

Study on the Application of MIMO System

Haiyang Fu, Weiwei Qian, Weihong Zeng, Xiangdong Jia

College of Communication and Information Engineering,

Nanjing University of Posts and Telecommunications, Nanjing 210003, P.R.China

fuhay@njupt.edu.cn

Abstract—As multi-antenna without phase-controlling being used in MIMO system to transmit signals with the same carrier frequency, directional transmission beam would be produced in MIMO system, which would form a number of blind spots of radio coverage. The above conclusions would be proved in the paper by mathematical analysis and radio beam simulation method. The present researches of the MIMO theory only proved that channel capacity could be increased on the setting mathematical model in base-band by the space division multiplex (SDM) principle. But the reasonable physical model matching to that mathematical model have not been given by those researches, resulting in that the SDM could not been realized in MIMO system physically.

Keywords—MIMO, channel capacity, phase-controlled antenna array

I. INTRODUCTION

The founders of MIMO theory proved mathematically on the basis of Shannon formula that MIMO techniques, i.e. multi-transmitting antennas and multi-receiving antennas to be used at the same time, performed perfectly in the improving of channel capacity (CC) compared with the other techniques, and also derived the MIMO CC formula similar to the Shannon formula. Pointing out by [1, 2, 3], MIMO technique is more suitable to be used in flat fading channel or frequency selective fading channel, especially in multi-scattering channels.

MIMO techniques could be split into to two groups basically: STC (Space Time Coding) [3] and SDM (Space Division Multiplexing) [1, 2, 3]. Channel coding over different transmitting branches is used to increase CC by STC technique, whereas SDM achieves its CC gain by transmitting same information on independent Rayleigh fading channels (IRFC) between multi-pair of transmitting and receiving antennas. It is hard to say that the CC gain of STC is introduced by multi-antenna, however we are sure that the CC gain introduced by SDM is introduced by multi-antenna, and it is fit with the original definition of MIMO [1].

MIMO theory is analyzed and proved in base-band without using the concept of phase controlled antenna (PCA) and the physical module in [1], so that the SDM is used in MIMO system to increase its CC in [1] is un-suitable. Furthermore, it is thought in [1] that the condition for IRFC between a pair of transmitting and receiving antennas always are satisfied when spacing between neighboring antennas is the half of

wavelength (λ) or 10λ , which also is un-suitable. Generally speaking, only when the spacing is larger than 10λ , it could be thought that two receiving signals from different antennas are mutual independent.

An explicit formula is given in [3] for the relation between CC and the number of antennas, i.e. MIMO CC formula, so as the physical model of MIMO. Based on the CC formula in [3] and the effect of beam forming by multi-antennas mentioned above, it can be judged that although the correctness of that the CC may be increased by MIMO theory is proved mathematically, it could not be realized physically, since the physical characteristics of antenna array have not been considered in the certifying.

Generally Speaking, the realization of SDM must make use of the function of PCA or Parabolic antenna in radio propagation. It must be emphasized that the basic concept of SDM is that different signals for different users are transmitted by several independent directional narrow-beam without mutual interferences in air. Ideal directional narrow-beams could be produced by parabolic antennas, whereas the non-ideal directional narrow-beams could be produced by PCA. SDM principle is the same with that of TDM or FDM, which is to use multi-channel without mutual interferences in the domain of time or frequency. It shouldn't be modified in one's like, otherwise confusion and error would be introduced in the field. PCA function hasn't been introduced in the field of MIMO, and SDM couldn't be formed by MIMO.

However, using 2 or more transmitting antennas, also being named as array element (AE) which is more reasonable for the antenna theory, there is always some position relation among these AEs which would determine the mutual interference function among those radio waves in the same frequency transmitted by multi-AE, and some directional beam-pattern must be produced, forming the function of antenna array. So the version of transmitting by multi-antenna or the same as that in MIMO is wrong, and should be named as transmitting by antenna array. Considering the custom of designation in MIMO, all of these two designation methods would be used in the latter without distinguishing for the easy. There is the same version for the receiving.

II. PHYSICAL MODEL OF MIMO SYSTEM

The physical model of MIMO system shown in Fig.1 was given in [3]. Those input signals of multi-antenna for Tx in

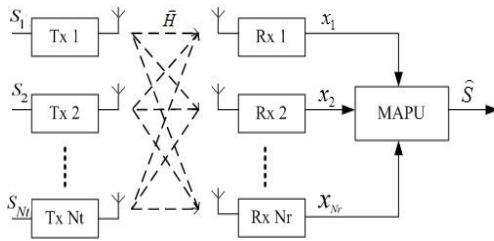


Fig.1 Physical model of MIMO system

space division multiplex (SDM) on the left of Fig.1 should be the same, i.e. $S_1 = S_2 = \dots = S_{N_t}$. According to the basic theory of MIMO, transfer matrix H there expresses those IRFCs between multi-pair of Tx and Rx antennas, which are produced by those multi-antenna for Tx and Rx respectively.

If channels which are produced by multi-path propagation are omitted, the physical model in Fig.1 could be used, it is defined in [1, 3] that JD or Multi Antennas Processing Unit (MAPU) must finish the channel estimation and receiving process of those IRFCs, and then adjust those time delays among M -path receiving signals, combining them by the criteria of maximum SNR ratio (MRC) to make use of the energies of N_r antennas for Tx. Obviously, Comparing with the single antenna system, the difficulty of making full use of the transmitting energy in MIMO system is greatly increased. Although the above processing can be expressed in a simple matrix, it is a very hard problem to be solved by the modern radio communication technique, since it is restricted with the physical feature of the antenna array.

Apart from the above problem, it's shown in Fig.1 that there are unexpected $N_r - 1$ path signals from N_r antennas in Tx being included in the receiving signal x_1 of Rx_1 for receiving the signal transmitted by Tx_1 , and those unexpected signals must be reduced from x_1 to form an IRFC between Tx_1 and Rx_1 . It hasn't been considered for how to make use of the energies of those $N_r - 1$ path unexpected signals, so as the noise restraining problem for those unexpected signals. It's mentioned in [1] that JD could be used to finish that process, though JD could be realized for the surrounding with multi-path propagation in CDMA system in theory, and there are still many problems to be resolved. How to solve these problems haven't been mentioned in the other MIMO references such as [2, 3], so correctness of those conclusions given by them should be considered again.

It should be emphasized that the surrounding condition for the JD realization is the coarse multi-path propagation surrounding, its physical meaning is that the time delay among multi-path signals must longer than a CDMA chip. The other condition is that JD should be used in spectrum spreading system. Delay between two multi-path signals introduced by two Tx antennas is very small since the space between them is also very small, belonging to thin multi-path propagation surrounding, so as for the indoor scattering propagation. In

these cases, the characteristic of multi-path channels couldn't be detected by training sequence or pilot with longer chip duration, so JD could not be realized in these situations. The channel bandwidth of general OFDM system is about 20 KHz, the symbol in the prefix which may be used for the detecting of the characteristic of multi-path propagation has Longer duration and without using CDMA mode, so it is too hard to realize JD in OFDM system. However, all of the papers used to prove the correctness of MIMO system are based on OFDM system. By the discussion above, It is sure that the basic condition of M IRFCs in MIMO theory is too hard to be satisfied. In the following, the model in Fig.1 and mathematical analysis would be used not only to prove that two IRFCs could not be constructed between a pair of Tx antennas and a Rx antenna in the base-band signal, but also to demonstrate that a directional beam would be constituted when using two transmitting antennas.

III. RADIO BEAM DIRECTION OF MULTI-ANTENNA FOR TX

MAPU being used to process the receiving signal x_1 of Rx_1 , the coherent demodulation processing is done on x_1 first. It is assumed that CDMA QPSK system is used with a downlink pilot signal and only two transmitting antennas are used for those two transmitting machine Tx_1 and Tx_2 respectively. It is need to provide the local carrier synchronized with the carrier of received signal when coherent demodulation is used. After the received pilot signal (Pilot) being processed by the carrier recovery circuit, the local carrier could be recovered, which is coherent with the received signal from Tx_1 , it can be expressed as follows,

$$C_{1L}(t) = \cos w_{1L}t - \sin w_{1L}t \quad (1)$$

Where w_{1L} is the frequency of local coherent carrier, the specific method was given in [12].

The components of signal $S_1(t)$ and $S_2(t)$, which are the outputs from Tx_1 and Tx_2 respectively, should be included in the output signal x_1 in Fig.1, and $S_1(t)$ and $S_2(t)$ could be expressed respectively as

$$S_1(t) = D_1(t)PN_{r1}(t)\cos w_1t - D_1(t)PN_{r1}(t)\sin w_1t \quad (2)$$

$$S_2(t) = S_1(t - t_{d1}) \quad (3)$$

According to the principle of coherent demodulation in the QPSK demodulator, it could be finished by making the recovered coherent carrier $C_{1L}(t)$ multiply with the receiving signal x_1 . The two orthogonal output signals of the demodulator could be expressed as follows,

$$\begin{aligned} I &= I_1 + I_2 \cos \theta_2 + Q_2 \sin \theta_2 \\ Q &= Q_1 + Q_2 \cos \theta_2 - I_2 \sin \theta_2 \end{aligned} \quad (4-2)$$

Obviously, there are three VIRFC signals in base-band signal I , in which I_1 is the IRFC signal corresponding to that

between Tx1 and Rx1. According to (2),(3) and (4), the correspondence relation among the following variables are as follows,

$$\begin{aligned} I_1 &= D_1(t)PN_{I1}(t) \\ Q_1 &= D_1(t)PN_{Q1}(t) \end{aligned} \quad (5-1)$$

$$\begin{aligned} I_2 &= D_1(t-t_{d1})PN_{I1}(t-t_{d1}) \\ Q_2 &= D_1(t-t_{d1})PN_{Q1}(t-t_{d1}) \end{aligned} \quad (5-2)$$

Because t_{d1} is the time-delay of the signal output from Tx2 compared with that of Tx1, so the phase-difference θ_2 should be the remainder of $[w_1(t-t_{d1})-w_1t]/2\pi$, and that the receiving signal of Tx2 in x1 could be expressed as

$$S_2(t) = I_2 \cos(w_1t + \theta_2) - Q_2 \sin(w_1t + \theta_2) \quad (6)$$

According to (4) and (6), it could be shown that the recovered carrier $C_{1L}(t)$ is not coherent with the receiving signal of $S_2(t)$ from Tx2, which hasn't been coherent demodulated in the signals I and Q output from the demodulator since that there is phase-difference θ_2 existed.

$S_2(t)$ should be considered as the multi-path interference (MPI) when formula (4-1) is used in the CDMA system with single-antenna for Tx in the coarse multi-path surrounding. The output amplitude of I_2 and Q_2 would be reduced and their polarity may even be reversed, which is determined by the factor $\cos \theta_2$, and also will affect the performance of diversity reception of RAKR receiver seriously. Secondly, there is an extra interference between I and Q signals, namely the orthogonal interference between I and Q signals, which also will have an important impact on the system performance. For the receiving signal of other path, the analysis is similar, and would be neglected here. Obviously, base-band processing methods could not be used to improve the performance of RAKE receiver when multi-path fading happened according to formula (4-1), only the method of multi-path carrier coherent detection [12] could be used to overcome the impact of MPI.

Assuming that the distance between two transmitting antennas is $\lambda/2$, those two local carriers sent to Tx_1 and Tx_2 have the same phase, then the carrier phases of the signals sent by Tx_1 and Tx_2 are the same, too. When the location of the receiver is on the vertical line of those two transmitting antennas, as the distance from the receiver to those two antennas is always the same, so $\theta_2 = 0$, and there are that

$$I = I_1 + I_2 \quad (7)$$

$$Q = Q_1 + Q_2. \quad (8)$$

Obviously, the receiving signals of two transmitting antennas in the receiver are added in-phase, the effect of diversity transmission in-phase being existed.

Considering that the location of receiver is in the extended line of the connecting line between two transmitting antennas, the distance difference from the two transmitting antennas to the receiver is $\lambda/2$, so $\theta_2 = \pi$. Then

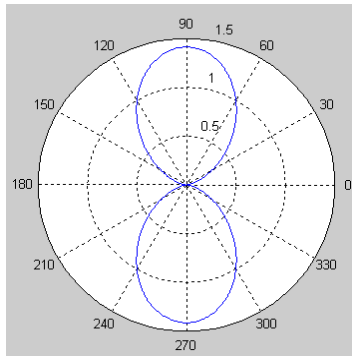
$$I = Q = 0. \quad (9)$$

If the location of the movable receiver is on the plane, θ should be in the range of $[0, 2\pi]$, at this moment the value after coherent demodulation of the receiving signal x_1 would be determined by (4). It should be changed with the location of the receiver. While in phase-controlled antenna array system, as the phase of signal sent to the antenna would be controlled, $\theta \equiv 0$ will be guaranteed, and the direction of transmitting is variable, so radio beam-shaping gain must be achieved. The value of power gain should be 3 dB in the above case. The calculation method of power gain for multi-AE could be found in [13]. It's obvious that the effect of directional transmitting have the function of collecting the energy of radio wave in the required direction, but MIMO didn't have that function, and non-even coverage of radio wave would be formed.

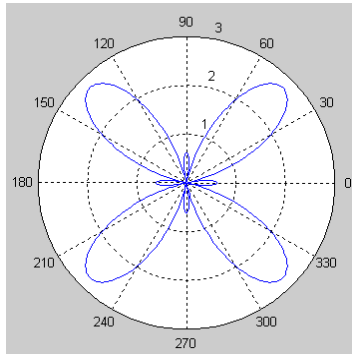
IV. THE PERFORMANCE SIMULATION FOR THE RADIO BEAM

Some transmitting radio wave patterns for some antenna arrays to be used in [1, 2, 3] would be given in this section. The simulation method for these patterns was mentioned in [4]. Since the phase of signal fed to each antenna haven't been controlled in MIMO system, so assuming that all the phases for different AE are equal, the assumption is reasonable because even if they are different, the gaps between them would keep unchanging, and similar patterns of radio wave beams could be obtained. While in PCA system, the phase of the signal fed to each AE is controlled, making the receiving signals from those Tx AEs with the same phase, then they could be added in-phase, and SNR gain is sharply increased, which could be used to increase CC. In MIMO system without that phase control scheme, mutual canceling might be happen in receiving signals come from different AEs in Tx.

Beam patterns of two kinds of multi-antenna used in [1] are given in Fig.2. It is shown in Fig.2 (a) that SNR is nearly 0 in the extended line of the connecting line between the two AEs, i.e. in the direction of 0° and 180° , making $R_b \approx 0$. The communication would be failed in more than half area, if this kind of MIMO system to be used. The rectangular 4-AE antenna array is used in Fig.2 (b), and it is shown that users in the direction of 0° and 90° can't communicate normally, too, resulting in $R_b \approx 0$.



(a) 2 AEs with $\lambda / 2$ spacing



(b) 4 AEs with $\lambda / 2$

Fig.2 Beam patterns of 2 and 4 antennas

In Fig.3, there is the beam pattern of 2 AEs spaced by 10λ , and there are also many directions with the intensity of signal equal to 0, making CC tends to 0.

The beam pattern of 3 antennas with 2λ spacing in [2] is shown in Fig.4, and there are also many directions with transmission power to be equal to 0.

V. CONCLUSIONS

It is shown by the beam patterns for many kinds of antenna array, which were taken as examples by those references listed in the paper, that the normal requirement for the receiving SNR couldn't be satisfied by the MIMO system, existing serious technique defect, so the correctness of MIMO theory should be researched and proved further.

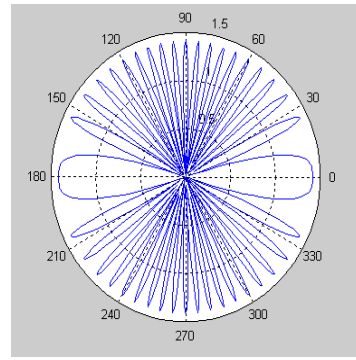


Fig.3 2AEs with 10λ spacing

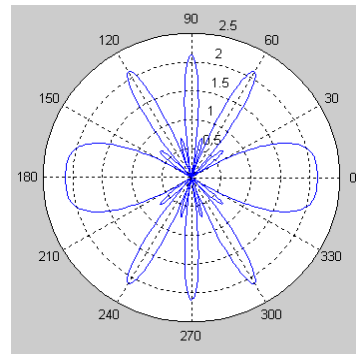


Fig.4 3AEs line spaced by 2λ

REFERENCES

- [1] G.J. Foschini and M. J. Gans, "On limits of Wireless Communications in a Fading Environment When Using Multiple Antennas," *Wireless Pers. Commun.*, vol.6, no. 3, pp.311-335, Mar. 1998.
- [2] Allert van Zelst and Tim C. W. Schenk, "Implementation of a MIMO OFDM-Based Wireless LAN System," *IEEE Transaction on Signal Processing*, vol.52, no.2, pp.483-494, Feb. 2004.
- [3] A. van Zelst, R. van Nee, and G. A. Awater, "Space Division Multiplexing (SDM) for OFDM Systems," in *Proc. IEEE Veh. Technol. Conf.*, May 2000, pp. 1070-1074.
- [4] Jia Xiangdong, Li Fan, Zhen Jianguang, Scheme of Beamforming for Smart Antenna by Using Base-Band Amplitude Weighing and Performance Analysis in CDMA, *Chinese Journal of Radio Science*, Vol.25, No.3, pp.505-511, 2010.6.