Research Article

Analysis of MIMO Diversity Improvement Using Circular Polarized Antenna

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MIMO (Multiple Input Multiple Output) technique is one of the important means to enhance the system capacity. Diversity gain could be acquired by using traditional $\pm 45^\circ$ dual-polarized antenna, but in the scenario where multipath scattering is not strong, power-unbalance in two polarizations caused by polarization mismatching between transmitting and receiving antennas will reduce diversity gain. This problem can be effectively solved by using circular polarized antennas. In this paper, through theory analysis and test, the improvement of MIMO diversity gain using circular polarization antenna is analyzed.

1. Introduction

MIMO technique uses multitransmitting and multireceiving antennas to combat channel fading and increase capacity and spectrum efficiency. MIMO system require low correlation between each pair of transmitting and receiving antenna elements, in order to achieve a good independent channel fading. There are two methods to dispose multi-antenna. The first one is space isolation. It is through the enough space distance to ensure non-correlation between each transmit/receive signals. The other one is polarization isolation. It is through electromagnetic wave orthogonal polarization to ensure non-correlation between each transmit/receive signals. Because the distance requirement is high for space isolation, commonly more than 10 wavelengths, the cost and difficulty of space isolation antenna deployment is higher. So polarization isolation proves to be an effective and economical method to deploy multiantennas.

For polarization isolation, signals go through independent fading in orthogonal polarization direction and hence ensure noncorrelation of two signals. In traditional 2×2 MIMO system, two signals are transmitted by dual-polarized base station antenna in $\pm 45^\circ$ polarization direction and received by terminal in vertical and horizontal polarization directions. During propagation, polarization direction of electromagnetic wave deflects because of reflection, refraction, and scattering. When signals arrive to the receiver, part

of signals in $\pm 45^\circ$ polarization direction could be coupled to vertical direction and the other part could be coupled to horizontal direction. Because of independent fading in vertical and horizontal direction, polarization diversity gain can be gained. When the power of the signal in vertical direction is equal to that in horizontal direction, maximum diversity gain can be gained [1, 2].

In some typical scenes, such as spacious indoor, large public square, and urban city area, electromagnetic wave polarization deflection is not obvious because of less obstacles. When signals arrive to the receiver, power of signals in $\pm 45^\circ$ polarization direction coupled to vertical and horizontal direction is not equal because electromagnetic wave polarization still keeps intrinsic polarization status in large part. System diversity gain is limited because of influence of minor signal. There is even no diversity gain if two received signals power has great difference [3].

Using circular polarized antenna in transmitter can solve this problem effectively. Two signals are transmitted through left-hand circular polarization and right-hand circular polarization wave (as shown in Figure 1). The noncorrelation between two signals is ensured by isolation of two circumgyrate directions.

The rest of this paper is organized as follows: MIMO system principle and channel capacity are introduced in Section 2. Section 3 gives the principle analysis of MIMO diversity improvement using circular polarized antenna

(Figure 9). The result of MIMO channel capacity improvement is given in Section 5 and conclusions are given in Section 6.

2. MIMO System and Channel Capacity

2.1. MIMO System. Each channel between a pair of transmitting and receiving antennas is considered to be a MIMO subchannel. Assume that there are n_R transmitting antennas and n_T receiving antennas. Hence there are $n_R \times n_T$ channel matrix which we name as channel matrix H :

$$H = \begin{bmatrix} h_{11} & h_{12} & \cdots & h_{1n_T} \\ h_{21} & h_{22} & \cdots & h_{2n_T} \\ \vdots & \vdots & \ddots & \vdots \\ h_{n_R1} & h_{n_R2} & \cdots & h_{n_Rn_T} \end{bmatrix}. \quad (1)$$

The element of H is a subchannel between one pair of transmitting and receiving antennas. When the distance of each pair is large enough, every signal between transmitting and receiving antennas is independent. Then, the rank of the matrix H will be large, even full when under ideal circumstances. Vice versa, when near, the rank will be small, because the signals are correlated to each other. From the above, we can conclude that the channel capacity of MIMO is highly related with the matrix H . If the channel condition of the transmitting point is unknown, but the index of the matrix and the overall transmission power P are fixed, the overall power can be designated to every transmission antenna averagely. Then, the capacity can be calculated as

$$C = \log_2 \det \left(I_{n_R} + \frac{P}{n_T \cdot N_0} HH^H \right). \quad (2)$$

2.2. MIMO Channel Capacity. The model of the channel capacity can be considered as a complex baseband linear system. It has been assumed that there are n_T transmission antennas, n_R receiving antennas, and the overall transmission power P . Then, the power of each antenna will be P/n_T and the receiving power of receiving antenna will be equal to the overall transmission power. If the channel is interfered by AWGN, and the noise power of each antenna is N_0 , then SNR of every receiving antenna will be

$$\varsigma = \frac{P}{n_T \cdot N_0}. \quad (3)$$

When the bandwidth of transmitting signal is narrow enough, the frequency response of the channel is flat, and the channel matrix is considered to be matrix H , whose element h_{ji} shows the channel fading index between transmission antenna i and receiving antenna j ; the capacity can be shown as

$$C = \log_2 \left[\det \left(I_{\min} + \frac{\varsigma}{n_T} Q \right) \right], \quad (4)$$

where “min” is the smaller of n_T and n_R and matrix Q is shown as

$$Q = \begin{cases} H^H H, & n_R > n_T, \\ H H^H, & n_R < n_T. \end{cases} \quad (5)$$

2.2.1. The MIMO System of “all 1” Channel Matrix [2]. If the correlation detection technology is used at receiving point, and then all the signals of each antenna will have the same frequency and phase. As a result, all signals which come from n_T transmitting antennas can be considered the same.

Considering $s_i = s$ and $i = 1, 2, \dots, n_T$, the signal coming from antenna j can be shown as $r_j = n_T s_i = n_T s$, $j = 1, 2, \dots, n_R$, the power of the dedicated antenna is shown as $n_T^2 (P/n_T) = n_T P$, and SNR of each receiving antenna is $n_T \varsigma$; the overall SNR of receiving point is shown as $n_T n_R \varsigma$.

This multiantenna system can be seen as a sole-antenna system which has $n_T n_R$ diversity gains. The capacity is shown as

$$C = \log_2 (1 + n_T n_R \varsigma). \quad (6)$$

If the receiving point adopts noncoherent detection technology, the SNR of each receiving antenna will still be ς , and the overall SNR will be $n_R \varsigma$. This sole-antenna system has an n_R gain compared to the typical sole-antenna system. The capacity is shown as

$$C = \log_2 (1 + n_R \varsigma). \quad (7)$$

2.2.2. The MIMO System of Orthogonal Transmitting Channel [2]. The MIMO system of orthogonal transmitting channel is a subsystem whose subchannel is orthogonal. Assuming the amount of antennas of transmitting and receiving point is the same ($n_T = n_R = L$), the matrix can be shown as $H = \sqrt{L} I_L$ (I_L is the unit matrix of $L \times L$). From (2), we can get the capacity as

$$\begin{aligned} C &= \log_2 \left[\det \left(I_L + \frac{\varsigma}{L} HH^H \right) \right] = \log_2 \left[\det \left(I_L + \frac{\varsigma}{L} L I_L \right) \right] \\ &= \log_2 [\det (1 + \varsigma)] = \log_2 (1 + \varsigma)^L = L \log_2 (1 + \varsigma). \end{aligned} \quad (8)$$

The channel capacity gets a gain of L compared to the old system due to the coupling of subchannels of each antenna.

If the channel index is changed randomly, the capacity of MIMO channel will be a random variable. The average capacity is

$$C = E \left\{ \log_2 \left[\det \left(I_r + \frac{\varsigma}{n_T} Q \right) \right] \right\}, \quad (9)$$

where r is the rank of matrix H , $r = \min(n_T, n_R)$.

3. Analysis of MIMO Diversity Improvement Using Circular Polarized Antenna

3.1. Polarization Matching. Polarization is an important character of antennas. It gives the changing orbit of electric vector and time in certain conditions. Normally, the wave along z can be shown in x -axis and y -axis as

$$\begin{aligned} E_x &= E_{xm} \cos(\omega t - kz + \varphi_x), \\ E_y &= E_{ym} \cos(\omega t - kz + \varphi_y). \end{aligned} \quad (10)$$

From the relationship of E_x 's and E_y 's amplitude and phase, we can conclude that the electromagnetic wave has three polarizations: linear polarization, circular polarization, and elliptical polarization. If $z = 0$,

$$\begin{aligned} E_x &= E_{xm} \cos(\omega t - \varphi_x), \\ E_y &= E_{ym} \cos(\omega t - \varphi_y). \end{aligned} \quad (11)$$

When $\varphi_y - \varphi_x = 0$ or $\varphi_y - \varphi_x = \pm\pi$,

$$\begin{aligned} E_x &= E_{xm} \cos \omega t, \\ E_y &= E_{ym} \cos \omega t. \end{aligned} \quad (12)$$

Electromagnetic amplitude $E = \sqrt{E_x^2 + E_y^2} = \sqrt{E_{xm}^2 + E_{ym}^2} \cos \omega t$ and phase

$$\alpha = \arctg\left(\frac{E_y}{E_x}\right) = \begin{cases} \arctg\left(\frac{E_{ym}}{E_{xm}}\right), & (\phi_x - \phi_y = 0), \\ -\arctg\left(\frac{E_{ym}}{E_{xm}}\right), & (\phi_x - \phi_y = \pm\pi). \end{cases} \quad (13)$$

As shown above, the resultant wave changes along with time, but the orbit is in the line which has a degree α over x -axis. It is linear polarization wave.

When $\varphi_y - \varphi_x = \mp(\pi/2)$, $E_{xm} = E_{ym} = E_m$,

$$E_y = E_m \cos\left(\omega t \mp \frac{\pi}{2}\right) = \pm E_m \sin(\omega t). \quad (14)$$

Electromagnetic amplitude $E = \sqrt{E_x^2 + E_y^2} = E_m$. The resultant wave is not changed with time, but direction changed with time. The vector of electronic field is rotating with angular velocity ω . It is circular polarization wave.

When $\varphi_y - \varphi_x = \theta$, $E_{xm} \neq E_{ym}$,

$$\begin{aligned} E_x &= E_{xm} \cos \omega t, \\ E_y &= E_{ym} (\cos \omega t + \theta). \end{aligned} \quad (15)$$

When t is subtracted,

$$\frac{E_x^2}{E_{xm}^2} + \frac{E_y^2}{E_{ym}^2} - \frac{2E_x E_y}{E_{xm} E_{ym}} \cos \theta = \sin^2 \theta. \quad (16)$$

The degree of the oval's axis over x -axis is

$$\tan 2\theta = \frac{2E_{xm} E_{ym} \cos \varphi}{E_{xm}^2 - E_{ym}^2}. \quad (17)$$

All the vectors are rotating with an oval shape. As a result, this polarization wave is named as elliptical polarization wave.

Only when the transmitting and receiving antenna match correctly can the antenna achieve the best receiving effect.

When vertical polarized antenna is receiving vertical polarized wave, the transmitting wave will be shown as

$$\begin{aligned} \vec{E} &= \vec{a}_y E_0 \cos(\omega t - \beta z), \\ \vec{e}_w &= \vec{a}_y. \end{aligned} \quad (18)$$

The receiving antenna is shown as

$$\begin{aligned} \vec{E} &= \vec{a}_y E_0 \cos(\omega t - \beta z), \\ \vec{e}_a &= \vec{a}_y. \end{aligned} \quad (19)$$

Polarization matching index is

$$\text{PLF} = |\vec{e}_w \cdot \vec{e}_a^*|^2 = |\vec{a}_y \cdot (\vec{a}_y)|^2 = 1. \quad (20)$$

The receiving antenna will get the maximum power from the wave and now the transmitting and receiving antenna match perfectly.

When circular polarized antenna is receiving linear polarized wave, the transmitting wave is shown as

$$\begin{aligned} \vec{E} &= \vec{a}_y E_0 \cos(\omega t - \beta z), \\ \vec{e}_w &= \vec{a}_y. \end{aligned} \quad (21)$$

For the receiving antenna,

$$\begin{aligned} \vec{E} &= \vec{a}_x E_m \cos(\omega t - \beta z) + \vec{a}_y E_m \cos\left(\omega t - \beta z + \frac{\pi}{2}\right), \\ \vec{e}_a &= \frac{1}{\sqrt{2}} (\vec{a}_x + \vec{a}_y). \end{aligned} \quad (22)$$

Polarization matching index is

$$\text{PLF} = |\vec{e}_w \cdot \vec{e}_a^*|^2 = \left| \vec{a}_x \cdot \frac{1}{\sqrt{2}} (\vec{a}_x + \vec{a}_y) \right|^2 = \frac{1}{2}. \quad (23)$$

The antenna will get half the power which means a 3 dB loss. The same result comes with linear polarized antenna receiving circular polarized wave.

When left-hand circular polarized antenna is receiving left-hand circular polarized wave, the wave is shown as

$$\begin{aligned} \vec{E} &= -\vec{a}_x E_{m1} \sin(\omega t - kz) + \vec{a}_y E_{m1} \cos(\omega t - kz), \\ \vec{e}_w &= \frac{1}{\sqrt{2}} (-\vec{a}_x + \vec{a}_y). \end{aligned} \quad (24)$$

For the receiving antenna,

$$\begin{aligned} \vec{E} &= \vec{a}_x E_{m2} \cos(\omega t - kz) + \vec{a}_y E_{m2} \sin(\omega t - kz), \\ \vec{e}_a &= \frac{1}{\sqrt{2}} (\vec{a}_x + \vec{a}_y). \end{aligned} \quad (25)$$

Polarization matching index is

$$\begin{aligned} \text{PLF} &= |\vec{e}_w \cdot \vec{e}_a^*|^2 \\ &= \left| \frac{1}{\sqrt{2}} (-\vec{a}_x + \vec{a}_y) \cdot \frac{1}{\sqrt{2}} (\vec{a}_x + \vec{a}_y) \right|^2 = 0. \end{aligned} \quad (26)$$

FIGURE 1: Left-hand circular polarization (LHCP) wave and right-hand circularly polarized (RHCP) wave.

The receiving antenna cannot get power, because they did not match in rotation direction. The same result comes with horizontal/vertical polarized antenna receiving vertical/horizontal polarized wave.

When two linear polarized antennas which are in vertical and horizontal direction are receiving circular polarized wave, the wave is shown as

$$\vec{E} = \vec{a}_x E_m \cos(\omega t - \beta z) + \vec{a}_y E_m \cos\left(\omega t - \beta z + \frac{\pi}{2}\right), \quad (27)$$

$$\vec{e}_w = \frac{1}{\sqrt{2}} (\vec{a}_x + \vec{a}_y).$$

For the receiving antenna,

$$\vec{E}_x = \vec{a}_x E_m \cos(\omega t - \beta z),$$

$$\vec{E}_y = \vec{a}_y E_m \cos\left(\omega t - \beta z + \frac{\pi}{2}\right), \quad (28)$$

$$\vec{e}_a = \frac{1}{\sqrt{2}} (\vec{a}_x + \vec{a}_y).$$

Polarization matching index is

$$\text{PLF} = |\vec{e}_w \cdot \vec{e}_a^*|^2$$

$$= \left| \frac{1}{\sqrt{2}} (\vec{a}_x + \vec{a}_y) \cdot \frac{1}{\sqrt{2}} (\vec{a}_x + \vec{a}_y) \right|^2 = 1. \quad (29)$$

The receiving antennas match transmitting wave in polarization direction perfectly.

3.2. Cross Polarization Ratio and Polarization Leakage Ratio. Cross polarization ratio (Figure 2), which means the ratio of main polarization electromagnetic wave and orthogonal polarization electromagnetic wave, is the index which shows

FIGURE 2: Cross-polarization ratio.

the dual-polarization antenna's polarization features. The higher the CPR is, the better performance dual-polarization antenna can achieve and hence the higher diversity gain.

Due to the multipath effect of reflection and refraction, the electromagnetic wave will deflect to cross polarization from main polarization. If so, the receiving power will not be determined by CPR. That means the CPR of dual-polarization antenna will be 0 dB. That will also maximize the diversity gain.

However, in some typical scenario which has less reflection, refraction, and scattering, the electromagnetic wave in UE side will keep the original polarization direction. The multipath effect cannot put half power of linear polarization wave to the orthogonal polarization direction; that is, CPR does not come to ideal condition 0 dB.

FIGURE 3: Transmitting antenna and receiving antenna configuration.

We define an index χ as polarization leakage ratio. It indicates the ratio of power received by UE antennas in vertical polarization and horizontal polarization:

$$\chi = \frac{E_V}{E_R}. \quad (30)$$

χ will be determined by CPR, transmitting channel, and receiving antenna. When transmitting and receiving antenna's polarization match perfectly and we do not consider the interference of transmitting channel, the relationship between χ and CPR will be

$$\chi = \frac{1}{\text{CPR}}. \quad (31)$$

3.3. Antenna Configuration and Transmitting Channel. Assume two transmitting antennas are Ant₁ and Ant₂. They keep vertical to each other and have 45° included angle with vertical direction (dual-polarization antenna configuration), as we can get from Figure 3. The same with receiving antennas named Ant₃ and Ant₄ which have a degree θ . θ is determined by the direction of equipment.

Assume Ant₁'s and Ant₂'s linear polarization component are T_{p1} and T_{p2} . They have the same amplitude and a 90° phase difference. That means circular polarized wave is transmitted:

$$\begin{aligned} T_{p1} &= E_m \cos(\omega t - \beta z), \\ T_{p2} &= E_m \cos\left(\omega t - \beta z - \frac{\pi}{2}\right). \end{aligned} \quad (32)$$

This is a left-hand circular polarized wave. When $T_{p2} = E_m \cos(\omega t - \beta z + (\pi/2))$, it will be changed to a right-hand circular polarized wave.

The channel model (Figure 4) is based on references [1, 3–5]. Matrix H shows each channel function relationship.

$$H = \begin{bmatrix} \Gamma_{11}e^{j\phi_{11}} & \Gamma_{12}e^{j\phi_{12}} \\ \Gamma_{21}e^{j\phi_{21}} & \Gamma_{22}e^{j\phi_{22}} \end{bmatrix}. \quad (33)$$

$\Gamma_{11}e^{j\phi_{11}}$ and $\Gamma_{22}e^{j\phi_{22}}$ show the cross-coupling relationship of T_{p1} to R_{p1} and T_{p2} to R_{p2} independently. Γ is a random

FIGURE 4: Transmission channel model.

variable that shows the multipath fading degree. References [2, 6, 7] give the relevant testing result. ϕ is the signal random phase which is in $[0, 2\pi)$.

3.4. Received Signal Power Ratio. Based upon antenna configuration and channel model, two received signals R_{p1} and R_{p2} are shown below:

$$\begin{bmatrix} R_{p1} \\ R_{p2} \end{bmatrix} = \begin{bmatrix} \Gamma_{11}e^{j\phi_{11}} & \Gamma_{12}e^{j\phi_{12}} \\ \Gamma_{21}e^{j\phi_{21}} & \Gamma_{22}e^{j\phi_{22}} \end{bmatrix} \begin{bmatrix} \sin \theta & -\cos \theta \\ \cos \theta & \sin \theta \end{bmatrix} \begin{bmatrix} T_{p1} \\ T_{p2} \end{bmatrix}. \quad (34)$$

R_{p1} and R_{p2} signal strength is expressed as

$$\begin{aligned} E[R_{p1}^2] &= E_m^2 \cdot \{E[\Gamma_{11}^2] + E[\Gamma_{12}^2]\}, \\ E[R_{p2}^2] &= E_m^2 \cdot \{E[\Gamma_{21}^2] + E[\Gamma_{22}^2]\}. \end{aligned} \quad (35)$$

From R_{p1} and R_{p2} , we can get the received LHCP wave power ratio in Ant₃ and Ant₄:

$$\chi_{\text{LHCP}} = \frac{E[R_{p2}^2]}{E[R_{p1}^2]} = \frac{E[\Gamma_{21}^2] + E[\Gamma_{22}^2]}{E[\Gamma_{11}^2] + E[\Gamma_{12}^2]}. \quad (36)$$

From the above, we can conclude that polarization leakage ratio is not decided by the direction relationship θ , but completely by channel condition.

If linear polarized antenna is adopted in transmitting point, $T_{p1} = E_m \cos(\omega t - \beta z)$ and $T_{p2} = 0$, we can get

$$\begin{aligned} E[R_{p1}^2] &= E_m^2 \cdot \{E[\Gamma_{11}^2] \cdot \sin^2 \theta + E[\Gamma_{12}^2] \cdot \cos^2 \theta\}, \\ E[R_{p2}^2] &= E_m^2 \cdot \{E[\Gamma_{21}^2] \cdot \sin^2 \theta + E[\Gamma_{22}^2] \cdot \cos^2 \theta\}. \end{aligned} \quad (37)$$

The received signal strength ratio in Ant₃ and Ant₄ is

$$\begin{aligned} \chi_{T_{p1}} &= \frac{E[\Gamma_{11}^2] \cdot \sin^2 \theta + E[\Gamma_{12}^2] \cdot \cos^2 \theta}{E[\Gamma_{21}^2] \cdot \sin^2 \theta + E[\Gamma_{22}^2] \cdot \cos^2 \theta} \\ &= \frac{E[\Gamma_{11}^2] \cdot \tan^2 \theta + E[\Gamma_{12}^2]}{E[\Gamma_{21}^2] \cdot \tan^2 \theta + E[\Gamma_{22}^2]}. \end{aligned} \quad (38)$$

FIGURE 5: Comparison of signal power balance between linear polarized antenna and circular polarized antenna.

When $T_{p1} = 0$ and $T_{p2} = E_m \cos(\omega t - \beta z)$,

$$\begin{aligned} \chi_{T_{p2}} &= \frac{E[\Gamma_{11}^2] \cdot \cos^2\theta + E[\Gamma_{12}^2] \cdot \sin^2\theta}{E[\Gamma_{21}^2] \cdot \cos^2\theta + E[\Gamma_{22}^2] \cdot \sin^2\theta} \\ &= \frac{E[\Gamma_{11}^2] + E[\Gamma_{12}^2] \cdot \tan^2\theta}{E[\Gamma_{21}^2] + E[\Gamma_{22}^2] \cdot \tan^2\theta}. \end{aligned} \quad (39)$$

When linear polarization antenna is adopted in transmitting point, polarization leakage ratio is determined by channel condition and direction relationship θ .

In the scenarios which have less multipath effect, $E[\Gamma_{21}^2]$ and $E[\Gamma_{12}^2]$ are small. The power coupling of different polarization channel is determined by CPR of dual-polarization antenna.

For circular polarized antenna,

$$\begin{aligned} \chi_{LHCP} = \chi_{RHCP} &= \frac{E[\Gamma_{21}^2] + E[\Gamma_{22}^2]}{E[\Gamma_{11}^2] + E[\Gamma_{12}^2]} \\ &= \frac{E[\Gamma_{21}^2]/E[\Gamma_{11}^2] + E[\Gamma_{22}^2]/E[\Gamma_{11}^2]}{1 + E[\Gamma_{12}^2]/E[\Gamma_{11}^2]} \\ &\approx \frac{CPR^{-1} + 1}{1 + CPR^{-1}} = 1. \end{aligned} \quad (40)$$

FIGURE 6: The realization of CPA by $\pm 45^\circ$ dual-polarized antenna.

For linear polarized antenna,

$$\begin{aligned} \chi_{T_{p1}} &= \frac{E[\Gamma_{11}^2] \cdot \tan^2\theta + E[\Gamma_{12}^2]}{E[\Gamma_{21}^2] \cdot \tan^2\theta + E[\Gamma_{22}^2]} \\ &= \frac{\tan^2\theta + E[\Gamma_{12}^2]/E[\Gamma_{11}^2]}{(E[\Gamma_{21}^2]/E[\Gamma_{11}^2]) \cdot \tan^2\theta + E[\Gamma_{22}^2]/E[\Gamma_{11}^2]} \\ &\approx \frac{\tan^2\theta + CPR^{-1}}{CPR^{-1} \cdot \tan^2\theta + 1}, \\ \chi_{T_{p2}} &= \frac{E[\Gamma_{11}^2] + E[\Gamma_{12}^2] \cdot \tan^2\theta}{E[\Gamma_{21}^2] + E[\Gamma_{22}^2] \cdot \tan^2\theta} \\ &= \frac{1 + (E[\Gamma_{12}^2]/E[\Gamma_{11}^2]) \cdot \tan^2\theta}{E[\Gamma_{21}^2]/E[\Gamma_{11}^2] + (E[\Gamma_{22}^2]/E[\Gamma_{11}^2]) \cdot \tan^2\theta} \\ &\approx \frac{1 + CPR^{-1} \cdot \tan^2\theta}{CPR^{-1} + \tan^2\theta}. \end{aligned} \quad (41)$$

FIGURE 7: Comparison of pattern between linear polarized antenna and circular polarized antenna.

We can conclude that, for circular polarized antenna, the power of circular polarization wave received by two receiving antennas is equal; for linear polarized antenna, the power received by two receiving antennas is decided by CPR and θ .

The received signal power balance of circular polarized antenna and linear polarized antenna can be compared (see Table 1 and Figure 7). The multipath fading vector Γ obeys Rayleigh distribution. Considering the condition of dual-polarization antenna, CPR is almost 30 dB. To better show the received signal power balance of circular polarized antenna and linear polarized antenna, the simulation is shown in Figure 5.

As we can see, in the same channel condition, the received signal power balance of linear polarized antenna power is decided by antenna polarization isolation. When $\theta = \pi/4$ or $3\pi/4$, the received signal power ratio is equal to circular polarization antenna. It is not realistic to keep the angle between transmitting and receiving antennas still along the

whole communication process. That means the signal balance can be harmed by the slight change of antenna angle, That means the signal balance can be harmed by the slight change of antenna angle, that is, reduce the polarization diversity gain.

4. Design of Circular Polarization Antenna

Assume antenna lies along z -axis and at the plane of yoz ; for $\pm 45^\circ$ dual-polarization antenna, the Tx (or Rx) signal can be decomposed as

$$E_{-45} = E_\theta - E_\phi, \quad (42a)$$

$$E_{+45} = E_\theta + E_\phi, \quad (42b)$$

where E_θ and E_ϕ are the complex signals in theta and phi polarization, respectively.

TABLE 1: Comparison of pattern performance between linear polarized antenna and circular polarized antenna.

	LHCP	RHCP	+45	-45
Gain	17.817	17.191	17.784	17.863
HPBW	66.525	67.78	67.032	66.784
Front-to-back ratio	31.773	27.836	29.258	29.804
Azimuth beam squint	-0.51985	0.51779	-0.018224	0.3826
Cross polar ratio-0	28.684	40.389	30.067	35.675
Cross polar ratio-60	14.077	11.241	10.484	12.035

For LH/RH dual circular polarization antenna, the Tx (or Rx) signal can be decomposed as

$$E_{LH} = E_{\theta} - jE_{\phi}, \quad (43a)$$

$$E_{RH} = E_{\theta} + jE_{\phi}, \quad (43b)$$

where $j = \sqrt{-1}$.

The most intuitive method is to combine the $\pm 45^\circ$ ports of the dual-polar antenna by 90° hybrid with a 90° phase difference. The schematic diagram is illustrated in Figure 6.

Contrast can be seen from the test results; circular polarized antenna performance is consistent with linearly polarized antenna. Circular polarized antenna axis ratio value is small enough; electromagnetic wave can maintain a good circular polarization characteristic. That is, the performance of the existing network will not be impacted using circular polarized antenna.

5. The Enhancement of MIMO Diversity Using Circular Polarized Antenna

At line-of-sight environment, the power received from antenna can be small, and the diversity gain is limited. The power of two received antennas is balanced when circular polarization antenna is adopted. However, the power of two received antennas is decided by antenna angle when linear polarization antenna is adopted. We give a better explanation of the relationship between received power balance and MIMO diversity gain loss by the calculation of computer.

The power of two received antennas is not even when linear polarization antenna is adopted. The diversity gain is limited by the signal that has the smaller power. That means the SNR of receiving antenna is lowered. According to (9), we can get the curve of channel capacity as in Figure 8.

By using circular polarization in the actual wireless environment in the realization of MIMO, through the cell 1 and cell 2 test results, can be seen that the average system throughput has relative 11%–18% ascension and has 25% of the highest lifting capacity.

6. Conclusions

MIMO diversity improvement using circular polarized antenna is given by principle analysis and test. System gain drops because of power imbalance in two receiving antennas in the scenes which do not have enough multipath effect when

FIGURE 8: Comparison of MIMO channel capacity between linear polarized antenna and circular polarized antenna.

FIGURE 9: Test result of MIMO diversity improvement using circular polarized antenna.

using traditional $\pm 45^\circ$ dual-polarization antenna. When using circular polarized antenna in transmitting point, this problem can be solved effectively. Two signals are transmitted through left-hand polarized and right-hand polarized electromagnetic waves. The noncorrelation between two signals is ensured by isolation of two circum-gyrate directions.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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