IJESMR

International Journal of Engineering Sciences & Management Research

TECHNICAL ANALYSIS OF MASSIVE MIMO KEY TECHNOLOGY IN 5G

Ratnesh Kumar Jain
Associate Professor, Department of Electronics and Communication Engineering,
RKDF University, Bhopal (M.P.)
Email id- ratneshjain29@rediffmail.com

ABSTRACT

The advent of the fifth-generation mobile communication network (5G) has sparked widespread interest and significant research efforts from global corporations, research organizations, and academic institutions. Among the key technologies envisioned for future 5G networks, massive Multiple Input Multiple Output (MIMO) technology stands out for its potential to enhance spectrum utilization and communication channel capacity. This paper provides a comprehensive analysis of the standardization process for MIMO technology and highlights the technical advantages of massive MIMO. It explores various application scenarios and examines channel measurement and modeling from a detailed perspective. Furthermore, the paper delves into the intricacies of channel estimation, precoding, and signal detection technologies within massive MIMO systems, concluding with a comprehensive summary.

INTRODUCTION

The exponential growth of wireless mobile communication has resulted in a surge in the number of mobile users and the scale of related industries. Consequently, wireless communication systems are required to support higher data transmission rates and increased system capacity. Efficient utilization of bandwidth resources is crucial due to the scarcity of spectrum resources. While traditional MIMO technology has enabled the use of limited spectrum resources to meet users' performance requirements, it is constrained by the limited number of antennas in base stations, thereby limiting system performance. Massive MIMO, recognized as a key technology for future 5G networks, addresses these limitations by enhancing spectrum efficiency and channel capacity, thereby improving link reliability and data transmission rates [1].

Traditional MIMO Technology:

First proposed by Marconi in 1908, MIMO technology involves equipping both transmitting and receiving ends with multiple antennas to enhance communication system capacity, data transmission rates, and reliability. The 3GPP LTE Release 10 already supports up to 8 antenna ports for transmission, enabling simultaneous transmission for 8 single-stream users or 4 dual-stream users. However, the scalability of traditional MIMO technology is limited by factors such as mobile terminal size, power consumption, and aesthetics. To further enhance data transmission capacity, increasing the number of data streams transmitted in parallel or the number of base station antenna ports is a logical approach.

Table1. MIMO technology standardization process

Standard	MIMO technology	Characteristic
Rel-8	Transmit diversity	Support up to 4 layers of transport
	Space division multiplex beamforming	Only support single layer transport

IJESMR
International Journal of Engineering Sciences & Management Research

	MU-MIMO	Up to two rank1 UE
Rel-9	Double stream beamforming	SU/ MU flexible switch
		Up to 4 data streams (up to 2 levels per UE) Use the transmission mode of non-code book
		Support channel reciprocity based feedback
Rel-10	High order MIMO	Support up to 8 layers of transport
		High precision feedback based on two level multiparticle codebook
	Uplink MIMO	Support up to 4 layers of transport
Rel-11	CoMP	Multi-cell coordination MIMO
Rel-12	CoMP/3DMIMO	Multi-cell coordination MIMO/ 3D
Rel-13	3DMIMO	Expanded into a three-dimensional (3D) antenna array

Massive MIMO technology

In 2010, Marzetta, a researcher at Bell Laboratories, introduced the concept of massive Multiple Input Multiple Output (MIMO) within the context of multiple cell and Time Division Duplexing (TDD) scenarios [2]. This brought to light various distinguishing features from the limited number of antennas typically found in a single cell. Massive MIMO technology entails equipping the base station with a large number of antennas, typically ranging from a hundred to several hundred antennas, which is orders of magnitude higher than those in existing communication systems. It facilitates simultaneous servicing of multiple users on the same time-frequency resource, with mobile terminals usually adopting a single antenna reception mode. The fundamental model of massive MIMO is depicted in Figure 1.

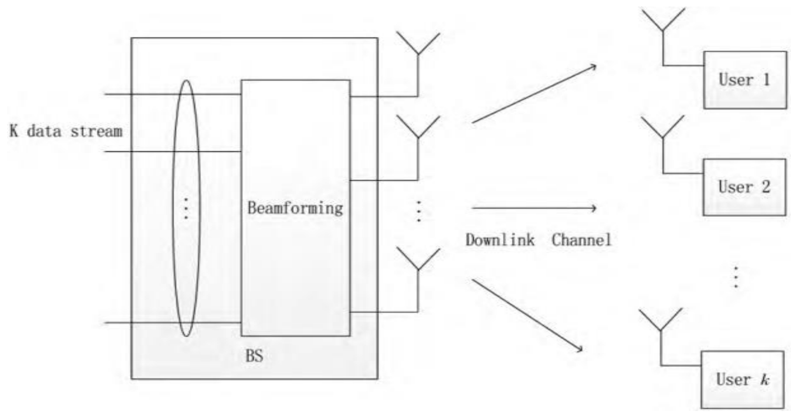

Figure 1 Basic model diagram of massive MIMO

Technical Advantages of Massive MIMO:

The primary advantages of massive MIMO technology are as follows:

Low Antenna Power Consumption: Ideally, with a fixed total transmitting power, the transmitted power utilized by each antenna decreases inversely with the number of antennas. Consequently, the power consumed per antenna diminishes inversely with the square of the number of antennas. Thus, the power consumption in massive MIMO applications is significantly reduced.

Channel "Hardening": As the number of antennas approaches infinity, the channel matrix can be analyzed using random matrix theory. The singular values of the channel matrix converge towards a

IJESMR
International Journal of Engineering Sciences & Management Research

known asymptotic distribution [4], and the channel vectors tend towards orthogonality. As a result, simple signal processing methods become asymptotically optimal.

Reduction of Thermal Noise and Small-Scale Fading Effects: Utilizing linear signal processing, the impact of thermal noise and small-scale fading on system performance decreases as the number of antennas increases. Consequently, the influence of thermal noise and small-scale fading becomes negligible compared to inter-cell interference.
Improved Spatial Resolution: With an increased number of base station antennas in a massive MIMO system, beamforming can focus transmitted signals to specific points in space. This enables the base station to accurately distinguish each user, thereby enhancing spatial resolution.

Performance Comparison between Massive MIMO and Traditional MIMO:
Within the framework of 3GPP, MIMO technology evolves across single-user MIMO, multi-user MIMO, and network MIMO. Compared to traditional MIMO technology, massive MIMO exhibits superior performance in various aspects. Table 2 presents a performance comparison between traditional MIMO and massive MIMO.

Table 2. Performance comparison between traditional MIMO and massive MIMO

Technology content	Traditional MIMO	Massive MIMO
The antenna number	≤8	≥100
Channel angular domain value	Uncertain	Certain
Channel matrix	Low requirement	High requirement
Channel capacity	Low	High
Diversity gain	Low	High
Link stability	Low	High
Resistance to noise	Low	High
Array resolution	Low	High
Antenna correlation	Low	High
Coupling	Low	Low
SER	High	Low
Pilot pollution	No	Yes

Massive MIMO application scenario
Macro cell and micro cell co-exist under the application scenario of 5G massive antenna array. The network is mainly divided into homogeneous and heterogeneous network, while the scenarios are divided into indoor scenarios and outdoor scenarios. It is known from the test of relevant literature that about 70% of mobile communication systems on land are indoor. Therefore, massive MIMO channels can be divided into micro cell base station for indoor or outdoor users and macro cell base station for indoor or outdoor users. At the same time, the micro cell can be used as relay base station to transmit information, and the channel can be divided into macro cell base station and micro cell base station. The number of antennas of base station can be increased infinitely, and the number of mobile user antennas in the cell can also be increased.

Massive MIMO channel measurement and modelling
When the wireless transmission condition is ideal, the channel vector between transmitter and receiver is gradually orthogonal due to the increase number of antenna of massive MIMO system. The following is the main research and analysis of massive MIMO channel measurement and modelling.

IJESMR
International Journal of Engineering Sciences & Management Research

The theoretical channel model of massive MIMO system can be effectively verified through the channel measurement in the actual wireless communication environment, and the performance of the entire communication system can be improved by measuring the actual channel [5].

- The distributed MIMO channel is measured under the condition of 2.6ghz micro cell. The measurement method is mainly to use three base stations under distributed MIMO to be equipped with four groups of antenna units, so that the height of its space meets the condition of co-directional polarization. The last base station is used to configure an antenna unit. A mobile platform consists of a uniform cylindrical array with 64 pairs of dual-polarization antenna units. By analysing the cross correlation of the massive fading of communication links between different base stations, the massive fading values of the channels at different locations are obtained.
- Measurement method of linear array with 128 units. Literature [6] described 26 users transmitting at different stadia under 2.6ghz and 10 users transmitting at non-stadia, and deployed 128 unit antenna array at the base station terminal, and set half wavelength as the antenna spacing, with 7.3m as the length of the antenna array. By verifying the massive MIMO channel under the above configuration, it can be known that the massive antenna array is a wireless communication channel when some invisible scattered or highly variable scattered power values exist, and cannot be regarded as a generalized stationary process. However, since the non-stationarity of the antenna array and the effect of near field can remove the correlation between the users, thus providing a relatively stable and low-interference channel environment.

Massive MIMO channel modelling

Due to the rapid development of 5G technology, massive MIMO channel modelling shows some new features. For example, in the deployment of massive antenna array at the base station terminal, spherical waves should be used to replace plane waves [7] and channel energy should be concentrated in limited space. The channel is no longer independent and identically distributed. With the increasing antenna array at the base station terminal, only different antenna units can see different scatterers, and the fading is characterized by non-static characteristics [8].

Channel state information acquisition technology

Bell Labs proposed a transmission scheme for the TDD mode of massive MIMO system. Mobile users in cellular networks (usually single antenna) transmit orthogonal pilot signals to base station terminal, by receiving the pilot signal to the target base station. According to the value of CSI of the uplink estimated by the channel, the reciprocity of the uplink and downlink of TDD system is used, and the CSI of the downlink is characterised by conjugate transpose of CSI of the uplink. Thusthe detection of uplink signal and downlink precoding are transmitted. When the number of cell users increases, the pilot cost estimated by the channel will also increase, especially in the case of medium and high speed mobile communication, the pilot cost will occupy most of the time -frequency resources. Therefore, when the pilot frequency of TDD transmission mode is limited, it is of great practical value to study the CSI technology of massive MIMO. Compared with FDD mode, TDD mode can provide a more ideal method to obtain CSI.

Massive MIMO precoding technology

Studies have shown that the massive MIMO precoding technology plays a crucial role in breaking the bottleneck of the downlink capacity of the system. Nowadays, in the downlink transmission of massive MIMO [9], the technology of signal processing of transmitter is largely used to transform the complexity of massive MIMO system from terminal side to base station side. At present, there are mainly linear and nonlinear precoding algorithms, linear is composed of ZF, MF precoding and Block

ISSN: 2349-6193
Impact Factor: 3.866

IJESMR

International Journal of Engineering Sciences & Management Research

Diagonalization (BD), while non-linear is composed of Dirty Paper Coding (DPC), auxiliary grid method, Vector Perturbation (VP) and so on.

Linear precoding

The current linear and non-linear precoding techniques have been extensively studied, enabling the massive MIMO precoding technique to mitigate the impact of pilot pollution on system performance. The typical linear precoding algorithm will be emphatically introduced below.

- ZF zero-forcing precoding. In the literature [10], it proposed that ZF precodingshould adopt channel parameters replaced by pseudo-inverse matrix. In the literature [11], the ratio α of the number of base station antennas M to the number of terminals K is constant. By simultaneously increasingM and K, the matrix Trace { $(G^H G)^{-1}$ } can be astringed to 1 / (α - 1), whereA^H represents the Hermite conjugate transpose of matrix A.
- MF matched filtering. The inverse operation of k *k dimension matrix in ZF precoding will increase the computational complexity of the algorithm. In the massive MIMO, GHG/M gradually approaches the identity matrix. By simplifying the inverse operation of the matrix, the performance of ZF precoding tends towards that of MF precoding. In the case of antenna array expansion, MF precoding matrix will be infinitely close to ZF.
- Precoding based on MMSE. The allocation of training sequence needs to be considered when designing the precoding scheme in the multi-cell massive MIMO system. The MMSE precoding scheme proposed in literature [12] can reduce pilot pollution. Compared with the single-cell scenario, the MMSE precoding matrixA^{opt} is obtained by the optimal solution of the target function. The target function is established mainly by the mean square error of the signal received by the same cell userand the mean square interference between the users of the cross cell.

Nonlinear precoding

Nonlinear precoding is composed of vector disturbance (VP) [13], DPC and auxiliary network methods [14]. When M and K are not very large in cell, nonlinear precoding can show some advantages. The approximate expression of SNR in VP with complete CSI is mentioned in literature [15].

Massive MIMO system signal detection algorithm

Base station distributes time-frequency resources to different users and provides services to a large number of users. In the massive MIMO system of multi-cell and multi-user, when the cell terminal sends the transmitted signal to the cell base station, the base station can detect the uplink signal received by the space signature.

Linear detection

When the cell base station is equipped with massive antenna array, the performance of MRC receiver can reach the optimal linear receiver (OLR) performance if the condition of lower signal to interference plus noise ratio (SINR) is satisfied, but it is lower than OLR under the condition of high SINR. In the case of large interference, the performance of OLR will be optimized compared with that of typical MMSE receiver system.

Nonlinear detection

- Algorithm based on tree structure (TB). Spherical decoding (SD) [16] can be said to be a typical nonlinear detection algorithm, and SD is actually a maximum likelihood (ML) decoder. The disadvantage of the SD algorithm is that it only takes into account the points within a specific radius and it should expand the radius to find any signalling point. In the existing low complexity TB, adding only the most valuable nodes can effectively reduce the search complexity.
- Random Step (RS) method. The principle of the algorithm is: select an initial vector, evaluate itsperipheral vector N_{Neigh} ,take MSE as the condition, select MSE as the minimum

ISSN: 2349-6193
Impact Factor: 3.866

IJESMR

International Journal of Engineering Sciences & Management Research

vector, repeat the above process $Niter$times.

CONCLUSION

Massive MIMO technology is considered by the industry as a key technology in future 5G. It can significantly improve the channel capacity, energy efficiency and spectrum efficiency of wireless communication system. This paper analyses the standardization process of MIMO technology in detail, and the performance advantages of massive MIMO compared with traditional MIMO. It analyses and compares the application scenarios, channel measurement and channel modelling of massive MIMO, and analyses the channel estimation technology, pre-coding technology and signal detection technology in massive MIMO system. In the future, due to higher requirements for hardware complexity by massive MIMO, pilot pollution limits the improvement of system performance, and there are still many challenges to be completed.

REFERENCES

1. HUH H , CAIRE G , PAPADOPOULOSHC , etal. Achieving " massive mimo" spectral efficiency with a Not-so-LargeNumber of Antennas[J]. IEEE Transactions on Wireless Communications , 2011 , 11 (9) ; 3226 -3239
2. MARZETTA T L. Noncooperative cellular wireless with unlimited numbers of base station antennas[J]. IEEE Trans- actions on Wireless Communications, 2010 , 9 (11) : 3590 - 3600
3. Qiu ling. MIMO communication technology of multi-user and multi-cell [M]. Beijing: people's posts and telecommunications press, 2011
4. TULINO A M, VERDU S.Random matrix theory and wireless communications[J]. Communications & Information Theory , 2004 , 1 (1) : 1 -182
5. GAO X , EDFORS O , RUSEK F , et al. Linear pre-coding performance in measured very-large mimo channels[C]. Vehicular Technology Conference, 2011 IEEE
6. PAYAMI S , TUFVESSON F. Channel measurements andanalysis for very large array systemsat 2 . 6 GHz[C]// Euro- pean Conference on Antennas and Propagation. 2012 : 433 - 437 .
7. ZHOU Z , GAO X , FANG J , et al. Spherical wave channel and analysis for large linear array inLoS conditions[C]// IEEE GLOBECOM Workshops. IEEE , 2015
8. GAO X , TUFVESSON F , EDFORS O. Massive MIMO channels — Measurements andmodels[C]// Asilomar Conference on Signals , Systems and Computers , 2013 : 280 -284 .
9. HARASHIMA H, MIYAKAWA H. Matched-transmissiontechnique for channels with intersymbol interference[J]. IEEE Transactions on Communications, 1972 , 20 (4) : 774 – 780.
10. LI H , LEUNG V C M. Low complexity zero-forcing beam- forming for distributed massive MIMO systems in large public venues[J]. Journal of Communications & Networks , 2013 , 15 (4) : 370 -382.
11. HOCHWALD B , VISHWANATH S. Space-time multiple access: linear growth in the sum rate[J]. Proc. annual Allerton Conf. communications Control & Computing , 2003 .
12. JOSE J , ASHIKHMIN A , MARZETTA T L , et al. Pilot contamination and precoding in multi-cell TDD systems[J]. IEEE Transactions on Wireless Communications , 2011 , 10 (8) : 2640 -2651 .
13. vector-perturbation technique for near-capacity multi- antenna multiuse communication-part II :perturbation[J]. IEEE Transactions on Communications, 2005 , 53 (1) : 195 -20
14. WINDPASSINGER C , FISCHER R F H, HUBER J B. Lattice-reduction-aided broadcast precoding[J]. IEEE Transactions on Communications , 2005 , 52 (12) : 2057 - 2060 .

ISSN: 2349-6193
Impact Factor: 3.866

IJESMR

International Journal of Engineering Sciences & Management Research

15. RYAN D J , COLLINGS I B , CLARKSON I V L, et al. Performance of vector perturbation multiuser MIMO systems with limited feedback[J]. Communications IEEE Transactions on , 2009 , 57 (9) : 2633 -2644 .
16. LARSSON E G. MIMO Detection methods: how they work [Lecture Notes][J]. IEEE Signal Processing Magazine, 2009 , 26 (3) : 91 -95 .