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Research Article

Analysis and Realization on MIMO Channel Model

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Abstract: In order to build the MIMO (Multiple Input Multiple Output) channel model based on IEEE 802.16, the way and analysis on how to build good MIMO channel model are described in this study. By exploiting the spatial freedom of wireless channels, MIMO systems have the potential to achieve high bandwidth efficiency, promoting MIMO to be a key technique in the next generation communication systems. As a basic researching field of MIMO technologies, MIMO channel modeling significantly serve to the performance evaluation of space-time encoding algorithms as well as system level calibration and simulation. Having the superiorities of low inner-antenna correlation and small array size, multi-polarization tends to be a promising technique in future MIMO systems. However, polarization characteristics have not yet been modeled well in current MIMO channel models, so establishing meaningful multi-polarized MIMO channel models has become a hot spot in recent channel modeling investigation. In this study, I have mainly made further research on the related theories in the channel models and channel estimation and implementation algorithms on the others' research work.

Keywords: Channel estimation, channel models, MIMO

INTRODUCTION

By adopting MIMO (Multiple-Input Multiple-Output) technology, the capacity and spectrum efficiency of wireless communication systems can be increased significantly without the expense of bandwidth. It is believed that the MIMO technology will be one of the key technologies that will be used in the high-speed broadband wireless Internet access networks and has wide application prospect in new generation mobile communications in the future (Philosof, 2007; Piazza *et al*., 2008; Lieberei and Zolzer, 2009)

The performances of the MIMO systems are decided by the fading characteristics of the wireless channel to a great extent (Mohamed, 2011a). Therefore, it needs to research the modeling and simulation of MIMO channels. The parametrical models of MIMO fading channels need to be established. In MIMO systems, with the increasing number of channel parameters and the extension of transmit signals in space dimension, the channel estimation have become the bottleneck of system performance and practical application. Therefore, it is important to make analysis on the MIMO channel and build the MIMO channel model.

MIMO technology can be applied on the communication technology by installing many air wires on the transmitter and receiver. That can form the MIMO air wires array and this technology can make full use of the space resource and strengthen space free degree on channel. Compared with SISO, MIMO technology can improve the frequency spectrum and channel capacity.

There is long history for the development of MIMO in the communication system. But until the latter of 19s, the MIMO technology is directly used in the communication system. Nowadays, MIMO technology is widely used in two major areas, including broadband mobile communication system and broadband wireless access systems, such as 3G, B3G, IEEE802.16, IEEE802.11n and other systems (Jiangang and Yinghua, 2006).

For the study on MIMO technology, there are two basic problems.

Which model on MIMO channel can describe the fading on space, time and frequency precisely?

How to expand the MIMO channel and make model for MIMO channel precisely? How to simulate the MIMO channel?

To solve the first problem, we should know the data on fading in channel in different wave environment. Now, there have been many organizations and universities to study on this title. The frequency is between 2 and 5 GHz and the test environment includes indoor, outdoor, city and suburb. The test contents include multipath delay, multipath fading amplitude and phase change.

To solve the second problem, there are two main methods to build MIMO channel model. On the one hand, deterministic fading channel modeling and it can describe transmitting environment accurately. It

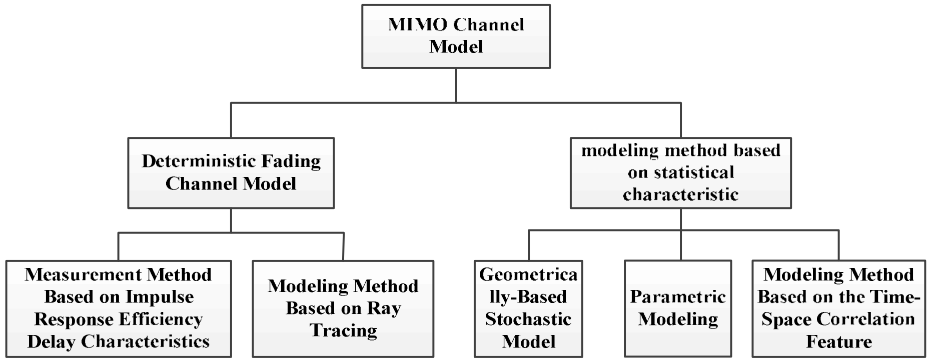


Fig. 1: Classification on MIMO channel model method

includes measurement method based on impulse response efficiency delay characteristics and modeling method based on ray tracing. On the other hand, the modeling method based on statistical characteristic and it can include geometrically-based stochastic model, parametric modeling and modeling method based on the time-space correlation feature. That is shown in Fig. 1.

MIMO technology can be applied on the communication technology by installing many air wires on the transmitter and receiver. That can form the MIMO air wires array and this technology can make full use of the space resource and strengthen space free degree on channel. Compared with SISO, MIMO technology can improve the frequency spectrum and channel capacity. That technology is widely used in the wireless communication, therefore, it is very important to make study on the MIMO technology and build the channel model for the MIMO channel (Taparugssanagorn and Ylitalo, 2009). With the development of the computer science and communication technology, more and more analysis will be made by more and more scholars.

The MIMO technology is widely used in communication. Therefore, it is necessary to make analysis on it. In this study, the Objective of the study is to build the MIMO channel model based on IEEE 802.16. For the building of the MIMO channel model, the way and analysis on how to build good MIMO channel model is the key technology, which can be shown in this study. With the simulation results, we can get the advantages of MIMO channel easily.

METHODOLOGY

MIMO channel model: The important of MIMO channel model is described in above. And it is the first problem for study on channel capacity, signal processing algorithm evaluation. Therefore, it is important to build the MIMO channel model. In the following, the main characters on MIMO channel will be described.

Fading character on channel: In wireless communication channel, the signal will be reflexed, diffracted and scattered because of the complex of the transmitting environment. And the signal can also be affected by shadow effect, multipath effect and Doppler effects. Therefore, the signal in the receiver will be faded. As usual, wireless channel can include large-scale transmitting model and small-scale fade.

Path loss and shadow effect: Path loss and shadow effect are applied on large-scale transmitting character. A basic method and test transmitting model is widely used in the wireless communication channel. And the average large scale path loss is shown in the Eq. (1):

$$PL(d)[dB] = \overline{PL}(d_0) + 10n\log\left(\frac{d}{d_0}\right) \tag{1}$$

n = Path loss exponent, it can indicate the growth rate for path loss
d_0 = Near earth reference range

Because of the difference of the environment, for one specific space, the path loss can be shown in Eq. (2):

$$PL(d)[dB] = \overline{PL}(d_0) + 10n\log\left(\frac{d}{d_0}\right) + x_\delta \tag{2}$$

x_δ represents zero mean Gaussian distribution random variables, the unit is dB and the standard deviation is σ.

Channel dispersion and selective fading: Dispersion will be occurred because of the different of the time, frequency and angle in the wireless channel. The power delay profile will be used in the dispersion on the time, Doppler power spectral density will describe the dispersion on the frequency (Mohamed and Muta, 2011b) and the power azimuth spectrum can describe the dispersion on the angle. Therefore, there will be three parameters in the describe on the channel dispersion and the three parameters will be described in the following (Yiming *et al*., 2011).

Time dispersion and frequency selection: Delay spread can describe the channel dispersion on the time. And the parameters include average additional time delay, RMS time delay. They are related to power delay profile.

The average additional time delay can be defined in the following equation:

$$\bar{\tau} = \frac{\sum_k a_k^2 \tau_k}{\sum_k a_k^2} = \frac{\sum_k P(\tau_k)\tau_k}{\sum_k P(\tau_k)} \tag{3}$$

a_k = The fading factor for the path with number K
P (τ_k)= The relative power of multipath fading on delay point τ_k

RMS time delay can be defined in the following:

$$\sigma_\tau = \sqrt{E(\tau^2) - (\bar{\tau})^2} \tag{4}$$

For the above expression:

$$E(\tau^2) = \frac{\sum_k a_k^2 \tau_k^2}{\sum_k a_k^2} = \frac{\sum_k P(\tau_k)\tau_k^2}{\sum_k P(\tau_k)} \tag{5}$$

Power delay profile can be defined in the following equation:

$$P(\tau) = \frac{1}{T} e^{-\frac{\tau}{T}} \quad 0 < \tau < \infty \tag{6}$$

And T is a constant and it is the average value of multipath delay.

Frequency dispersion and time selection: The station of frequency dispersion and time selection will be occurred, because of the relative motion of transmitter and receiver. And this station can be also called Doppler frequency shift phenomenon. How to describe Doppler spread. Two parameters will be used (Nayagam and Katar, 2011) and they are named B and B_D. The two parameters will have relationship with Doppler Power Spectral Density (DPSD) S (*f*).

Average Doppler expansion $\bar{B}$ can have relationship with DPSD S (*f*) and this relationship will be described in the Eq. (7):

$$\bar{B} = \frac{\int_{-\infty}^{+\infty} fS(f)df}{\int_{-\infty}^{+\infty} S(f)df} \tag{7}$$

Doppler expansion B_D also have the relationship with DPSD S (*f*) and this relationship will be shown in the following:

$$B_D = \sqrt{\frac{\int_{-\infty}^{+\infty} (f - \bar{B})^2 S(f)df}{\int_{-\infty}^{+\infty} S(f)df}} \tag{8}$$

The coherence time Tc can be used to describe the channel time selective. The value of coherence time can be shown in Eq. (9):

$$T_C \approx \frac{9}{16\pi f_m} \tag{9}$$

f_m represents the max Doppler frequency shift.

Angle dispersion and space selection: The station of angle dispersion and space selection occurred, because of environment of mobile station and base station and the different space of the antenna system.

Angle spread Δ occurred because of the radiation from transmitter and the receiver and it has relationship with Power Azimuth Spectrum (PAS) P (θ). The relationship can be shown in the following equations:

$$\Delta = \sqrt{\frac{\int_0^{+\infty} (\theta - \bar{\theta})^2 P(\theta)d\theta}{\int_0^{+\infty} P(\theta)d\theta}}$$

and

$$\Delta = \sqrt{\frac{\int_0^{+\infty} \theta P(\theta)d\theta}{\int_0^{+\infty} P(\theta)d\theta}}$$

Table 1: The characteristics of fading channel

Channel selectivity	Channel extension	Coherent parameters
Frequency selectivity	Delay spread	Coherent bandwidth
Time selectivity	Doppler spread	Coherent time
Space selectivity	Angle spread	Coherent distance

Table 2: The classification of fading channel

Coherent parameters	Classification of fading channel	Conditions of satisfaction
Delay spread	Flat fading channel	Signal bandwidth<coherent bandwidth signal period>delay spread
	Frequency selectivity fading channel	Signal bandwidth>coherent bandwidth signal period<delay spread
Doppler spread	Fast fading channel	Signal period>coherent time signal bandwidth<Doppler spread
	Slow fading channel	Signal period<coherent time signal bandwidth>Doppler spread
Angle spread	Scalar channel	Single antenna system
	Vector channel	Angle expansion is not zero multiple antenna systems

The value of angle spread is between 0 and 360. The value of dispersion will be larger if the value of angle spread is larger (Levin and Loyka, 2008) (Table 1 and 2).

Coherent distance D_C can be used to describe the time selectivity. And the value of coherent distance will be shown in Eq. (10):

$$D_C \approx \frac{0.187}{\Delta \cos\theta} \tag{10}$$

The new statistical properties of the envelope: The envelope of signal in receiver presents randomness, because of the multipath phenomena of the wireless communication channel. Through study, the envelopes are Rayleigh distribution and Riccan distribution.

The probability density function of Rayleigh distribution is shown in Eq. (11):

$$p(r) = \frac{r}{\sigma^2}\exp\left(-\frac{r^2}{2\sigma^2}\right) \quad 0 \le r < \infty \tag{11}$$

σ = The RMS value of voltage signal before envelope detection
σ^2 = The average time value before envelope detection

The cumulative distribution function will be shown in Eq. (12):

$$P(R) = \Pr(r \le R) = \int_0^R p(r)dr = 1 - \exp\left(-\frac{R^2}{2\sigma^2}\right) \tag{12}$$

The average value of Rayleigh distribution will be described in Eq. (13):

$$r_{mean} = E[r] = \int_0^\infty rp(r)dr = \sigma\sqrt{\frac{\pi}{2}} = 1.2533\sigma \tag{13}$$

The variance of Rayleigh distribution is shown in Eq. (14):

$$\sigma_r^2 = E\left[r^2\right] - E^2[r] = \sigma^2\left(2 - \frac{\pi}{2}\right) = 0.4299\sigma^2 \tag{14}$$

Therefore,

$$r_{mean} = 1.177\sigma$$

The Ricean distribution is shown in Eq. (15):

$$p(r) = \frac{r}{\sigma^2}\exp\left[-\frac{\left(r + A^2\right)}{2\sigma^2}\right] I_0\left(\frac{Ar}{\sigma^2}\right) \quad A \ge 0, r \ge 0 \tag{15}$$

One parameter K will be the factor of Ricean and the value of K will be shown in the following:

$$K = \frac{A^2}{2\sigma^2}$$

The characteristic of second order statistics: That characteristic is widely used in the small fading channel and there are two statistical magnitude, named level crossing rate and average duration of fade. The two parameters will be shown in the following equations.
For level crossing rate:

$$N_t = \int_0^\infty \dot{\rho} f_{R\dot{R}}\left(\rho, \dot{\rho}\right) d\dot{\rho} \tag{16}$$

For Rayleigh fading channel:

$$N_t = \sqrt{2\pi} f_m \rho e^{-\rho^2}$$

$$f_m = v/\lambda$$

$$\rho = R/R_{rms}$$

For average duration of fade, the average fading time:

$$\bar{t} = \frac{1}{N_t}\int_0^R f_R(\rho)d\rho \tag{17}$$

For Rayleigh fading distribution:

$$\bar{t} = \frac{e^{\rho^2} - 1}{\sqrt{2\pi}\rho f_m} \tag{18}$$

Statistics MIMO channel model:

The main parameters in MIMO channel model: There are many parameters in the MIMO system. There are many space parameters including the AOD of signal from transmitter, the AOA of signal from receiver, the PAS of signal, AS and so on. And it also includes the number of wireless from transmitter and receiver and the distance between antenna structure and the factor of antenna.

The system of communication technology on MIMO can be shown in Fig. 2.

For the system of communication technology on MIMO technology, the number of air wires on transmitter is N and the number of air wires on receiver is M. And if the speed of the system taking sample is same with the speed of symbols, the transmission information flow c (t) can become many layers of transmission symbols flow s (t) (i = 1, 2,…, N). The number of the layers is N. These symbols flow is transmitted by the N transmitter air wires. And the information is received by the M transmitter, the receiving symbols flow is shown as y (t) (j = 1, 2,…, M). s (t) and y (t) can be shown in the following equations:

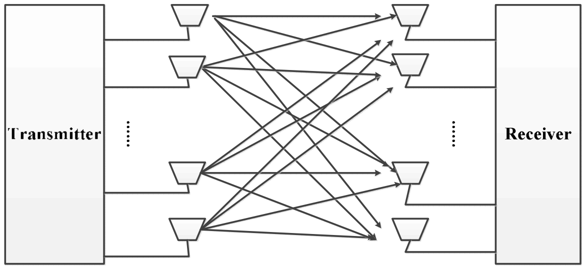


Fig. 2: The system of communication technology on MIMO technology

$$s(t) = \left[s_1(t), s_2(t), \cdots, s_N(t)\right]^T \tag{19}$$

$$y(t) = \left[y_1(t), y_2(t), \cdots, y_M(t)\right] \tag{20}$$

The MIMO wireless channel can be shown in Eq. (21):

$$H(\tau) = \sum_{t=1}^{L} A_l \delta(\tau - \tau_l) \tag{21}$$

In above:

$$H(\tau) \in C^{M \times N}$$

and

$$A_l = \begin{bmatrix} a_{11}^{(l)} & a_{12}^{(l)} & \cdots & a_{1N}^{(l)} \\ a_{21}^{(l)} & a_{22}^{(l)} & \cdots & a_{2N}^{(l)} \\ \vdots & \vdots & \vdots & \vdots \\ a_{M1}^{(l)} & a_{M2}^{(l)} & \cdots & a_{MN}^{(l)} \end{bmatrix}_{M \times N}$$

$a^{(l)}_{MN}$ = The transmitting coefficient from transmitter to receiver
L = The number of resolved path

The relationship between s (t) and y (t) will be shown in the following:

$$y(t) = \int H(\tau) s(t - \tau) d\tau \tag{22}$$

or

$$s(t) = \int H^T(\tau) y(t - \tau) d\tau \tag{23}$$

If $a^{(l)}_{MN}$ is in Rayleigh distribution. We can get the following points:

- If the transmitting coefficient is in the same path, the average power will be same.
- If the channel is wide sense stationary uncorrelated scattering, the transmitting coefficient will be different and there will be no relationship among them.
- There will be no relationship between the decline of receiving antenna correlation coefficient and transmitting antenna.

But there will be some relationship among transmitting antenna:

$$\rho_{n_1 n_2}^{TX} = \left\langle a_{mn_1}, a_{mn_2} \right\rangle \tag{24}$$

For transmitter and receiver, we can get the symmetry correlation matrixes R_{RX} and R_{TX}:

$$R_{RX} = \begin{bmatrix} \rho_{11}^{RX} & \rho_{12}^{RX} & \cdots & \rho_{1M}^{RX} \\ \rho_{21}^{RX} & \rho_{22}^{RX} & \cdots & \rho_{2M}^{RX} \\ \vdots & \vdots & \cdots & \vdots \\ \rho_{M1}^{RX} & \rho_{M2}^{RX} & \cdots & \rho_{MM}^{RX} \end{bmatrix}_{M \times M}$$

$$R_{TX} = \begin{bmatrix} \rho_{11}^{TX} & \rho_{12}^{TX} & \cdots & \rho_{1N}^{TX} \\ \rho_{21}^{TX} & \rho_{22}^{TX} & \cdots & \rho_{2N}^{TX} \\ \vdots & \vdots & \cdots & \vdots \\ \rho_{N1}^{TX} & \rho_{N2}^{TX} & \cdots & \rho_{NN}^{TX} \end{bmatrix}_{N \times N}$$

Therefore, we can get the MIMO channel model:

$$R_{MIMO} = R_{TX} \otimes R_{RX} \tag{25}$$

RESULT ANALYSIS

The simulation on MIMO wireless channel:

Simulation procedure on MIMO channel model: To make the simulation on MIMO wireless channel, we should do something. Firstly, we should choose the simulation scene and it includes the wireless channel in typical city, bad city, the suburbs or the country. Secondly, choose the right array structure for transmitter and receiver and make sure the number of antennae for transmitter and receiver, topological structure and others. Thirdly, make sure the parameters in MIMO channel, including PDP, Doppler power spectrum, PAS, AOA, AOD, AS and so on and calculate space correlation matrix in transmitter and receiver named R_{RX}, R_{TX}. Fourthly, make branch power distribution. Fifthly, calculate the channel matrix.
The simulation procedure can be shown in Fig. 3.

Simulation of MIMO channel: There are many standards are invented by many researchers. And there are many developments among the standards. IEEE802.16 is developed from 802.16a. Therefore, the MIMO channel is built according to this standard.

We can build the simulation model for MIMO channel according to the parameters in the Table 3. And build the model, the model is shown in Fig. 4.

Table 3: Parameters in MIMO channel according to IEEE802.16

Propagation type	Tap number	Tap amplitude	Tap delay
Type 0	1	1.0000	0
Type 1	1	0.9950	0
	2	0.9900 exp (-j0.75)	400/R
Type 2	1	0.2860 exp (-j0.75)	0
	2	0.9530	400/R
	3	-0.0095	800/R

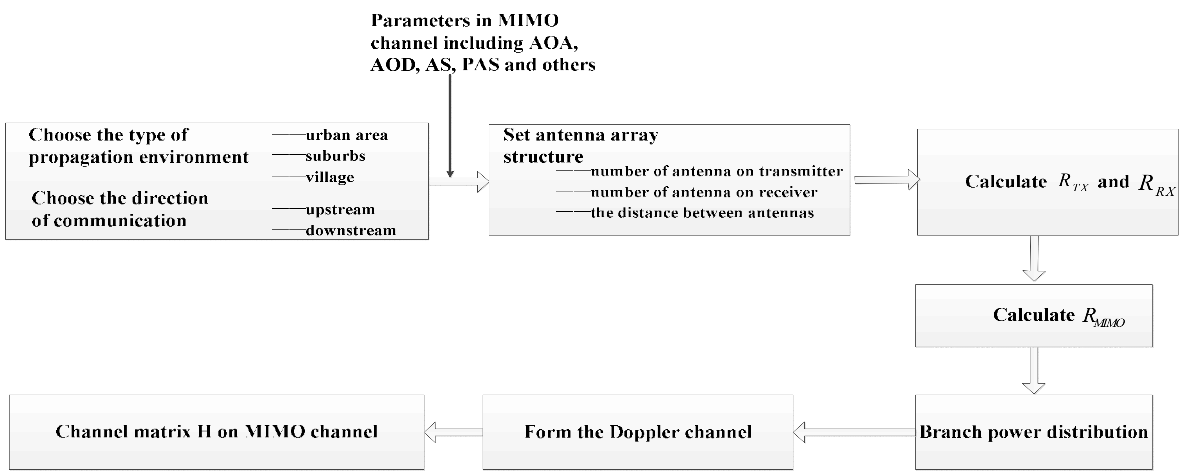


Fig. 3: Simulation procedure of MIMO channel

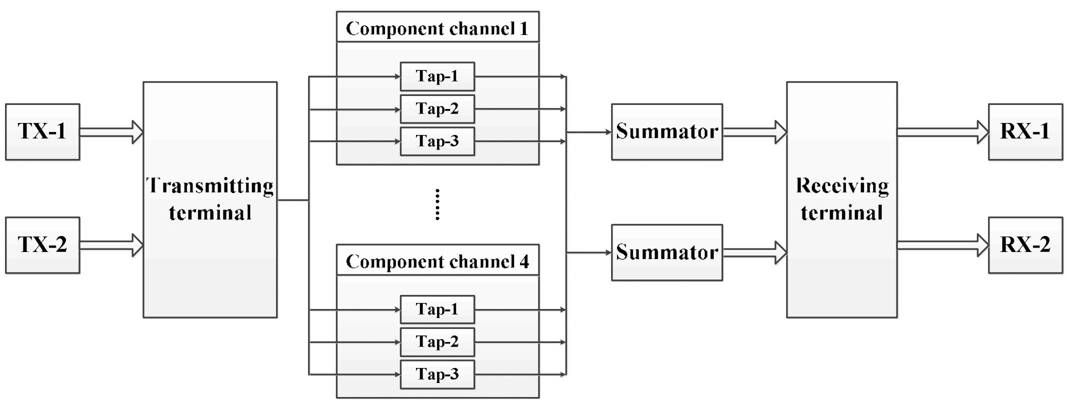
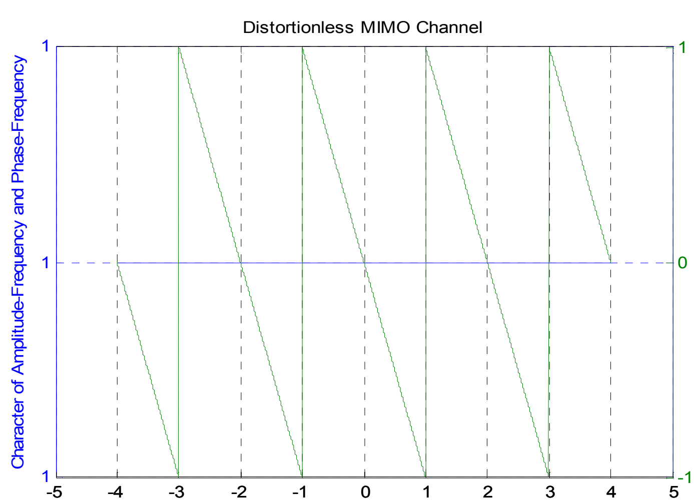


Fig. 4: Simulation model on MIMO channel according to IEEE802.16



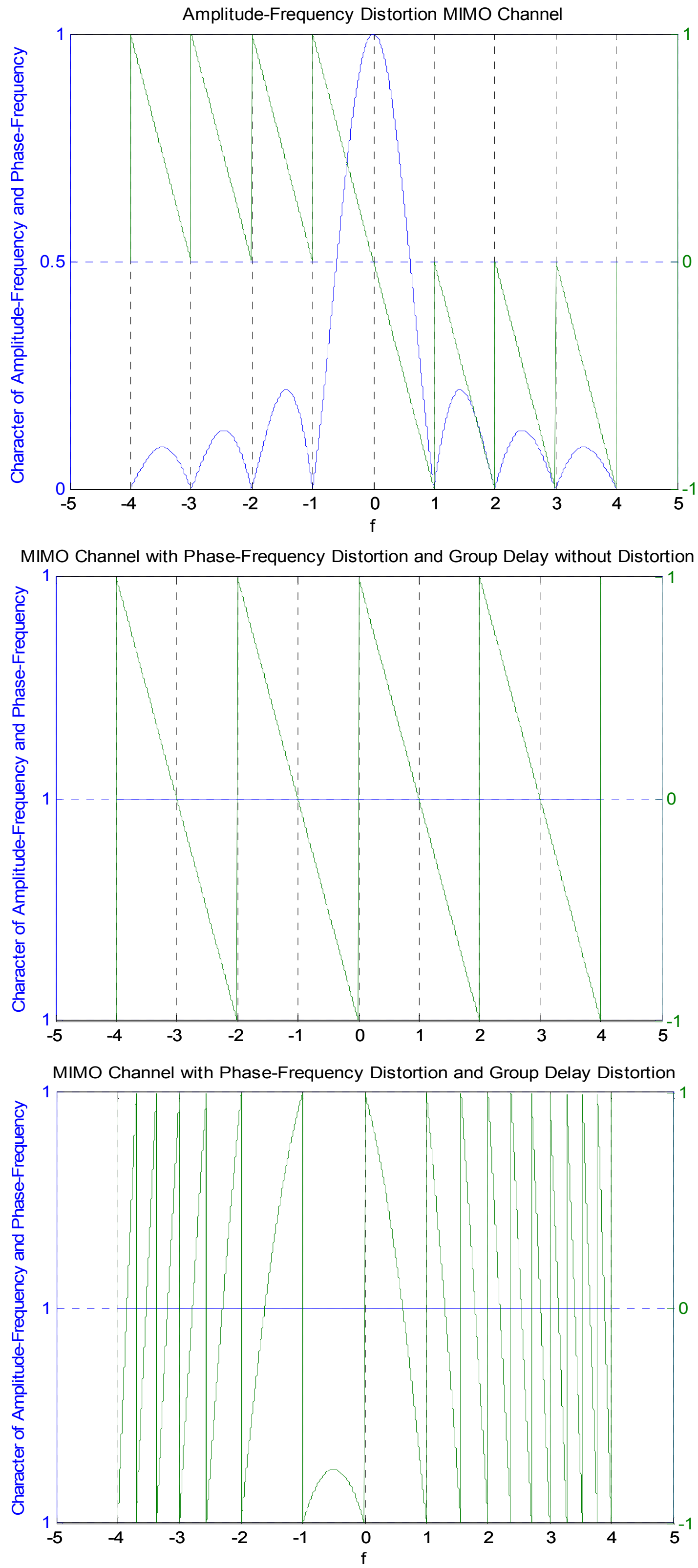


Fig. 5: Analysis on MIMO channel

Simulation result: Through the analysis on second segment and the simulation model on third segment, we can build the model by MATLAB. The simulation results can be shown in the following Fig. 5.

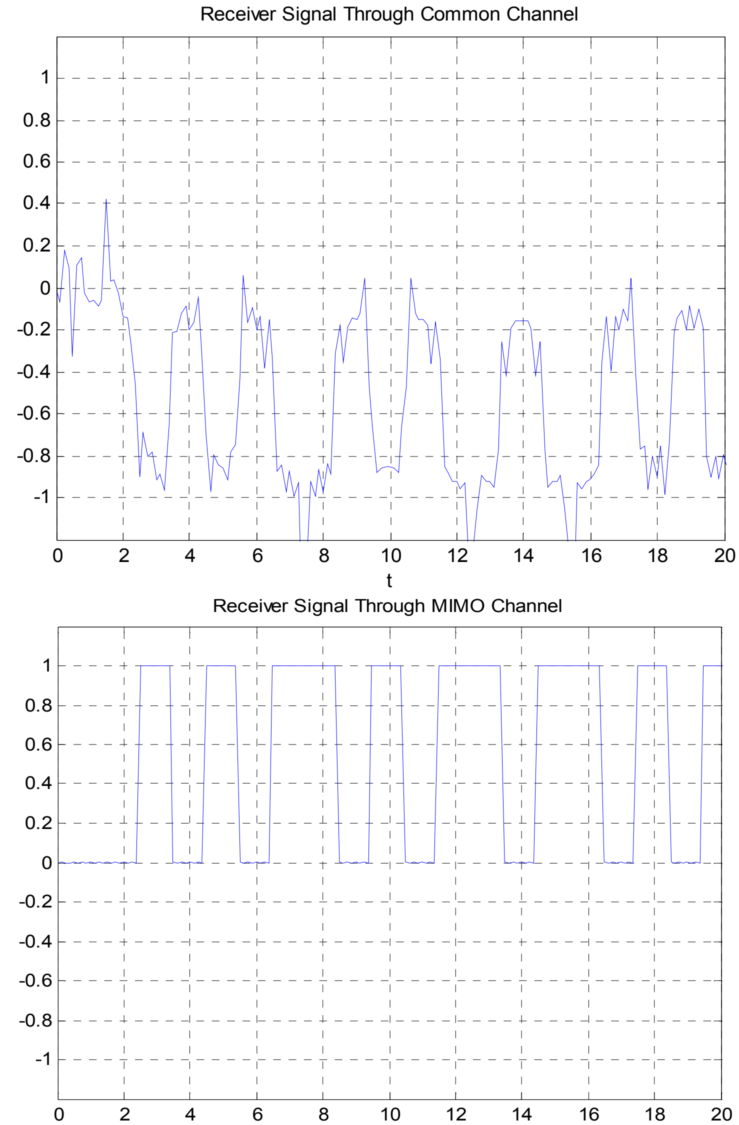


Fig. 6: Analysis on signal from common channel and MIMO channel

Through the simulation in above figures, we can get the result that compared with the common channel MIMO channel will have more advantages and that has been shown in Fig. 5. Through some distortions will be taken place in MIMO channel, but in the receiving signal will have higher quality in MIMO channel than in common channel and that has been shown in Fig. 6.

With the development of computer science and communication technology, I believe, more and more study will be taken on the MIMO technology. And better and better methods will be invented by more and more scholars.

CONCLUSION

Multiple- Input Multiple- Output Radio Transmission Technology has become to be one of the key technologies for the future wireless communication systems. The performance of MIMO communication depends largely on the fade characteristics of the radio channels. Hence, researches on the modeling of MIMO channel and the simulation technology are needed in order to facilitate the development of MIMO techniques.

In this study, some analysis on MIMO channel is described. It includes the concept and the key technology in the MIMO channel. And author makes analysis on how to build the MIMO channel model. There are many ways to build the channel, author choose to build the channel based on the concept of the MIMO system. Some analysis of the simulation on MIMO channel model is also described in this study. I think the way of simulation on MIMO channel model is very important and the results of simulation can show the advantages of MIMO channel, compared with the common channel.

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REFERENCES

Jiangang, L. and L. Yinghua, 2006. Antenna spacing effect on indoor MIMO channel capacity. Proceeding of Asia-Pacific Conference Microwave Conference Proceeding, 3: 142-145.

Levin, G. and S. Loyka, 2004. Statistical analysis of a measured MIMO channel. Proceeding of Canadian Conference on Electrical and Computer Engineering, 2: 875-878.

Lieberei, M. and U. Zolzer, 2009. MIMO channel measurements inside an aircraft cabin with planar transmit antennas. Proceeding of IEEE 9th Malaysia International Conference on Communications (MICC), pp: 229-233.

Mohamed, E.M., 2011a. Static and dynamic channel estimation techniques for MIMO-constant envelope modulation. Proceeding of IEEE GLOBECOM Workshops, pp: 549-554.

Mohamed, E.M. and O. Muta, 2011b. Channel estimation technique for MIMO-constant envelope modulation. Proceeding of 7th International Wireless Communications and Mobile Computing Conference, pp: 1433-1440.

Nayagam, A. and S. Katar, 2011. Tradeoff between channel estimation accuracy and application throughput for in-home MIMO power line communication. Proceeding of IEEE International Symposium on Power Line Communications and Its Applications (ISPLC), pp: 411-417.

Philosof, T., 2007. The cost of uncorrelation and noncooperation in MIMO channel. IEEE T. Inform. Theory, 53(11): 3904-3920.

Piazza, D., N.J. Kirsch, A. Forenza, R.W. Heath and K.R. Dandekar, 2008. Design and evaluation of a reconfigurable antenna array for MIMO systems. IEEE T. Antenn. Propag., 56(3): 869-881.

Taparugssanagorn, A. and J. Ylitalo, 2009. Characteristics of short-term phase noise of MIMO channel sounding and its effect on capacity estimation. IEEE T. Instrum. Meas., 58(11): 196-201.

Yiming, W., Z. Weihua, W. Jiawei, O. Aijun and Y. Jinming, 2011. Modified MIMO scattering wireless channel model and performance. Proceeding of 4th International Congress on Image and Signal Processing (CISP), 5: 2486-2489.