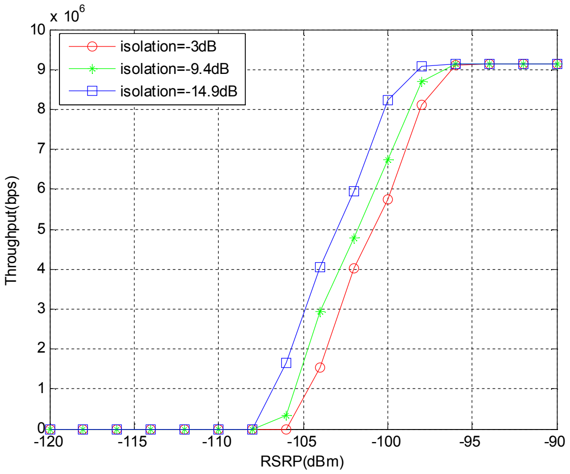

Fig.3 Effect of antenna isolation on system throughput with RSRP

IV. CONCLUSION

In this paper, we analyzed the relationship between antenna parameters and MIMO capacity, and then derived a closed-form expression. Consequently, the corresponding evaluation model was established. Based on the WINNER II 2D channel model, a 3D channel model was presented by adding the elevation angles, therefore the characteristic of spatial channel can be described more exactly. The evaluation approach is simplicity, and practically, it supports the designing of antennas on LTE MIMO mobile devices.

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