

The advanced progress of precoding technology in 5g system

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Abstract. With the development of technology, people began to put forward higher requirements for the mobile system, the emergence of the 5G subvert the track of the development of mobile communication technology. In the research of the core technology of 5G mobile communication, large scale MIMO, and precoding technology is a research hotspot. At present, the research on precoding technology in 5G system analyzes the various methods of linear precoding, the maximum ratio transmission (MRT) precoding algorithm, zero forcing (ZF) precoding algorithm, minimum mean square error (MMSE) precoding algorithm based on maximum signal to leakage and noise ratio (SLNR). Precoding algorithms are analyzed and summarized in detail. At the same time, we also do some research on nonlinear precoding methods, such as dirty paper precoding, THP precoding algorithm and so on. Through these analysis, we can find the advantages and disadvantages of each algorithm, as well as the development trend of each algorithm, grasp the development of the current 5G system precoding technology. Therefore, the research results and data of this paper can be used as reference for the development of precoding technology in 5G system.

1. Introduction

Mobile communication technology has brought infinite convenience to our lives, but also to make our lives more fun, while narrowing the distance between people, changing people's way of communication, interconnection. With the continuous increase of the number of mobile users, people's requirements on the speed and quality of mobile communication are also increasing, which will promote the sustainable development of mobile communication. At present, the fifth-generation mobile communication (5G) technology has the advantages of low energy consumption, higher security, faster speed, high efficiency, and 100% coverage. How to improve the capacity of the system and reduce the energy consumption is an important part of the research on the key technologies of 5G. In the core technology of 5G, large scale MIMO, precoding technology [1-3] is the core technology of MIMO can improve the capacity, reduce the bit error rate and simplify the complexity of the receiver, which plays an important role in the performance of the system.

In the Linear Precoding algorithm, maximum ratio transmission (MRT) precoding algorithm is very simple, is close to the optimal algorithm of constrained system, each user can maximize the signal-to-noise ratio (SNR), but did not consider the interference between users. The zero forcing (ZF) precoding algorithm can completely remove the interference from other users in the cell, but it will lose some signal gain, without considering the influence of noise on the signal. According to the scheme, each antenna cannot be processed by using the ZF precoding algorithm. Better than the pre ZF precoding technology, the minimum mean square error (MMSE) precoding algorithm for smaller SNR, MMSE matrix to allow retention of some interference cost, can maximize the receiver signal to



interference plus noise ratio (SINR). Though and MMSE precoding scheme is similar to that of the maximum signal to leakage and noise ratio (SLNR) based on precoding algorithm not only maximizes each user desired signal energy, and reduce the target users leaked to the interference and noise power of other users and at the same time, the number of schemes for transmitting and receiving antenna without limit, the balance users and the equivalent channel gain caused by adjacent cell interference users. Compared with Linear Precoding, nonlinear precoding is more complex, but also improves the accuracy, so that it can be closer to the upper limit of MIMO channel capacity. In the nonlinear precoding technology, dirty paper precoding can cancel the interference at the transmitter. When the noise and interference are independent and identically distributed, this kind of precoding can theoretically approach the ideal capacity of the channel, so it is regarded as the optimal algorithm. As a sub-optimal implementation method of dirty paper precoding, THP precoding can effectively avoid the noise being amplified and offset the interference between multiple antennas and multiple users in MIMO system. It can be adjusted according to the actual situation, so as to realize the optimization of

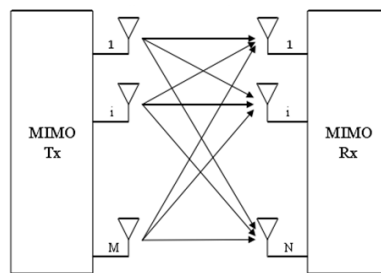


Fig. 1. Simplified diagram of large-scale MIMO

the performance.

According to the precoding technology of 5G system research, collects the domestic and foreign research literatures in this area, to understand the theoretical knowledge and research background, through the derivation of the basic mathematical theory and physical basis, in-depth study of each precoding algorithm. This paper analyzes and summarizes the advantages and limitations of Linear Precoding and nonlinear precoding from the theoretical point of view, and puts forward the improvement scheme, which provides reference for the development of precoding technology in 5G system. As a research hotspot, precoding technology plays an important role in the development of mobile communication technology. The precoding technique in complexity optimization of 5G system to improve the performance of capacity, reduce the error rate, simplify the receiver, can reduce energy consumption and improve the speed and quality of mobile communication, it has a good application prospect.

Large Scale MIMO System

Large scale MIMO system is one of the most important components of 5G, which can greatly improve the system capacity and spectrum efficiency, and reduce energy consumption. MIMO communication system in the transmitter receiver using multiple antenna elements, by using the characteristic of the high dimensional space of wireless channel, the data stream is divided into multiple independent data streams have assigned to the antenna port the same time-frequency resources on parallel transmission, transmission channel estimation at the receiver and then sent to the user space characteristics of data detection and recovery. MIMO system simplified transmission model shown in Fig. 1: MIMO Tx side contains M transmit antenna, MIMO Rx side contains N receiving antenna, the entire antenna Space Bureau rights $M \times N$ data communication link, with the Receiving signal through the MIMO channel receiver can be expressed as:

$$\mathbf{r} = \mathbf{H}\mathbf{y} + \mathbf{n} \quad (1)$$

Among them, \mathbf{n} represents the additive Gauss white noise vector of the Rx side receiving antenna. In order to obtain higher gain and reduce the complexity of signal processing in recent years, the large

scale MIMO system has been proposed, the antenna system base station side equipment large magnitude (100 and above), and a single antenna terminal service. Before analyzing the precoding method, we first analyze the spectral efficiency of the system

2. System Spectral Efficiency

For point-to-point MIMO systems, the transmitter and receiver are equipped with M and N antennas, respectively. In the transmission of a signal vector condition, the received signal vector \mathbf{r} on the receiving side can be expressed as:

$$\mathbf{r} = \sqrt{\rho}\mathbf{H}\mathbf{y} + \mathbf{n} \quad (2)$$

where \mathbf{H} denotes the system downlink channel matrix, \mathbf{n} denotes the noise and interference signal, and the scalar coefficient ρ denotes the transmission power. Assuming that the transmitted signal is a Gaussian signal that is independent of the same distribution, the system capacity can be expressed as:

$$C = \log_2 \det \left(\mathbf{I} + \frac{\rho}{M} \mathbf{H}\mathbf{H}^H \right) \frac{bps}{Hz} \quad (3)$$

When the receiver antenna is infinite, the transmitter antenna is the constant, that is, $N \gg M$, $N \rightarrow \infty$, for the case that M is a fixed constant, similarly to obtain the spectral efficiency can be approximated as:

$$C \approx M \log_2 \left(1 + \rho \frac{N}{M} \right) \frac{bps}{Hz} \quad (4)$$

2.1 Uplink

When the number of antennas on the base station side increases near infinity, it is assumed that the small-scale fading of different terminals is independent. The theory can deduce that the column channel vectors obtained by different terminals are progressive and orthogonal, and obtain:

$$\mathbf{H}^H \mathbf{H} = \mathbf{D}^{1/2} \mathbf{G}^H \mathbf{G} \mathbf{D}^{1/2} \approx \mathbf{N} \mathbf{D}^{\frac{1}{2}} \mathbf{I} \mathbf{D}^{\frac{1}{2}} = \mathbf{N} \mathbf{D} \quad (5)$$

A simple MF (Match Filter) detection process on the base station side can be obtained:

$$\mathbf{H}^H \mathbf{r} = \mathbf{H}^H (\sqrt{\rho}\mathbf{H}\mathbf{y} + \mathbf{n}) \approx \mathbf{M} \sqrt{\rho} \mathbf{D} \mathbf{y} + \mathbf{H}^H \mathbf{n} \quad (6)$$

When the base station antenna number tends to infinity, the channel vector is progressive and orthogonal, and the inter-terminal interference can be eliminated, but the MF detection cannot filter out the noise. When there is no interference between the end signals, the spectral efficiency of the single terminal is close to the limit of the spectrum efficiency. In this scenario, the simplified MF detection process on the base station side can achieve the optimal detection effect.

2.2 Downlink

The downlink terminal side \mathbf{y} represents the signal vector received by all N terminals. In TDD mode, the downlink MIMO system downlink channel can be represented by the transpose \mathbf{H}^T of the upstream channel. The terminal reception signal can be expressed as:

$$\mathbf{r} = \sqrt{\rho}\mathbf{H}^T \mathbf{y} + \mathbf{n} \quad (7)$$

After receiving the MRT precoding process, the receiving end receives the signal as:

$$\mathbf{r} = \sqrt{\rho}\mathbf{H}^T \mathbf{H}^* \mathbf{D}^{-1/2} \mathbf{P}^{-1/2} \mathbf{y} + \mathbf{n} \approx \sqrt{\rho} \mathbf{M} \mathbf{D}^{\frac{1}{2}} \mathbf{P}^{-\frac{1}{2}} \mathbf{y} + \mathbf{n} \quad (8)$$

With the appropriate power distribution options, the above equation can achieve optimal system spectral efficiency, which also means that when the base station side antenna number tends to infinity, using simplified MRT precoding processing can obtain a rate near the channel capacity. In the following, we will analyze linear precoding and nonlinear precoding algorithms.

3. Analysis of Linear Precoding Algorithm

In the large-scale MIMO system, the precoding technology is divided into linear and non-linear, each precoding technology its own adaptation condition. Linear precoding is divided into single antenna precoding and multi-antenna precoding algorithm. In the implementation of precoding technology, it can get better performance, while the complexity is also low, and also easy to realize. In a single-cell large-scale MIMO system, the base station precodes the signal and sends the signal vector to the user.

3.1 Maximum specific emission (MRT) Precoding algorithm

In the downlink, the maximum ratio transmission (MRT) precoding algorithm [4-6] performance depends largely on the channel transmission environment. When in the ideal case that the algorithm in the base station to different users of the terminal signal, there is a big advantage. The MRT precoding expression for the kth user in the cell is:

$$W = H^H \quad (9)$$

MRT precoding can maximize the signal-to-noise ratio of each user. In the case where the interference between users is negligible compared with noise, MRT is a near-optimal algorithm in signal constrained systems and is very simple. But it does not take into account the interference between users, it does not apply to such as the interference between the larger user complex transmissions environments.

3.1.1 Forced Zero (ZF) precoding algorithm. Compared to the pre MRT precoding technology, zero forcing (ZF) precoding algorithm [7][8] can eliminate the interference between users, the signal received in the user system is less affected other user interference, the channel matrix K users, in addition to the main diagonal elements other than are close to 0. ZF precoding algorithm specific experimental procedures for the:

(1) In the end, the channel is estimated by using the pilot signal, and the estimated value of the channel matrix is obtained.

(2) The estimated channel matrix is fed back to the base station, and the precoding matrix is calculated.

(3) The precoding matrix is calculated at the transmitter, and the ZF precoding can be used as the pseudo inverse matrix of the user channel matrix:

$$W = H^H (HH^H)^{-1} \quad (10)$$

It can be concluded that the ZF precoding technology makes the receiving end of the signal received by the cell is less affected by other user interference. But at the same time, the user interference is lost, and some signal gain is lost. Therefore, when the number of users in the cell or the noise is relatively small compared with the interference, ZF precoding has better performance. However, the ZF precoding technology can only deal with the overall data processing of the antenna, the antenna cannot be separated one by one, and there are some limitations.

3.1.2 Minimum Mean Square Error (MMSE) precoding algorithm. MMSE precoding algorithm [9] compared with ZF precoding algorithm considering the performance of the whole system, as far as possible to maximize the SINR performance, by introducing a parameter, the scheme in low signal-to-noise ratio under the conditions of a better performance. The precoding matrix is expressed as:

$$W = H^H (HH^H + \beta I)^{-1} \quad (11)$$

The expression can be seen when SNR, beta tends to zero MMSE precoding algorithm results in ZF and precoding algorithm, inter user interference is the main factor affecting the system performance; when the SNR is low, the beta becomes large, MMSE allows users to retain part of the interference and do may the maximum signal-to-noise ratio, no loss of signal gain. The MMSE precoding algorithm is superior to the ZF precoding algorithm in eliminating the interference between users and noise.

3.1.3 Precoding algorithm based on maximum signal to noise ratio (SLNR). Similar to MMSE, maximum signal to noise ratio (SLNR) precoding algorithm [9] in the goal of maximizing the user desired signal based on energy at the same time, reduce the target users to other users with the channel of the total interference power, namely power interference and noise to maximize each user desired signal power and channel with other users and caused. Specific expressions are as follows:

$$SLNR_k = \frac{\|H_k W_k\|^2}{\sum_{m=1, m \neq k} \|H_m W_k\|^2 + \left(\frac{\sigma_n}{\sigma_s}\right)^2} \quad (12)$$

Thus, the maximum signal to leakage and noise ratio based precoding matrix based on SINR is different from the maximum precoding matrix, SLNR precoding, each matrix is not mutually coupled, so according to the actual situation of each user in SLNR optimization and adjustment of the

precoding matrix. In multi user MIMO system based on SLNR precoding (SLNR) eliminates the co channel interference (CCI) and noise, regardless of the number of antennas for transmitting and receiving, the balance of the cell user and the equivalent channel gain of adjacent cell interference problems caused by the user. At the same time to reduce the interference to other users, the interference is reduced accordingly, so the system performance is improved.

3.2 Analysis of Nonlinear Precoding Algorithm

3.2.1 Dirty Paper Precoding. The nonlinear precoding algorithm [10] is different from the Linear Precoding algorithm, which has higher accuracy and complexity. The following will introduce the DPC precoding. The dirty paper precoding was proposed by Costa, he will be in the process of signal transmission interference compared to paper stain, specific location and size assumes known stain, then according to the known information to get the same amount of information and no stain on the paper, the amount of information is transmitted signal, noise and interference and. Under the condition of known interference intensity, the technology can be used to cancel the interference at the transmitter. It is proved that the dirty paper precoding is the closest to the ideal channel capacity when the noise is independent and identically distributed.

In the dirty paper precoding, signal power and interference power energy simultaneously in the additive Gauss noise channel transmission, and the interference signal and the target signal is not affected, it has been recognized as a dirty paper precoding is optimal. However, due to the huge amount of dirty paper precoding calculation, it is difficult to realize the interference and noise, and the matrix is completely removed.

3.2.2 THP precoding. Compared with dirty paper precoding, THP precoding [11] is a suboptimal implementation method. THP precoding in 1972 by Tomlinson and Harashima put together, it was originally used in the time domain to resist inter symbol interference, and has been widely used in the space under the MIMO system to cancel the interference among many users, compared to Linear Precoding is more expensive, the system is more complex, but also effectively avoid the noise the problem of amplification. There are three main components in the THP system, which are the feedforward filter, the feedback filter and the modulo arithmetic. Its method is to use the finite feedback filter under the condition of known CSI and combine the modulo adder to achieve the purpose of canceling ISI. As a result, second users cancel the interference of the first user, the third user offsets the interference of the first two users, and so on, and the interference from the preceding user that is contained by the user can be offset. According to the actual number of users, the THP precoding can be divided into two categories, including the THP precoding system applied to a single user and the THP precoding system applied to multi-user.

(1) Precoding System Design Suitable for Single-user

In the single user MIMO system, in order to eliminate the interference between the antennas, the feedback filter B is placed at the transmitter, and the feedforward filter F is placed at the terminal to ensure the joint processing of all antennas. The gamma scale diagonal matrix.

(2) System Design Suitable for Multi-user

Considering multi-user MIMO, the feedforward filter cannot guarantee that all users are jointly processed. Therefore, the feedforward filter at the receiving end in the single-user MIMO system is moved to the transmitting end to avoid the joint processing of the receiving antenna, which greatly simplifies the receiving end of the device. At the same time, THP precoding is divided into centralized THP precoding and distributed THP precoding according to the different positions of the scale diagonal matrix.

Among them, the centralized precoding system is mainly for users in the basic similar environment, with a variety of identical conditions such as noise interference. The decentralized precoding system is for those users who are independent of each other and with much different environment conditions.

4. Conclusion

Precoding technology is a hot spot in the current research, through a variety of different algorithms to the real life in different conditions of the signal to be processed to maximize the signal received by the end user. This paper discusses the linear and nonlinear precoding, linear precoding concern with low complexity and can obtain better performance at the same time, also to be able to analyze nonlinear precoding technology is close to the ideal channel capacity on the greatest degree. Thus, it is concluded that the optimal choice for precoding in various situations. The research and analysis foundation for large-scale MIMO application in 5G system.

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