ISSN: 2710-0588

Research Status and Progress of Multi-antenna Technology

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Abstract

With the continuous upgrading of wireless communication technology, the types of mobile service businesses continue to increase, and the number of communication terminal equipment has also increased sharply, greatly increasing people's demand for wireless data traffic and network coverage. As one of the research hotspots of wireless transmission, multi-antenna technology can improve system transmission rate, improve spectrum utilization and expand network coverage. According to the different implementation methods, this paper discusses the research status of three typical multi-antenna technologies, such as antenna diversity technology, beamforming technology and spatial multiplexing technology, and looks forward to the potential research direction of multi-antenna technology in the future.

Keywords

Multi-antenna Technique; Research Status; Prospects.

1. Introduction

With the continuous emergence of new services and applications in the wireless network terminal, the traditional single-antenna communication system which can only transmit information in the time domain or frequency domain can not meet the higher business requirements. Compared with a single antenna, multi-antenna technology increases the utilization of the space domain, which demonstrates the great potential of this technology, and also makes it a key technology of modern mobile communication.

The introduction of multi-antenna technology can make wireless communication system obtain many performance gains, including array gain, diversity gain, power gain, spatial multiplexing gain and interference suppression gain. In a multi-antenna system, array gain mainly refers to the increase of the Signal-to-Noise Ratio (SNR) at the receiving end by adjusting the directivity of the beam; Diversity gain refers to the improvement of the received signal strength stability and link reliability by reducing the amplitude fluctuation after the combination of multiple signals by designing the sending and receiving mode; Power gain is the use of multiple antennas to transmit signals to increase the total transmitted power to expand the communication coverage; On the premise that transmit power and channel bandwidth are the same, spatial multiplexing gain refers to the increase of channel capacity with the increase of antenna. Interference suppression gain is realized by weighting multiple antennas to improve the transmission reliability of the system. The application of different multi-antenna technologies can obtain a variety of different gain superposition, which can achieve the effect of improving the system performance in many aspects at the same time.

2. Research Status

According to different standards, the classification of multi-antenna technology has different results. This paper mainly introduces the multi-antenna technology classified according to different implementation methods, which mainly includes the following three kinds:

ISSN: 2710-0588

2.1. Antenna Diversity Technology

Due to the presence of signal fading in wireless channels, the signal amplitude will fluctuate frequently and extensively over time, resulting in an impact on the reliability of the link. In the multi-antenna system, diversity technology uses different independent paths to transmit the same information, and then merges the multiple signals by a suitable method. Since the probability of deep fading is very low for each path signal that is not affected by each other, and the probability of deep fading for the combined signal is also greatly reduced, antenna diversity technology can be used to effectively combat fading and improve transmission reliability. Antenna diversity technology can be divided into transmit diversity and receive diversity.

The main idea of transmitting diversity is to provide diversity gain by transmitting the same signal on multiple transmitting antennas and even preprocessing the transmitting signal in combination with coding. In the cellular network, the relatively large data traffic is mainly generated by downloading the downlink through the mobile terminal. Although there are many kinds of emission diversity technologies, space-time coding technology is the most concerned[1-4]. In space-time coding, space transmission and time transmission are combined, and the data is divided into multiple tributaries after passing through the space-time encoder to correspond to each transmitting antenna, and then sent out from different transmitting antennas at the same time, where the signals sent by different antennas are non-correlated. The literature has studied the application of Alamouti encoding, which is one of the earliest proposed space-time encoding methods[1].

The literature studied the channel transmission performance based on orthogonal space-time block codes in different communication scenarios, and this coding method extended the Alamouti model using orthogonalization ideas[2,3]. Space-time lattice codes in orthogonal frequency division multiplexing systems have been studied in literature. Besides diversity gain, this coding method can obtain additional coding gain[4].

The main idea of receiving diversity is to combine the signals on several uncorrelated paths received by multiple receiving antennas in a suitable way to obtain diversity gain. Reception diversity mainly includes spatial diversity, polarization diversity, frequency diversity and so on. Spatial diversity is the use of multiple antennas at different spatial locations to receive the same transmitted signal. Since the received signal fading at different locations is not correlated, it is necessary to pay attention to the distance setting between antennas to ensure spatial independence[5]. Polarization diversity gain is obtained by arranging multiple antennas to receive signals from different polarization directions. This technique can reduce the distance between antennas, but will lose the transmission power. Frequency diversity uses multiple frequency bands to transmit the same information to combat frequency-selective fading, but needs to multiply transceiver devices and frequency bands, reducing spectrum utilization. The above-mentioned reception diversity techniques can be combined to complement each other. Relevant literature has studied MIMO antennas that can achieve spatial diversity and polarization diversity[7], and studied the characteristics of spatial diversity and frequency diversity in mobile global satellite navigation systems[8].

2.2. Beamforming Technology

When the transmitting antenna transmits signals in all directions, the signal intensity received by a single mobile terminal is limited, and the electromagnetic wave energy radiated in other directions is wasted. In order to compensate for signal fading and distortion caused by space loss, multipath effect and other factors during wireless propagation, wireless communication scholars have proposed a signal processing technology of array directional transmission and reception signals to improve signal strength, which is called beamforming technology. By adjusting the parameters of each element in the antenna array, the beamforming technology makes the signal of some angles produce long interference or cancelling interference, so that

ISSN: 2710-0588

the signal is focused into a directional beam and the direction of the antenna is enhanced. Therefore, beamforming can also be seen as a spatial domain filter that concentrates the energy radiated by the antenna[9].

Using beamforming technology can obtain obvious array gain, which has great advantages in expanding system coverage, improving network edge throughput and wireless interference suppression. Beamforming technology has brought a broader development space for wireless communication and has long been standardized and commercialized by the industry, and has been successfully applied in time division synchronous Code division multiple access systems, Wi-Fi and other standards such as IEEE 802.11 and TDLTE R8.

Beamforming technology can give different antenna gain in different arrival directions according to dynamic channel information, form real-time optimal beam direction to align the main lobe beam with the receiving device, and improve the system capacity through directional transmission and reception [10]. The optimization of beamforming vectors mainly relies on algorithms, and the optimization design of beamforming has attracted extensive attention and in-depth research. Aiming at the hybrid beamforming technology combining digital and analog beamforming, literature[11] is based on instantaneous CSI. The hybrid beamforming design of average CSI is introduced, and the complexity of different structures is discussed. For intelligent reflector assisted wireless communication system, different beamforming optimization algorithms are studied in literature[12-14]. The traditional beamforming optimization relies on the iteration of algorithms, and some algorithms have too high computation delay, which is difficult to apply and implement, so a deep learning-based beamforming optimization research has emerged. Literature[15] constructs a deep learning framework for optimizing downlink beamforming vectors in MISO systems. Literature[16] proposes a fast beamforming design method based on deep learning to achieve MIMO systems and rate maximization under power constraints. It can be seen that although the beamforming technology can dynamically adjust the beam of the antenna array to greatly improve the signal intensity, it will increase the algorithm complexity and require higher accuracy of real-time channel parameters. Therefore, how to obtain accurate channel parameters is the key to adaptive beamforming.

2.3. Spatial Multiplexing Technique

In order to meet the growing demand of network traffic, communication technology has been deeply studied in the time-division, frequency division and other dimensions of transmission technology, but restricted by limited resources, these transmission technologies have reached the bottleneck of network capacity enhancement. Spatial reuse technology can realize the reuse of the same frequency band and the same time period in different Spaces by partitioning space resources. The higher the degree of spatial multiplexing, the greater the amount of data transmitted, so that the peak rate and transmission rate of data can be greatly improved without increasing bandwidth and frequency resources, which provides a new development direction for communication expansion.

As early as the 1990s, spatial multiplexing technology had already received preliminary research[17-19] and widespread attention from the industry. It has been applied in the third-generation mobile communication system standard TD-SCDMA proposed by China. Due to the existence of spatial selectivity, each transmitting antenna has different spatial characteristics at the receiving end. Spatial multiplexing technology uses different antennas at the sending end to send different data symbols, and the receiving end distinguishes different data symbols from different antennas according to different spatial characteristics[20].

Considering that each sub-data stream is superimposed on each other in the transmission process, the antenna array formed by the receiving and receiving ends needs to provide enough spatial dimension so that the receiving end can better distinguish different data streams. Therefore, the number of receiving antennas needs to be sufficient, which increases the

ISSN: 2710-0588

hardware cost and system complexity. At the same time, in order to ensure certain error performance, channel coding is usually adopted at the originating end, and interference cancellation algorithm is used to separate the merged signal at the receiving end. Therefore, the performance optimization of spatial multiplexing systems has been studied for a long time. The layered space-time structure proposed by Bell LABS in literature[18] is a well-known spatial reuse structure. In view of the mutual interference between spatial modulation and spatial multiplexing in multi-antenna systems, literature[21] studies the influence of spatial modulation interference on spatial multiplexing systems, and explores ways to reduce the adverse effects caused by spatial modulation interference. A novel spatial modulation method based on hybrid precoding is proposed to improve the spatial multiplexing gain of MMwave MIMO systems[22]. For secondary cognitive networks using spatial multiplexing, literature[23] proposes an optimal power scheme to suppress the interference of the main network and improve system performance.

3. Summary and Prospect

As one of the key technologies of modern mobile communication, multi-antenna technology can greatly increase the data transmission rate, improve the spectrum utilization rate, improve the transmission signal quality, and expand the system coverage without increasing the channel bandwidth and transmission power, and is widely used in various mobile communication systems and standards. However, in practical communication networks, multi-antenna transmission usually requires the channel state information obtained by finite feedback technology, and the quantification accuracy of feedback channel state information is affected by the feedback cost and the number of active RF antennas, so the increase of working antennas will increase the system feedback cost. In addition to increasing feedback costs, the expansion of the scale of multiple antennas will also lead to an increase in the number of hardware devices such as RF links, further increasing the demand for hardware costs, power resources and computational complexity of communication systems. The influence of limited feedback overhead and power resources on the transmission performance of the system can be adjusted by antenna selection technology. In addition, the openness of multi-antenna wireless network architecture and the diversity of environments also bring about physical layer security problems. Therefore, in the future work, it will be an important research direction to study the adaptive multi-antenna selection scheme based on multi-user communication with limited feedback to improve the transmission performance of the wireless system, which will be of great help to further improve the transmission performance of the wireless system.

References

[1] Zhai C, Li Y, Wang X, et al. Heterogeneous non-orthogonal multiple access with distributed Alamouti space-time coding[J]. IEEE Transactions on Vehicular Technology, 2021, 70(5): 4796-4808.

[2] Arti M. K, Jindal S K. OSTBC transmission in shadowed-Rician land mobile satellite links[J]. IEEE Transactions on Vehicular Technology, 2016, 65(7): 5771-5777.

[3] Toka M, Kucur O. Performance analysis of OSTBC-NOMA system in the presence of practical impairments[J]. IEEE Transactions on Vehicular Technology, 2020, 69(9): 9697-9706.

[4] Yeh H G, Yıldız S. Space–time trellis-coded OFDM systems in frequency-selective mobile fading channels[J]. IEEE Transactions on Circuits and Systems II: Express Briefs, 2017, 64(6): 660-664.

[5] Lee W C Y. Effects on correlation between two mobile radio base station antennas[J]. IEEE Transactions on Communications, 1973, 21(11): 1214-1224.

[6] Lee W C Y, Yeh Y S. Polarization diversity system for mobile radio[J]. IEEE Transactions on Communications, 1972, 20(5): 912–923.

ISSN: 2710-0588

[7] Sofi M A, Saurav K, Koul S K. Four-port orthogonal circularly polarized dual-band MIMO antenna with polarization and spatial diversity using a dual-band linear-to-circular polarization converter[J]. IEEE Transactions on Antennas and Propagation, 2022, 70(9): 8554-8559.

[8] Fan P, Cui X, Lu M. Space and frequency diversity characterization of mobile GNSS receivers in multipath fading channels[J]. Tsinghua Science and Technology, 2020, 25(2): 294-301.

[9] Veen B D V, Buckley K M. Beamforming: a versatile approach to spatial filtering[J]. IEEE ASSP Magazine, 1988, 5(2): 4-24.

[10] Mietzner J, Schober R, Lampe H J, et al. Multiple-antenna techniques for wireless communications - a comprehensive literature survey[J]. IEEE Communications Surveys & Tutorials, 2009, 11(2): 87-105.

[11] Molisch A F, Ratnam V V, Han S, et al. Hybrid beamforming for massive MIMO: A survey[J]. IEEE Communications Magazine, 2017, 55(9): 134-141.

[12] Wu Q, Zhang R. Beamforming optimization for wireless network aided by intelligent reflecting surface with discrete phase shifts[J]. IEEE Transactions on Communications, 2020, 68(3): 1838-1851.

[13] Wu Q, Zhang R. Joint active and passive beamforming optimization for intelligent reflecting surface assisted SWIPT under QoS constraints[J]. IEEE Journal on Selected Areas in Communications, 2020, 32(8): 1735-1748.

[14] Abeywickrama S, Zhang R, Wu Q, et al. Intelligent reflecting surface: practical phase shift model and beamforming optimization[J]. IEEE Transactions on Communications, 2020, 68(9): 5849-5863.

[15] Xia W, Zheng G, Zhu Y. A deep learning framework for optimization of MISO downlink beamforming[J]. IEEE Transactions on Communications, 2020, 68(3): 1866-1880.

[16] Huang H, Peng Y, Yang J, et al. Fast beamforming design via deep learning[J]. IEEE Transactions on Vehicular Technology, 2020, 69(1): 1065-1069.

[17] Foschini G J, Gans M J. On the limits of wireless communications in a fading environment when using multiple antennas[J]. Wireless Personal Communications, 1998, 6(3): 311–335.

[18] Foschini G J. Layered space-time architecture for wireless communications in a fading environment when using multi-element antennas[J]. Bell Labs Technical Journal, 1996: 41–59.

[19] Telatar I E. Capacity of multi-antenna Gaussian channels[J]. European Transactions on Telecommunications, 1999, 10: 585–595.

[20] Lozano A, Jindal N. Transmit diversity vs. spatial multiplexing in modern MIMO systems[J]. IEEE Transactions on Wireless Communications, 2010, 9(1):186-197.

[21] Basnayaka D A, Hass H. MIMO interference channel between spatial multiplexing and spatial modulation[J]. IEEE Transactions on Communications, 2016, 64(8): 3369-3381.

[22] He L, Wang J, Song J. Spatial modulation for more spatial multiplexing: RF-chain-limited generalized spatial modulation aided MM-wave MIMO with hybrid precoding[J]. IEEE Transactions on Communications, 2018, 66(3): 986-998.

[23] Miridakis N I, Xia M, Tsiftsis T A. Optimal power allocation and active interference mitigation for spatial multiplexed MIMO cognitive systems[J]. IEEE Transactions on Vehicular Technology, 2018, 67(4): 3349- 3360.