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Studies of Large-scale Antenna Beamforming Technology

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Abstract

The large-scale antenna has the advantage of application is strong, it can greatly improve the average throughput of the system, but also can save transmission power, becoming one of the key technologies of the fifth generation mobile communications. However, in FDD system, the sender configure a large number of antennas, the access of channel state information has become a problem to achieve; for this problem, we propose a bit allocation scheme, this scheme is based on jointly zero forcing beamforming, using random vector quantization method, and getting a better performance, the success of the application of traditional finite feedback technology to large-scale antenna system, the simulation results show the effectiveness and correctness of the proposed algorithm.

***Keywords**: combined with zero forcing beamforming; limited feedback; large scale antenna; bit allocation*

1. Introduction

Multiple input multiple output (MIMO) technology is an important innovation of current wireless communication transmission technology. Through the sending end and receiving end to configure multiple antenna, MIMO technology can improve the transmission rate of the system is exponentially, so as to improve the transmission rate and reliability of communication transmission power and bandwidth significantly in the same conditions. 3GPP introduced long term evolution (LTE) the most notable feature is the use of orthogonal frequency division multiplexing (OFDM) and MIMO technology.

At present, the application of MIMO technology has been more and more widely, the scale and complexity are increasing. In mobile cellular systems, along with the increasing data business and new business emerging, 3GPP has launched a study on the theory of LTE-Advanced, the peak data rate of up to 1.6Gbit/s LTE-Advanced, compared with the peak data rate of LTE technology in support of 326Mbit/s, the peak rate increased 5 times, has been to bring people into the era of "G". Among them, the multi user MIMO, based on MIMO technology for the characteristics of the relay technology and coordinated multi point transmission technology for the entire area of the spectrum utilization, solve problems and improve the network coverage area boundary throughput and average cell capacity upgrade problem plays a crucial role in. LTE-Advanced 3GPP Release 10 (R10) as an important component of the formulation, at the end of 2010, the final version. With the determination of R11 details, Release12 and arrange the subsequent versions of officially launched in 2012 June, enhanced version including MIMO technology, in the enhanced version of the MIMO technology, MIMO technology and CoMP on a large scale enhancement technology for the characteristics. While the deployment problem in large scale antenna has become a bottleneck for large scale MIMO application. Despite the deployment of large-scale multi antenna in the horizontal direction, it can obtain very good performance, but space is limited deployment makes its implementation problems. In order to overcome the disadvantages of the deployment of space constrained, full dimensional MIMO (FD-MIMO) technology is introduced in the wireless cellular system, it effectively solve the problem of large-scale MIMO deployment. With the introduction of full dimension MIMO, full dimension MIMO-OFDM system transmission scheme with the change, the resource allocation and scheduling strategy also needs to reconsider and optimize. Therefore, it is necessary to the resource allocation policy for all

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dimensions of MIMO-OFDM system combined with optimized characteristics of all dimensions MIMO, in order to achieve a better system performance.

All dimensions MIMO-OFDM system, since the arrangement of antenna from a horizontal arrangement changed into a two-dimensional lattice arrangement, in the spatial degrees of freedom, in addition to the horizontal dimension, it also increased the vertical dimension; directly bring the MIMO-OFDM channel model change, two-dimensional channel model by previously determined time frequency resource block under, changing to determine the time-dimension MIMO-OFDM channel model under the frequency resource block. As everyone knows, in the channel dimension changing conditions, resource block allocation mode, channel estimation method and its transmission in the process of sending and receiving the signal processing method and its space-time-frequency components are changed. However, with the increase of channel dimensions, it can also increase the scheduling of resources, thus it improves the spectrum utilization, further improve the system capacity. Compared to the relay technology, the CoMP technology can further improve the cell edge throughput, and improve coverage area. Combined with cognitive radio technology, the carrier aggregation technology and heterogeneous network technologies, to further the effective use of space-time spectrum resources combined, high efficient and reliable transmission of realization of the system. To sum up, with the introduction of wireless cellular system of all dimensions of the MIMO technology, wireless cellular LTE-Advanced system with MIMO-OFDM as the core and can exploit the spatial dimension increased, improves the performance of the whole system. How to make full use of the space dimension increase, responding to changes by the channel dimensions increase scheduling resources, space efficient allocation of resources increases, it is very meaningful to maximize the performance of the whole system.

2. Related Research

At present, the following unresolved difficulties still exist on how to realize the reasonable distribution of resources in all the dimensions in MIMO-OFDM system. (1) The completeness and general problem of all dimensions MIMO-OFDM channel model: in cellular mobile system, due to a variety of scenes, so according to different scenes, the establishment of full dimension MIMO-OFDM channel models; due to the lack of complete description method of full dimension MIMO-OFDM channel, resulting in most of all dimensions are for the MIMO-OFDM channel model the particular type of scene, so it does not have generality and completeness, which is not conducive to resource allocation of the follow-up. (2) The problems of channel estimation of full dimension MIMO-OFDM: since the full dimension MIMO-OFDM channel model of increased vertical dimension in the spatial domain, the conventional MIMO-OFDM channel estimation is two-dimensional, and all dimensions of MIMO-OFDM channel estimation related characteristics need to develop airspace, so it is the multi-dimensional channel estimation, the need to redesign meet the pilot sequences for channel estimation. Due to the lack of research, characteristics of the pilot sequence of channel parameters estimation of multidimensional therefore, relevant standards how to design relevant mechanism in all dimensions of MIMO-OFDM channel estimation and channel estimation performance is also a very difficult problem. In addition, in many cases, the system needs to consider the channel estimation overhead, this channel estimation method can be extended to put forward higher requirements. (3) The transmitting and receiving signal processing problem of full dimension MIMO-OFDM system: full dimension MIMO-OFDM system can be achieved in the large scale multi antenna deployment, but it can realize the traditional horizontal beam forming algorithm, but also can realize the vertical beamforming algorithm, the development and utilization of the vertical dimension can eliminate interference effectively, thereby enhancing the effectiveness and reliability of the communication system. In addition, the large-scale multi antenna deployment can be combined with the comprehensive consideration and CoMP technology and relay technology, deal with the sending and receiving signals will become more complex, it needs to consider many factors, this is the transmitting and receiving signal processing problems of the full dimension MIMO-OFDM system, it is one of the important problems of the design of full dimension MIMO-OFDM system. (4) The resource scheduling problem of the full dimension MIMO-OFDM system: the resources that needing for scheduling of full dimension MIMO-OFDM system can be divided into power, time, frequency and space resources, although only the space resources increased vertical dimension, but how to match power, time and frequency, to achieve optimal system performance; in addition, with the development of heterogeneous network, how to coordinate the network of a cellular network with other heterogeneous frequency and space resources, considering the power factor, to eliminate the interference of multiple networks, considering the user quality of service provided by multiple networks (QoS, Quality of Service), to achieve the optimal allocation of resources. Therefore, how to comprehensive coordination of power, time, frequency and space resources, and consider the interference coordination problem of different systems, the establishment of resource scheduling mechanism related to achieve optimal allocation of resources, more and more attention and concern, it has become a hot research subject.

At present, in the wireless cellular MIMO system and other radio system, channel modeling can be divided into three categories: (1) statistical model modeling method; (2) deterministic model modeling method; (3) random channel model modeling method. The advantages of statistical modeling approach is that the model has a certain universality, complexity modeling is relatively low, the disadvantage is relative to the actual channel, model error is larger, because of all kinds of parameters in the model are only used by the statistic characteristics and random generation. The method of the deterministic model modeling, modeling type suitable for residential planning, it can effectively carry out the best position analysis of base station deployment and then caused the coverage, capacity, prediction data transmission rate, the formulation but not suitable for transmission and resource allocation mechanism; with the modeling method of channel model of random criterion in wireless channel is generated based on the statistical model, because the shortcomings of large error, and the deterministic model implementation complexity is too high, thus compromising produced a modeling method of stochastic channel model. This method effectively classification greatly affects the accuracy of random channel model and the universality of the propagation environment. At present, the random channel modeling method is a widely studied channel modeling method based on geometric distribution, the statistical distribution of scattered through the body description exists in the communication of the scene in this method, the basic rules of using ray propagation in space through reflection, diffraction and scattering is followed to establish MIMO channel model. Using the 3GPP standard in the process of stochastic channel model based on geometric framework SCM (Spatial Channel Model) channel model and SCME (Spatial Channel Model Extended) channel model; channel of these models of MIMO are two-dimensional plane, without considering the transmitting antenna and the receiving antenna array and the highly scattering the transmission channel, and each sub path is in the two-dimensional plane, i.e. the various statistical features of them exist only azimuthal component, and no elevation component. Some foreign research organization such as WINNER launched a MIMO channel measurement and a lot of work, the statistical distribution of various channel characteristic parameters under different scenarios are obtained, and achieved great progress in the construction of full dimension MIMO model. The application of 3D antenna pattern, method given in [1] 3D antenna applied in SCM model, it used a 3D to 2D (Two dimensions) transform methods, but it remains essentially unchanged for the properties of the 2D MIMO channel model. To build a 3D MIMO channel model, the literature [2] was proposed based on the XPD (Cross-Polarization Discrimination) 3D MIMO channel model generated. The model used the plane of polarized component based on the superposition method to construct the 3D channel model, but this method uses the past experience on the relationship between XPD and channel modeling coefficients, there are still some deviations in the simulation of the actual MIMO channel. The literature [3] increased elevation components based on SCM, it presents the 3D SCM channel model. In addition, according to different application scenarios, literature [4] established full dimension MIMO channel model based on relay, literature [5] established vehicle network full dimension MIMO channel model. But so far there has been no comprehensive analysis and classification of full dimension MIMO-OFDM channel essential parameters, thus forming a completeness and general channel model.

Channel estimation is the method and process of the receiver know the channel state information, the accurate channel estimation is the key to improve the performance of receiver and the quality of data transmission, there is a premise condition which the space channels response in each group between transmitter and receiver have accurate estimation. At present, the MIMO-OFDM system channel estimation algorithm can be divided into the following three categories: non-blind channel estimation algorithm, semi-blind channel estimation algorithm and blind channel estimation algorithm. Based on. pilot symbol aided channel estimation algorithm is the signal processing needs the help of reference signal, the receiving end uses the reference signal, according to certain criteria to determine or adjust the weighting coefficient, so that the MIMO antenna output and input signal maximum correlation. Although the algorithm occupies a portion of the spectrum resources, but the implementation is easy and stability is good. Semi-blind channel estimation algorithm, the idea of the algorithm is to determine the initial value of non-blind algorithm, and then the blind algorithm for track adjustment. A blind channel estimation algorithm is proposed, the algorithm does not need to be transmitted reference sequence at the transmitter, as long as according to certain standards, to ensure the cost function to obtain the minimum value. This estimation method depends on the statistical properties of the transmitted data or uncertain information, through the corresponding signal processing technology to obtain the channel estimation value. As early as in 1978, R.A.Wiggins began to blind channel estimation by using the idea of higher order statistics, other researchers subsequently carried out on the basis of deep research. But the algorithm that this time to estimate the result precision is not high, when there is noise ,the error of estimation results is large . In addition, due to the high order statistics using the signal, thus causing another disadvantage of this kind of algorithm: it needs a huge amount of data, the convergence speed is very slow. Statistical methods the subsequent development are mostly focus on the two order statistics using the signal, such as auto correlation function, correlation matrix, it is the most studied subspace method. The noise subspace blind channel estimation method was proposed by Moulines, it has the advantages of fast convergence speed, high estimation accuracy, does not require accurate channel order estimation and other advantages, but when the zero of the channel appear in the subcarrier channel, it cannot be estimated, the researchers in-depth study on the basis of noise, for subspace, it has many fruitful improvement, and achieved remarkable results. Then there are scholars will be the algorithm combined with MIMO technology, and developed the noise subspace method for MIMO-OFDM system. The literatures present several commonly used techniques of channel estimation, including blind channel estimation method, semi-blind channel and non-blind channel, and gives the advantages and feasibility of these methods; literature [5] studies and discusses the MIMO-OFDM channel identification conditions and achieve a based on subspace blind channel estimation technique. The method is that the existing blind channel OFDM SISO system in the subspace estimation algorithm with unified finally popularized in MIMO-OFDM system.

Full dimension MIMO-OFDM channel estimation is the initial stage at present, which are based on pilot channel estimation algorithms, literature [6] is the earliest concerned the space correlation problem of the sending end, and apply it to the channel estimation, forming a three-dimensional pilot estimation model, so as to improve the accuracy of channel estimation. The literature [7], Gunter Auer to design the effective bandwidth full dimensional MIMO-OFDM system in the downlink channel of the pilot, the pilot design optimization from the pilot overhead perspective, the introduction of the multidimensional sampling theory to the conventional pilot, reduce 50% of the pilot overhead.

Domestically, the full dimension MIMO-OFDM channel estimation algorithm is studied mainly in the Tsinghua University, Beijing University of Posts and Telecommunications, Southeast University, University of Science and Technology of China, University of Electronic Science and technology and other units. Most of the domestic research can be classified as "the channel estimation algorithm based on pilot", such as three kinds of pilot design in four dimensions on full dimension MIMO-OFDM channel estimation based on Beijing University of Posts and Telecommunications proposed by Zhang Jianhua et al. Tsinghua University professor Gao Feifei for two-way relay topology scenarios channel estimation algorithm are studied deeply. Professor Zhang Zhongpei of University of Electronic Science and technology building on all dimensions of the MIMO channel model, channel estimation and beamforming algorithm was studied in many aspects. Research status of full dimension MIMO-OFDM channel estimation above, can be estimated even in the initial stage of that full dimension MIMO-OFDM channel, the research mostly concentrated in the first class of blind channel estimation algorithm based on non-blind channel estimation, for semi-blind channel estimation and blind channel estimation algorithm are lacking of research. In addition, the first class of non-blind channel estimation algorithm research for non ideal factors considered less based on robustness, so the research is relatively poor. Present situation of comprehensive research, how to build can be estimated accurately with robust channel estimation mechanism is yet to be studied and solved.

Objective to study the sending and receiving signal processing of full dimension MIMO-OFDM system is: in the configuration of full dimensional multi antenna conditions, it can make full use of the space dimension, the frequency dimension resources, through the combined signal processing with receiver and transmitter, eliminate the interference between the antennas, including inter carrier, among many users, the inter cell and heterogeneous system between, improve system performance. The research of this aspect is estimated control research status of full dimension MIMO-OFDM channel model and MIMO-OFDM channel full dimension, the research is limited to the sending end design of beam forming. The vertical dimension Yang Song for full dimension multi antennas to increase proposed vertical dimension beam forming method, improves the throughput of the system. Literature [6] presented Kronecker product codebook design based on limited feedback multi-user scenarios frequency division duplex communication system. Literature [7] presented 3D MIMO-OFDMA interference coordination technology based on the vertical beam forming, the simulation results show the effective improving user SINR. Document [7] first introduced the double code separate levels codebook and vertical codebook in the design plan, to effectively improve the district average spectral efficiency of the system.

In view of the above mentioned aspects of research status, far from the sending and receiving signal processing limitations involved in beamforming algorithm, balanced way of comprehensive research on space time frequency coding mode, the receiving end and beamforming implementation mode. In addition, the combination of CoMP technology and relay technology, sending and receiving the signal processing is more complex, it needs much time and energy on input.

3. The Proposed Scheme

Consider a multi cell downlink transmission model in this paper, consider L cell, each cell's base station antenna configurations are large-scale, large-scale antenna and transmission mode is FDD, so for obtaining channel state information, there is relatively difficult, this article is based on this, according to the existing channels with limited feedback in FDD, the allocation of the number of feedback bits, each base station antenna configuration is N_t , and the number of antenna more than 100, the number of users each base station service is K , each user configure one antenna, with k_i is the k -th user of i -th cell, which the channel of the j -th BS to the user k_i can use vector $\mathbf{h}_{j,k_i}$. In order to channel model is established considering the large scale and small scale fading, so the vector $\mathbf{h}_{j,k_i}$ can be defined as

$$\mathbf{h}_{j,k_i} = \sqrt{d_{j,k_i}}\mathbf{w}_{j,k_i} \tag{1}$$

Where d is the path gain between the BS j to the user k_i, $\mathbf{w}_{j,k_i}$ represents small-scale fading , each element of the real and imaginary parts are subject to the standard normal distribution, so every link follows Rayleigh fading. Assuming each time slot allocated its quasi-static distribution of small-scale fading, each slot holds independent and identically distributed. This paper argues for a large -scale fading, the BS side is aware that the received signal for the user k_i

$$y_{j,k_i} = \mathbf{h}_{j,k_i}\mathbf{x}_i + \sum_{\substack{j=1,k_i=1 \\ j\neq i}}^{K} \mathbf{h}_{j,k_i}\mathbf{x}_j + n_{k_i} \tag{2}$$

Where $\mathbf{x}_i$ is column vector of signals transmitted by the i -th cell , and n_{k_i} represents the variance of normalized white Gaussian noise signal.

In this article, because it is a large-scale antennas disposed on the BS side, so the use of a relatively simple way of beamforming, *i.e.*, combined zero forcing beamforming, thus eliminating inter-cell interference between the clusters associated collaborative BSs, since such beamforming mode under high SNR conditions optimal full multiplexing gain, as defined the BS i and its associated user channel direction information recorded as $\tilde{\mathbf{h}}_{i,k_i} = \frac{\mathbf{h}_{i,k_j}}{\|\mathbf{h}_{i,k_j}\|}$, while other user channel state information may be expressed as $\tilde{\mathbf{h}}_{i,\mathrm{j}} = \frac{\mathbf{h}_{i,j}}{\|\mathbf{h}_{i,\mathrm{j}}\|}$. Beamforming matrix can be obtained from the principle of zero-forcing algorithm

$$\mathbf{T}_i = \tilde{\mathbf{H}}_i\left(\tilde{\mathbf{H}}_i^H\tilde{\mathbf{H}}_i\right)^{-1} \tag{3}$$

where, $\tilde{\mathbf{H}}_i = \begin{bmatrix}\tilde{\mathbf{h}}_{i,k_i} \\ \tilde{\mathbf{h}}_{i,\mathrm{j}}\end{bmatrix}$. According to the above mentioned collaboration zero forcing algorithm for FDD systems, no longer has the uplink and downlink channel duality, therefore, limited feedback technology, we use random vector quantization method , this method uses a certain fixed bit quantify, considering a certain number of bits is B, the number of bits used to quantify $\mathbf{h}_{j,k_i}$, but the number of bits used to quantify $\tilde{\mathbf{h}}_{i,\mathrm{j}}$, with B_I represents the number of bits used in quantizing $\mathbf{h}_{j,k_i}$, using B_J represents the number of bits which quantizing $\tilde{\mathbf{h}}_{i,\mathrm{j}}$. Then

$$B = B_I + B_J \tag{4}$$

And whether it is B_I or B_J , using the following formula (5) represents

$$\hat{\mathbf{h}}_{i,\mathrm{j}} = \arg\max_{c\in C} \frac{\left|\mathbf{h}_{i,\mathrm{j}}C_i\right|}{\|\mathbf{h}_{i,\mathrm{j}}\|^2\|C_i\|^2} \tag{5}$$

In such a quantization scheme, user k_i get the signal to interference noise ratio

$$\Psi_{i,k_i} = \frac{P_{k_i}\left|\mathbf{h}_{i,k_j}\hat{\mathbf{T}}_{k_i}\right|^2}{\sum_{l\neq k} P_{l_i}\left|\mathbf{h}_{i,k_j}\hat{\mathbf{T}}_{l_i}\right|^2 + \sum_{j\neq i,n} P_{l_i}\left|\mathbf{h}_{i,k_j}\hat{\mathbf{T}}_{n_i}\right|^2 + 1} \tag{6}$$

The final cell capacity can be obtained based on the feedback obtained transmission rate, which can be expressed as

$$R_i = E\left[\sum_{k=1}^{K} \log_2(1+\Psi_{i,k_i})\right] \tag{7}$$

According to cell capacity, the paper identifies the feedback bits, we can define the optimization problem of the bits of feedback as

$$\max_{\{B_I, B_J\}} \sum_{i=1}^{L}\sum_{k=1}^{K} \log\left(1+\Psi_{i,k_i}\right) \quad , s.t.\ \mathrm{B}_I, \mathrm{B}_J \in [0, \mathrm{B}] \tag{8}$$

According to the optimization problem, we can get the optimal bit allocation scheme . In this paper, the bit allocation poor search method , process for its allocation

1. For n=1； B=B-1;
2. Calculating $M(n) = \sum_{i=1}^{L}\sum_{k=1}^{K} \log\left(1+\Psi_{i,k_i}(n)\right) - \sum_{i=1}^{L}\sum_{k=1}^{K} \log\left(1+\Psi_{i,k_i}(n-1)\right)$ ； n=2， …,B;
3. If $M(n)$ >0;
4. n=n+1;
5. Else
6. B= B_I ;then B_J =B- B_I
7. END

We can also use the distribution characteristics of random matrices, according to this feature, getting simple suboptimal solution ; the solution process can be:

$$\Psi_{i,k_i} = \frac{P_{k_i} E(e_1)}{\sum_{l \neq k} P_{l_i} E(e_2) + \sum_{j \neq i,n} P_{l_i} E(e_3) + 1} \tag{9}$$

Where

$$e_1 = \cos^2\left(\angle\left(\tilde{\mathbf{h}}_{i,k_i}, \hat{\mathbf{c}}_{k_i}^H\right)\right) \tag{10}$$

$$e_1 = \cos^2\left(\angle\left(\tilde{\mathbf{h}}_{i,k_i}, \hat{\mathbf{c}}_{l_i}^H\right)\right) \tag{11}$$

$$e_1 = \cos^2\left(\angle\left(\tilde{\mathbf{h}}_{i,k_i}, \hat{\mathbf{c}}_{n_i}^H\right)\right) \tag{12}$$

While

$$E(e_1) = \left(\frac{1}{2}\right)^{\frac{\log_2 e}{N_t - 1}\sum_{n=1}^{2^{B_i}}\frac{1}{n} + \log_2 e \sum_{n=1}^{N_{t-1}}\frac{1}{n}} \tag{13}$$

Formula (11-12) also can get the same distribution , according to this distribution , we can get local optimal solution for their specific expression

$$B_I = (\mathrm{N}_t - 1)\log_2\left(e^{-\frac{\gamma}{N_t - 1}} + \sqrt{\left(e^{-\frac{\gamma}{N_t - 1}} + \frac{P_k(\mathrm{K}-1)+1}{2^{-t_1} P_n K}\right)}\right) \tag{15}$$

4. Simulation Results and Analysis

In the following simulation, all simulations are based on a multi-cell assignment carried out , the number of cells used in this paper is a 19 -cell coordinated clusters , each cluster has seven cells collaborate article focuses on two bits of feedback information assigned numbers , it does not concern about the distribution of inter-cell users , consider the quantized channel direction information, and the use of random vector quantization method, the paper select the transmitting antenna is most commonly used in large-scale antenna 128, each cell uses 20 need customer service, so you can get the total of nineteen small capacity, which were compared to obtain comparative this program and other programs.

For different scenarios, SINR and the average area of the total transmission rate is obtained, and the total average transmission rate for the i-th cell, shown in Figure 1-2. In Figure 1 is an ideal CSI, 12 bits and the capacity of 4 bits.

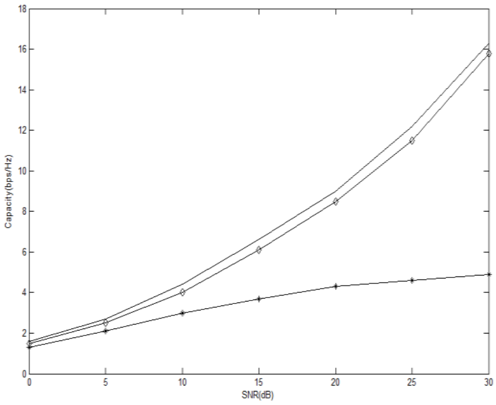

Figure 1. Feedback Bits vs. Rate

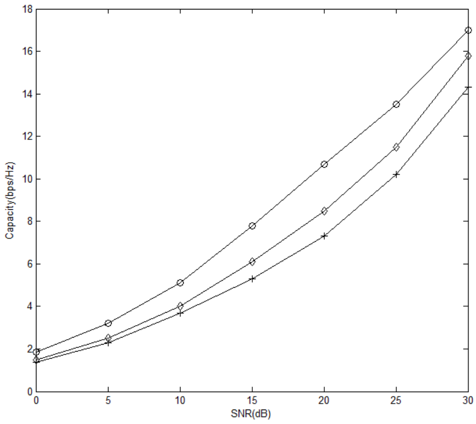

Figure 2. SNR VS. Capacibility

In Figure 2 is an ideal CSI, 8 bits and the capacity of 6 bits. From Figure 1-2, it can be seen, the proposed scheme, *i.e.*, under conditions of mutual cooperation, when the number of bits per cell exceeds 20 bits , and its advantages will gradually become apparent.

5. Conclusion

Through the proposed joint zero-forcing algorithm, the success of the FDD mode limited feedback channel state information acquisition method is applied to large-scale multi-cell cooperative antenna configuration scenarios, and by derivation, has been poor search law optimal bit allocation solution; at the same time, according to the random nature of the matrix, the calculation of its statistical properties, and it finally get a relatively low computational complexity suboptimal solution, this solution can effectively calculate the bit allocation , and more practical. Simulation results show the effectiveness and correctness of the proposed scheme.

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