Indoor Distributed Multiple-input Multiple-output (MIMO) System Capacity Research Based on Angular Domain Information

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Abstract. In this paper, we research the indoor distributed multi-input multi-output (MIMO) system. We propose a method based on channel angular domain information feedback to improve the indoor distributed MIMO system capacity and stability. We elaborate on the theoretical analysis and modelling process of this method. The simulation results show that using angular domain information at the transmitter to construct the channel information matrix according to the antenna selection to optimize the power allocation and making use of the indoor distributed MIMO offers extra spatial degrees of freedom gain and antenna diversity gain. The proposed approach can significantly improve the signal to noise ratio (SNR), system capacity and stability of the system.

Keywords: Indoor Distributed MIMO, Angular Domain Information, Channel Capacity

1 Introduction

In modern life, the indoor data business traffic has grown rapidly. The related data shows that worldwide 3G indoor business accounted for nearly 70 percent of the total business volume.

However, using high-band 3G or LTE, the penetration and diffraction ability of its waves is much weaker than that of GSM. Therefore, much radio wave transmission attenuation is produced, forming a weak signal area or even a blind one. In [1] the respective advantages and disadvantages of the 900 MHz band and the 1.7 GHz band in the indoor radio communications systems were presented.

The indoor distributed system is a successful program for indoor users based on improving the mobile communication environment within buildings. Using an indoor antenna distributed system to distribute the base station signal more uniformly in every indoor corner will ensure that the indoor area has the ideal signal coverage. However, transmissions in indoor environments face harsh multipath channel degradation and obstacles. To ensure information reliability many papers have proposed that we create channel information feedback using the channel statistics characteristics that do not change with channel fluctuations [2]. In [3][4] the statistical properties of indoor multipath angle of arrival (AOA) were described. However, this method has poor accuracy and requires a lot of feedback, increasing the burden on the system. Reference [5] explored multi-antenna channel capacities in a more realistic propagation environment simulated via the ray-tracing tool.

This paper proposes an approach to improve the channel capacity of an indoor distributed MIMO system using angle domain information feedback to reconstruct the channel information matrix at the transmitter. This system format constructs an angular domain information model. This paper also uses the distributed MIMO technology and measured data to create a system simulation and performance analysis. The results show that this approach reduces the receiver complexity and amount of feedback and also improves the system channel capacity and spectral efficiency performance.

2 The Principle of Indoor Distributed MIMO System Based on the Angular Domain Information

2.1 Hardware Framework of System

This paper takes the structure of Base Band Unit (BBU) added with some Radio Remote Units (RRU) as the system framework, shown in Figure 1. The RRU of each floor leads to two feeders to transmit different signals. Each feeder connects multiple distributed antennas, which constitute the framework of the entire system. This new distributed network coverage mode uses optical fibre pulling the radio frequency modules in the base station to the remote radio units. This approach saves a large number of conventional solution engine rooms to realize the transition between the capacity and coverage.

The distributed MIMO technology makes efficient use of the space and time diversity effect to achieve more satisfactory link performance. Compared with the traditional single-antenna system or the multi-antenna system at the receiving end only, the MIMO channel provides power gain and improves the freedom gain as well.

In the distributed antenna propagation environment signal clusters are conducted as a unit, with more obvious multi-directional and multipath scatter propagation. A more accurate channel angular domain model can be used to describe the distributed system [6][7]. The angular domain information can be used to reconstruct the channel information matrix at the sending end to provide good data processing and resources allocation. At the same time the matrix can help produce fast power allocation and antenna selection, thus optimizing power allocation and reducing channel fading.

The system can also be extended to more than two feeders to further enhance the indoor distributed MIMO system performance.

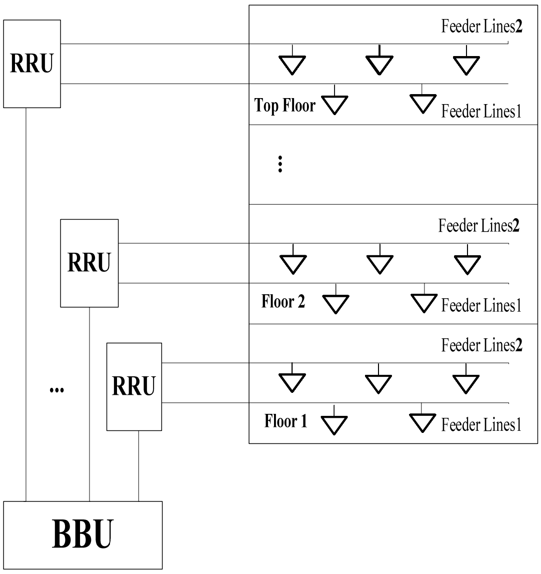

Fig. 1. System framework

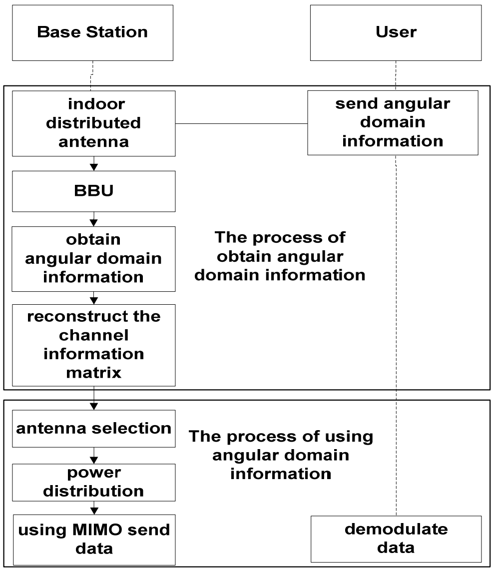

Fig. 2. The flow chart of using angle domain information to improve system capacity

2.2 Improving Indoor Distributed MIMO System Capacity Based on the Angular Domain Information

This paper proposes a method to enhance the indoor distributed MIMO system capacity based on channel angular domain information feedback. According to the angular domain information feedback from the receiver, the transmitter reconstructs the channel information matrix for different indoor environments and establishes an angular domain distributed MIMO channel model. It uses the singular value decomposition (SVD) method to decompose the channel information matrix after antenna selection. Power allocation for the selected transmitting antennas is made by the power water-filling algorithm. This method selects antennas that have larger channel gain and larger difference in angle of arrival, making use of the indoor distributed MIMO system to send each user the signal which that is waiting in each channel. The flow chart is shown in Figure 2.

3 System Model

3.1 System Channel Information Matrix

Before reconstructing the channel information matrix, the receiver needs to obtain the angular domain information through channel estimation, including the angle of arrival in receiving antennas φ, normalized distance between antennas Δ , that is the antenna spacing ratio and the carrier wavelength, the carrier wavelength λ_c, the actual distance of antennas interval $d = \Delta\lambda_c$, attenuation factor α. The receiver brings the angular domain information back to the transmitter, the transmitter reconstructs the channel information matrix, forms a MIMO channel angular domain model and thus clearly describes the channel fading situation and constructs an antenna diversity sending program.

If the state of the indoor distributed MIMO system channel is good and there is a strong line-of-sight (LOS) path, we can only select a transmitting antenna with a good state channel from every indoor distributed feeder to transmit signals. At the same time, different signals can be reused in the multiple feeders.

If severe multipath fading is present in an indoor distributed MIMO system, we will select more than one antenna with better angular domain information from each feeder to create transmission diversity to improve the signal to noise ratio and enhance channel stability. At the same time, different signals can be reused in the multiple feeders.

Therefore, the indoor distributed system can provide multiple degrees of freedom for reuse and also provide a variety of antenna combinations for diversity sending.

3.1.1 The Indoor Space Only Exists Line-of-sight (LOS) Transmission

The construction method for any line-of-sight channel gain between transmitting antenna and receiving antenna is [8]:

$$\overline{h}_{ik} = \alpha\sqrt{n_t n_r}\exp(-j2\pi d_{ik}/\lambda_c)\cdot e_t(\Omega_t)\cdot e_r(\Omega_r)\ . \tag{1}$$

The matrix of line-of-sight channel gain is:

$$\overline{H} = \begin{bmatrix} \overline{h}_{11} & \overline{h}_{12} & \overline{h}_{13} & \cdots & \overline{h}_{1n_\tau} \\ \overline{h}_{21} & \ddots & \cdots & \cdots & \vdots \\ \overline{h}_{31} & \cdots & \ddots & \cdots & \vdots \\ \vdots & \cdots & \cdots & \ddots & \vdots \\ \overline{h}_{n_r1} & \overline{h}_{n_r2} & \overline{h}_{n_r3} & \cdots & \overline{h}_{n_rn_\tau} \end{bmatrix} \tag{2}$$

In which, $\overline{h}_{ik}$ is line-of-sight channel gain between the kth transmitting antenna and the ith receiving antenna, α is the attenuation factor along the line-of-sight path, n_t and n_r are the amount of transmitting antennas and receiving antennas respectively, d_{ik} is the distance between the kth transmitting antenna and the ith receiving antenna. λ_c is the carrier wavelength.

Suppose ϕ_r and ϕ_t are the angle of arrival for the line-of-sight path of transmitting antenna and receiving antenna respectively. Define:

$$\Omega_r = \cos\phi_r \quad \text{and} \quad \Omega_t = \cos\phi_t\ . \tag{3}$$

The unit space feature map of Ω_r receiving direction and that of Ω_t transmitting direction are:

$$e_r(\cdot) = 1/\sqrt{n_r}[1, \exp(j2\pi\Delta_r\Omega_r), \cdots, \exp(j2\pi(n_r - 1)\Delta_r\Omega_r)]^T\ , \tag{4}$$

$$e_t(\cdot) = 1/\sqrt{n_t}[1, \exp(j2\pi\Delta_t\Omega_t), \cdots, \exp(j2\pi(n_t - 1)\Delta_t\Omega_t)]^T\ . \tag{5}$$

3.1.2 Existing Line-of-sight Propagation and Multipath Propagation in an Indoor Space

The channel gain construction method is:

$$H = \overline{H} + \widetilde{H}\ . \tag{6}$$

Here, the channel matrix H consists of two parts, in which $\overline{H}$ is the part of line-of-sight, and $\widetilde{H}$ is the part of non- line-of-sight (NLOS).

After scattering, the transmit signals with a form of multi-path to reach the receiving end, its angle of arrival is $\theta_{m,k}$, $k=1,\cdots,N_P$ is a random variable, in which N_P is the amount of multiple paths. According to the theory of electromagnetic propagation, the channel gain from the mth transmitting antenna to the nth receiving antenna is $\tilde{h}_{n,m}$, which can be expressed as the superposition of the every multipath signal:

$$\tilde{h}_{n,m}=\sum_{k=1}^{N_P}\alpha\exp(-j2\pi d_m/\lambda_c)\exp(-j2\pi(n-1)\Delta_r\cos\theta_{m,k})\ . \tag{7}$$

The matrix for the non-line-of-sight channel gain is:

$$\tilde{H}=\begin{bmatrix}\tilde{h}_{11} & \tilde{h}_{12} & \tilde{h}_{13} & \cdots & \tilde{h}_{1n_\tau}\\ \tilde{h}_{21} & \ddots & \cdots & \cdots & \vdots\\ \tilde{h}_{31} & \cdots & \ddots & \cdots & \vdots\\ \vdots & \cdots & \cdots & \ddots & \vdots\\ \tilde{h}_{n_r1} & \tilde{h}_{n_r2} & \tilde{h}_{n_r3} & \cdots & \tilde{h}_{n_rn_\tau}\end{bmatrix} \tag{8}$$

In which, d_m is the distance between the mth antenna and the first receiving antenna (the reference antenna) along the propagation path, Δ_r is the normalized distance between receiving antennas.

After channel matrix reconstruction, we can understand the real-time status of the channel, clearly know the channel capacity of different combinations of transmitting and receiving antennas, from which the maximum channel capacity antenna option can be chosen to realize antenna selection.

We use singular value decomposition (SVD) method to decompose channel information matrix after antenna selection, and use power water-filling algorithm to make power allocation for the selected transmitting antennas. Normalized indoor distributed MIMO channel capacity can be expressed as [9]:

$$c=w\sum_{i=1}^{n}\log_2[1+\frac{p_i\lambda_i^{\,2}}{\sigma^2}]\ . \tag{9}$$

In which, λ_i is the equivalent channel diagonal matrix $diag(\lambda_1,\lambda_2,...,\lambda_n)$ that is obtained by singular value decomposition after the receiving end obtains the channel information matrix. p_i presents the allocated power of the ith sub-channel under MIMO system. P is the total power. The constraint is then:

$$\sum_{i=1}^{N}p_i=P,i=1,2,...,N\ . \tag{10}$$

The purpose of the water-filling algorithm is to maximize equation (9). According to the Lagrange multipliers, we can get:

$$p_i=\frac{1}{P}-\frac{\sigma^2}{\lambda_i^{\,2}}\ . \tag{11}$$

By choosing P which meets the total power constraint, we can make power allocation of each antenna. According to the preset threshold, the system will allocate more power to the sub-channel with better channel conditions, while for the channel in poor condition, the system does not allocate power. The system can send data through the indoor distributed MIMO system according to the power allocation program.

3.2 The Channel Angular Domain Model

Suppose the angle of arrival (AOA) at the receiving end and the angle of departure (AOD) at the transmitting end obey uniform distribution. The power azimuth spectrum (PAS) is the angle distribution of signal power spectral density. Research shows PAS obeys three kinds of distribution: uniform distribution, truncated Gaussian distribution and truncated Laplace distribution. In this paper we use the truncated Laplace distribution [10], it can be given by

$$PAS_L(\varphi)=\sum_{k=1}^{N_c}\frac{Q_{L,k}}{\sqrt{2}\sigma_{L,k}}\exp(-\frac{\sqrt{2}|\varphi-\varphi_0|}{\sigma_{L,k}})\{u[\varphi-(\varphi_{0,k}-\Delta\varphi_k)]-u[\varphi-(\varphi_{0,k}+\Delta\varphi_k)\}\ . \tag{12}$$

Here $u(\phi)$ denotes unit step function, N_C is the number of wave cluster, φ_0 is average AOA, $\Delta\phi$ is range of AOA variation. Taking into account the potential power imbalance wave cluster, we can launch the normalization constant $Q_{L,k}$ to make $PAS_L(\varphi)$ to meet the requirements of the probability distribution function. The normalization condition of PAS is:

$$\sum_{k=1}^{N_c} Q_{L,k}[1-\exp(-\frac{\sqrt{2}\Delta\phi_k}{\sigma_{L,k}}]=1 . \tag{13}$$

Azimuth spread (AS) is the square root of second-order central moment of PAS, which distributes in $[0,2\pi]$. It reflects the signal power spectrum dispersion angle. The greater AS is, the smaller channels' spatial correlation is, and vice versa. In the indoor distributed system of this paper, antennas on every feeder line transmit the same signal, and adjacent antennas have the similar propagation environment. So we must consider the relation when building the channel matrix.

Under the condition of known AS, we can use the indiscernibility path in every wave cluster and build correlation matrix based on Kronecker [11][12] algorithm, then according to the relationship between the receiving and transmitting ends the channel matrix is determined, which is called the NLOS channel matrix. This method reduces the design complexity, making the receiving and transmitting end correlation matrix independent, that is, for all transmitting antennas, the receiving correlation matrix is the same, and vice versa.

For MIMO channel, the spacial distribution of different receiving antennas is defined as

$$R_{Rx}(\phi_0)=\sum_{m=1}^{Mr}\sum_{l=0}^{L-1} a((m-1)d\sin(f_{m,l}^{Rx}))\cdot a^H((m-1)d\sin(f_{m,l}^{Rx}))P_0(\phi) . \tag{14}$$

Here $R_{Rx}(\phi_0)$ denotes the correlation matrix of receiving end under the average AOA ϕ_0. $a(m-1)$ is the channel attenuation function, d is the normalized antenna distance. $f_{m,l}^{Rx} \in [\phi_0-\Delta\phi,\phi_0+\Delta\phi]$, $f_{m,l}^{Rx}$ is the AOA of the lth indiscernibility path of the mth receiving antenna, $\Delta\phi$ is angle spread, $P_0(\phi)$ is the power azimuth spectrum (PAS). Similarly, the spacial relativity of the transmitting end is

$$R_{Tx}(\phi_1)=\sum_{m=1}^{Mt}\sum_{l=0}^{L-1} a((m-1)d\sin(f_{m,l}^{Tx}))\cdot a^H((m-1)d\sin(f_{m,l}^{Tx}))P_1(\phi) . \tag{15}$$

Figure 3 is the flow chart of constructing channel matrix according to the correlation matrix of receiving and transmitting end, in which the correlation matrix is obtained according to angular domain model parameters and indoor measured data from WINNER channel models.

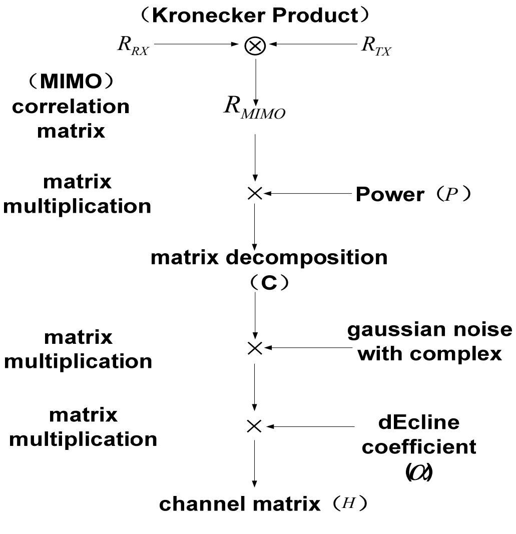

Fig. 3. Flow chart of structure MIMO channel model

Using R_{RX} and R_{TX} by Kronecker algorithm we can build the whole correlation matrix R_{MIMO} of MIMO channel, then we can decompose the R_{MIMO} to get MIMO channel spatial correlation matrix C. Next we allocate the power of every transmitting antenna according to the fading fact to determine the channel matrix H. This H is the channel matrix under multi-path channel.

In the situation of narrow-band Kronecker algorithm, MIMO channel matrix can be described as:

$$H = \Phi(R_{RX})^{1/2} H_W ({R_{TX}}^T)^{1/2} . \tag{16}$$

After getting NLOS and LOS channel matrix respectively, we can define channel matrix as [13]

$$H\,(d_n)=\alpha_{sh}^n(d_n)\cdot(\sqrt{\frac{K}{K+1}}H_{LOS}^n(d_n)+\sqrt{\frac{1}{K+1}}H_{NLOS}^n)\ . \tag{17}$$

Here H_{NLOS} is NLOS matrix, H_{LOS} is the part of LOS, K is Rice factor, α_{sh}^n is the shadow fading and path loss between mobile station (MS) and the nth antenna, it is defined as

$$\alpha_{sh}^n(d_n)=(\frac{d_n}{d_{\min}})^{-\frac{\varepsilon}{2}}\cdot 10^{\frac{\xi_n}{20}}\ . \tag{18}$$

Here $d_{\min}=\min\{d_n\mid n=1,\cdots,N\}$ is the minimum distance between transmitting antenna and MS, ε is path loss factor, ξ_n is Gaussian random variable, $\xi_n\sim N(0,\sigma_{sh,n}^2)$, $\sigma_{sh,n}^2$ is the standard deviation of shadow fading between the mobile station (MS) and the nth antenna.

The distributed MIMO system combines the characteristic of ordinary MIMO system and distributed antenna system, and it can be built using one MS and N feeder lines. Assuming that every MS has M antennas and every feeder line has L antennas. This system can be simplified as (*M*, *N*, *L*), and the whole channel matrix H containing *N* independent *L*M* sub-channel matrix can be written as:

$$H(d)=\begin{bmatrix}H_1(d_1)\\ H_2(d_2)\\ \vdots\\ H_N(d_N)\end{bmatrix}_{NL*M} \tag{19}$$

Here, we build an indoor distributed MIMO channel model, this model contains path loss, shadow fading and small-scale fading which obeys Rician distribution.

4 Numerical Results

In order to describe clearly the indoor propagation environment, the indoor antenna distribution schematic of one floor is shown in Figure 4. Position 1 presents preferable line-of-sight because of the open environment. Signal can be transmitted under good quality of channel by choosing antennas in different feeder lines. Position 2 is a place with a complicated environment that creates the signal multipath effect. Therefore according to the antenna determination strategy, using sub-antennas on some feeder lines to transmit individually can improve the SNR. Simulation results below are based on Figure 4. Assuming that the number of transmitting and receiving antenna is Mr and Mt, Rice factor is K, angle spread is AS, channel bandwidth is W.

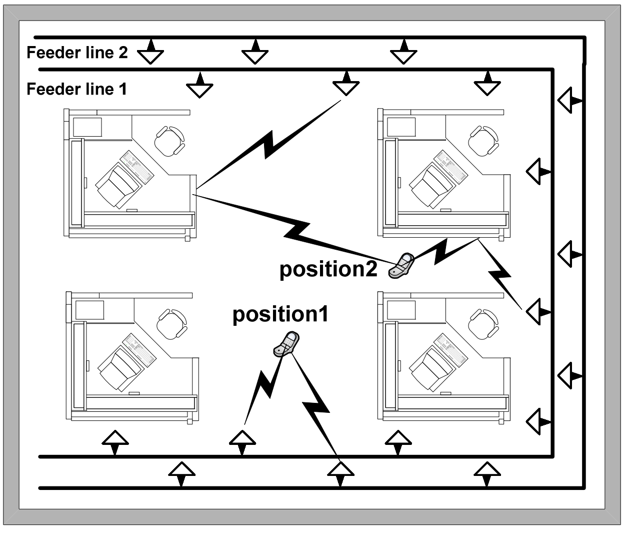

Fig. 4. Indoor antenna distribution schematic diagram

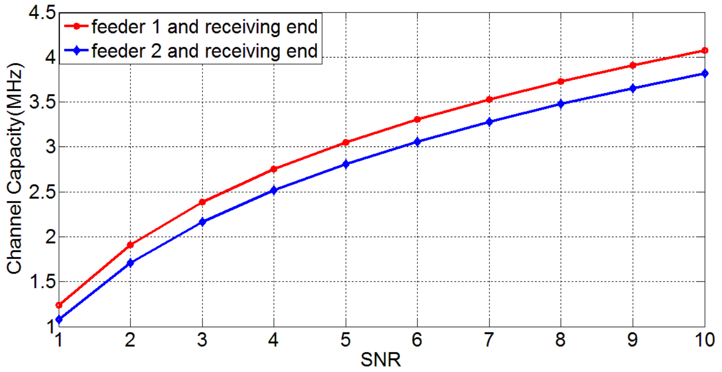

Fig. 5. Channel capacity contrast between feeder line 1 and 2, Mr=2, Mt1=Mt2=5, K=2, AS=5, W=1MHz

For simplicity, we normalize the channel bandwidth as 1MHz in the simulations. In Figure 5 we compare the channel capacity between feeder line 1 and 2 where average AOA is 20° and 25° respectively, and feeder line 1 is nearer to receiver than feeder line 2. It is clear that in this case the channel capacity of feeder line 1 is better as the SNR increasing.

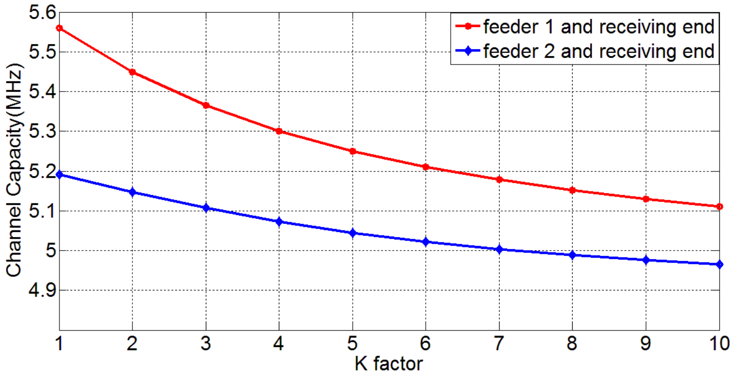

Fig. 6. Channel capacity contrast between feeder line 1and 2, Mr=2, Mt1=Mt2=5, SNR=15, AS=5, W=1MHz

From Figure 6 we can see channel capacity falls as Rice factor K rises. K stands for the LOS weight, if K increases, the NLOS is suppressed. As mentioned before, NLOS affects channel capacity, while LOS is a benefit for the SNR, the weight of LOS and NLOS must Compromise, so channel capacity will decrease.

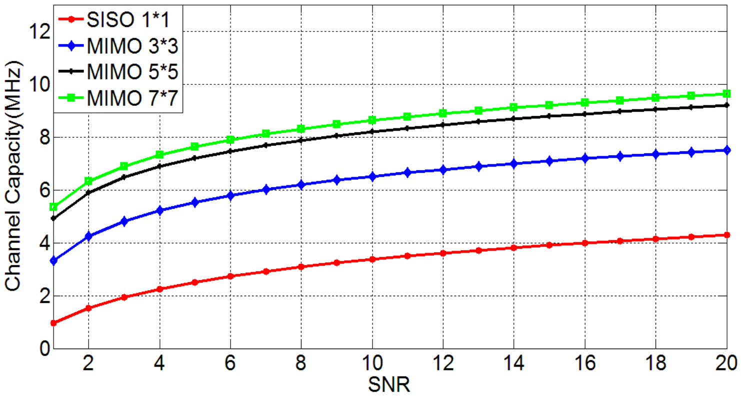

Fig. 7. Channel capacity in 4 kinds of indoor distributed system , K=2, AS=5, W=1MHz

Figure 7 shows the channel capacity simulation results in four kinds of indoor distributed systems. As the number of antenna pair rises, the channel capacity goes up, but the amplitude of rising goes down. So we must compromise between cost and requirement.

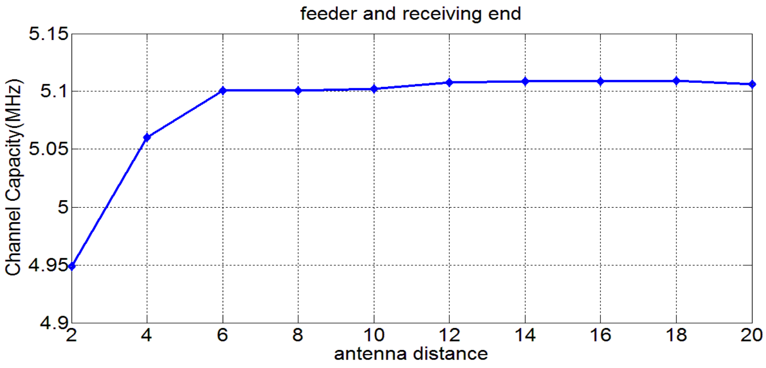

Fig. 8. Channel capacity in different antenna distance, Mr=2, Mt=5, SNR=15, K=2, W=1MHz

Next we study the distance effect between transmitting antennas on channel capacity as shown in Figure 8. With increasing normalized antenna distance, the relativity between antennas decreases, so the interference goes down and the channel capacity increases. When the distance grows over 12, we can see the channel capacity is stable, at this time every antenna is nearly independent.

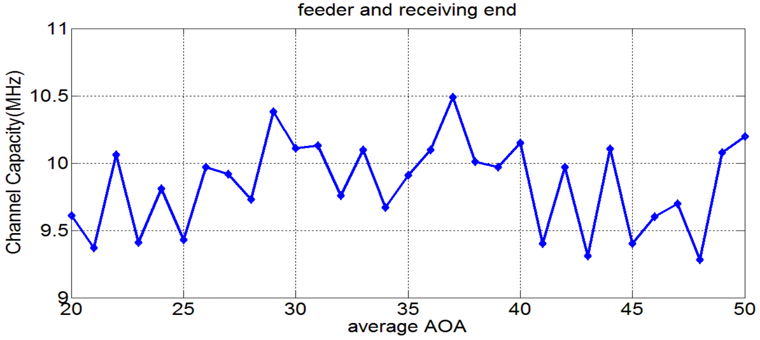

Fig. 9. Channel capacity in different AOA,Mr=5, Mt=5, SNR=15, K=2, W=1MHz

In Figure 9, channel capacity fluctuates greatly in different AOD. It results from the channel characteristic of time-variation.

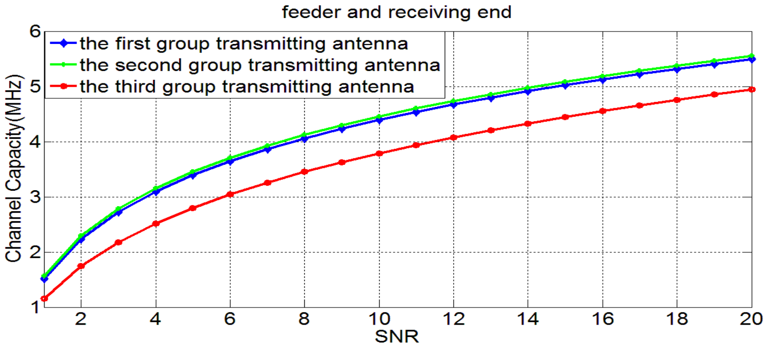

Fig. 10. Channel capacity in different group of transmitting antennas, Mr=2, Mt=6, K=2, W=1MHz

From Figure 10, we can see antennas on the same feeder line may have different AOD, according to the principle that the antennas that have similar AOD will be put into a group. We make 6 transmitting antennas into 3 groups and the number of receiving antennas is 2. So we build three groups 2*2 MIMO systems. Suppose the third group experiences harsh obstacles and has no LOS, we can see its channel capacity is obviously less than the other two groups. So we can design a threshold to choose the antenna groups reasonably and allocate power to the chosen antennas to produce channel capacity maximization.

5 Conclusion

This paper analysed the existing distributed MIMO system and proposed an approach to improve indoor distributed MIMO system channel capacity. This approach reduces the receiver complexity, the amount of feedback, makes antenna selection and power allocation rapidly, and thus will not only improve the system performance but also enhance the channel capacity and spectrum utilization.

This model synthetically considers small-scale fading, large-scale fading, shadow fading and the relative space between antennas. It is more comprehensive in reflecting the characteristic indoor distributed MIMO system, but also corresponds to the realistic application environment.

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