Analysis on Theory of MIMO and Research on Channel Capacity of MIMO System

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Abstract. By 2023, the average rate of global mobile network will increase to 44Mbps, 5G mobile communication network rate will reach 575Mbps [1]. Compared with 4G mobile communication, 5G mobile communication can support higher quality, higher transmission rate, higher user density and higher mobility performance, as well as lower delay and lower energy consumption scenarios [2]. With the advent of large-scale commercialization of 5G technology, the improvement of transmission performance can meet the growing communication needs of people well, and multiple antenna system (MIMO) has certain superiority in improving channel capacity. This article is aimed at introducing the working principle of MIMO system and the improvement of transmission performance brought by the technologies adopted. Furthermore, the proof of improvement of channel capacity brought by MIMO will be given. A channel model of MIMO communication system will be established through MATLAB, generating channel matrices randomly according to Gaussian distribution and then getting channel capacity by means of calculating the average value of multiple groups of data. The result shows that the channel capacity could improve greatly with the increase of the number of antennas under the condition of the same signal noise ratio (SNR), reaching the conclusion that MIMO system can effectively improve channel capacity.

1. Introduction

With the rapid development of the information society, intelligence has become the direction of development of society. There are three typical application scenarios of 5G, including emBB (enhanced mobile broadband), uRLLC (ultra reliable and low latency communication) and mMTC (massive machine type communication). Among them, technologies such as telemedicine, unmanned driving and virtual reality have become hot spots [3]. In order to deal with the continuously growing demand of mobile Internet and Internet of things, the fifth generation mobile communication has been officially put into commercial use.

As one of the key technologies of 5G, large-scale millimeter wave MIMO wireless transmission can expand the use of spectrum resources, deeply exploiting the spatial dimension of wireless resources, and greatly improving the wireless transmission rate, which is one of the most potential research directions of wireless communication system in the future.

This paper will introduce the principle of MIMO wireless transmission system, and simulate the MIMO wireless communication system through MATLAB according to the formula provided, so as to get the channel capacity of MIMO system. This paper aims to prove that the channel capacity can be greatly improved by means of increasing the number of antennas according to the derived formula with the same signal-to-noise ratio, thus improving the wireless transmission rate.
2. Theory of MIMO communication system

MIMO refers to multiple input multiple output indicating that there are multiple antennas in both transmitter and receiver for communication. Assuming that there are M antennas for transmitting signals and N antennas for receiving signals in the system, the signal \( x \) ready to be transmitted from the transmitting end will be divided into M channels of sub signals with the same power with each other, \( 1/M \) of the total power. The sub signal is then modulated by frequency and phase (same frequency, different phase) and transmitted after processed by RF front-end. After multipath propagation, N antennas are utilized to receive the signals and generate original data stream through corresponding signal processing [4].

3. Techniques in MIMO

3.1. Diversity, Multiplexing and Coding

With the increase of the number of antennas in MIMO communication system, more techniques could be better implemented, such as spatial multiplexing, spatial diversity and spatial coding. Among them, spatial multiplexing technology is to transmit independent signals, which means different data, on multiple independent antennas to make full use of system resources [5], while spatial diversity technique transmits the same data on multiple independent antennas, and the receiving end will restore the data through merging processing. Spatial multiplexing technology can make full use of system resources, improving spectrum efficiency and system capacity (data rate). What is more, spatial diversity technology can effectively resist channel fading, improving transmission reliability and reducing bit error rate.

In addition, the coding system can obtain a higher power gain than the system without coding at the same bit error rate and diversity gain, which is the coding gain. In order to obtain the best multiplexing gain and diversity gain, an effective coding method should be taken use of.

3.2. Beamforming

At the mean time, a large number of antennas can also be used for beamforming. When transmitting signals from multiple antennas, beamforming can shoot the transmitting energy to the receiver at a specific location through wireless channel of a specific angle. By adjusting the phase and amplitude of the transmitted signal, the corresponding signal superposition can be obtained at the receiving end, which can improve the strength of the received signal and ultimately improve the user's throughput. Simultaneously, the more antennas that are used, the narrower the beam width will be. The advantage of multiple antenna array is that there is less interference between different beams and different users, because different beams have their respective focus areas, which are very small and the intersection between them is very small [6].

4. Simulation of MIMO channel capacity

This section will simulate the MIMO communication system channel capacity through MATLAB, and prove the important role that MIMO plays in improving the channel capacity by simulating the following situations: the base station has 64 antennas, and the transmitter has 1, 2 and 4 antennas, within a range of SNR, observe the channel capacity (bits / s / Hz) taking the base station as transmitting end and receiving end respectively (downlink and uplink respectively).

According to the formula of Luo [5], the MIMO channel capacity simulation system is established on MATLAB. Firstly, a three-dimensional matrix is established, in which the two dimensions are the number of antennas at the transmitter and receiver. A large number of two-dimensional matrices are randomly generated through normal distribution to form a three-dimensional matrix. Then, it is brought into the formula to obtain the average value by calculating the average number, so as to obtain the channel capacity.

\[
C = \log_2 \left| I_n + \frac{A}{n_T} Q \right| 
\]  

(1)
\[ A = 10^{\frac{SNR}{10}}, Q = H H^H \]  \hspace{1cm} (2)

Downlink simulation: assuming that the transmitter base station has 64 transmitting antennas, and the receiving end has 1, 2, and 4 antennas for receiving signals, the simulation results of channel capacity are shown in figure 1 when the signal-to-noise ratio is from -10dB to 30dB.

Uplink simulation: assuming that the transmitter has 1,2,4 transmitting antennas and the receiving end (base station) has 64 antennas for receiving signals, the simulation result of channel capacity is shown in figure 2 when the signal-to-noise ratio is from -10dB to 30dB.
5. Discussion
There are several conclusions that can be drawn from the results of simulation which are listed in the following. First of all, when the number of antennas at the transmitter and receiver is fixed, the channel capacity increases with the increase of signal-to-noise ratio. What is more, when the number of antennas at the transmitter or receiver is fixed, increasing the number of antennas at the other end can greatly increase the channel capacity, that is, under the condition of the same signal-to-noise ratio, the channel capacity increases with the increase of the number of antennas; at the same time, when the signal-to-noise ratio is higher, the gain of channel capacity will increase with the increase of antenna, meaning that at a high SNR value, gain of channel capacity brought by MIMO is significantly enhanced.

However, there are also some shortages of this paper, for example, the complexity of the channel model is relatively simple comparing with the complexity in reality. In addition, only the random channel matrix with independent identical distribution as normal distribution is considered to calculate the channel capacity; and the modeling of beamforming and some other aspects could be taken into account to better upgrade the model.

MIMO wireless communication is one of the important technologies of 5G communication, which can improve the channel capacity, frequency band efficiency and power efficiency of wireless communication. At the same time, MIMO transmission is still facing challenges, and there is still progress to be made for further improvement. There are many aspects need to be further studied, such as the adaptability of scenarios, 5G proposed more moving scenarios, and the establishment of channel models for high-speed scenarios such as subway and high-speed rail still need further research.

6. Conclusion
This paper introduces the basic principle of MIMO communication system, techniques utilized in MIMO system and finally gives the channel simulation of capacity of MIMO wireless channel. In MIMO wireless transmission system, the signal is initially divided into many groups of sub signals, which are modulated and transmitted through multiple sets of antennas, and then received by multiple groups of received signals, at the end processed and restored. There are various techniques used in MIMO due to multiple antennas of MIMO system that make the spatial multiplexing, spatial diversity, spatial coding and other techniques well implemented, which effectively improves the data rate, frequency band efficiency and reduces the bit error rate. In addition, the energy of the receiver can be focused to the specified position of the channel, and the signal transmission efficiency can be greatly improved benefiting from beam forming technique. In the last part of the research, the capacity of MIMO channel is simulated. The results show that the multiple antenna system can greatly improve the channel capacity both in uplink and downlink under the same SNR. The research has succeeded in proving the advantages of MIMO. However, there are still much progress that could be made in several aspects. The method introduced in the paper only takes consideration of independent identically distributed, and additionally, more scenarios like high speed train and plane require more research.

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References
[1] ITU-R. IMT vision-Framework and overall objectives of the future development of IMT for 2020 and beyond. ITU Working Document, Tech. Rep, October 2015.
[2] ITU-R. Minimum requirements related to technical performance for IMT 2020 radio interface(s). ITU Working Document, Tech. Rep, 2017.

[3] Guo Y. Q., Zhang J. L., Key technologies and applications of 5G. Communication power technology, 2020, 37(04):174-175.

[4] LI X. Y., Wong L., et al. Application research of large-scale MIMO technology in 5G. Digital communication world, 2019(10):128-129.

[5] Luo X. Q, Yao X. Y. Research on channel Capacity of multi-antenna system. Mechanical and electrical technology, 2020(01):5-8.

[6] Lan S. H. Principles of Massive MIMO and its application in LTE. China New Communications, 2020, 22(14):85-86.