Performance Analysis of Beamforming Techniques in 5G MIMO Systems Using Various QAM Modulation Schemes

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Abstract: ***In 5G communications, MIMO technology is instrumental in enhancing system performance without additional transmission power. This paper investigates the performance of a 5G communication system using different QAM modulation schemes, including 16QAM, 64QAM, and 256QAM. The study analyzes the effectiveness of beamforming techniques in optimizing system performance under various modulation conditions, providing insights into their practical applications and impact on error rates.***

Keywords: 5G, QAM, Beamformer, MIMO, Bit Error Rate

1. Introduction

3G wireless networks are giving way to a new generation of networks that offer high-speed, high-quality services. Signal distortion is a major issue in wireless communications, though, as modern communication systems require broadband wireless access technologies for things like mobile internet and multimedia. It can be categorized as Co-Channel Interference because of the multiple accesses that will impair system performance and potentially result in major link failure in a wireless communications environment, and Inter-Symbol Interference (ISI) because of the signal delay caused by multipath fading [1]. Adaptive strategies are among the most dependable methods for enhancing wireless communication system performance. Specifically, its capacity to cancel CCI regardless of arrival angle is a significant feature. An array has more degrees of freedom (DOF) to counteract interference and multipath fading the more antenna components it has. An N-element antenna array, for example, may cancel (N −1) CCIs regardless of the multipath environment since it has (N −1) DOF. However, ISI is unable to interpret the delayed copies of the sent signal as independent signals since traditional adaptive arrays utilizing narrowband beamformers only handle the received signal in the spatial domain. Using tapped delayed line (TDL) structure, the issue may be resolved by preventing the arrays from needing to employ their spatial processing in conjunction with a temporal filter [9]. Wideband beamformer adaptive arrays is another name for it. Therefore, temporal equalization based on an antenna array will emerge as a ground-breaking method capable of successfully suppressing both CCI and ISI. There has been a lot of study proposed on the use of an antenna array at base station (BS) for spatial and temporal signal processing. Many adaptive algorithms, which have been demonstrated in literature, are perspectives of extending techniques of spatial and temporal digital equalization for determining the ideal weight vector in the time domain. Examples of these algorithms are Least Mean Squares, Recursive Least Squares, and Constant Modulus Algorithm.

However, because it necessitates recursive computation and sluggish convergence in the search for the ideal weight vector, concurrently solving the CCI and the ISI is a challenging issue for spatial and temporal adaptive arrays (STAA). Particular attention has been paid to multiple antenna structures that are split into two groups, especially in the previous 20 years. They include two main arrangements: using an array of antennas only at the receiver (also referred to as single-input multiple-output (SIMO) systems) and using an antenna only at the transmitter (sometimes referred to as multiple-input single-output (MISO) systems). All the same, multiple-input multiple-output (MIMO) systems have been proposed recently to meet the demands of high performance and capacity in wireless communications systems through the employment of antenna arrays at both transmitter and receiver. MIMO systems outperform SIMO and MISO systems in terms of capacity and performance when multipath scattering is plentiful and well utilized. While the majority of studies have focused on the theoretical capacity and output maximum Signal-to-Noise and Interference Ratio (SINR) of MIMO systems in flat fading environments, there are still many unanswered questions regarding the implementation of wideband MIMO systems in frequency-selective fading environments.Spatial multiplexing OFDM has been proposed as a solution for MIMO frequency-selective fading channels. It allows for the simultaneous transmission of multiple independent streams, with the number of streams being limited by the minimum number of antenna elements at both ends. This results in the transformation of several frequency-flat MIMO channels from multiple frequency-selective MIMO channels. In addition, the decision feedback equalization approach has been presented to mitigate frequency-selective fading using MIMO antenna systems equipped with tapped delayed line (TDL) structure. Nevertheless, their limited processing power and inexpensive, small hardware continue to be problems [2-3]. While many methods with or without prior knowledge of Channel State Information (CSI) at the transmitter and/or receiver have been proposed for MIMO systems in frequency-selective fading environments, none specifically address the efficient cancellation of delayed channels through adaptive beamforming. In particular, there is still not much research on how to modify the MIMO system's broadcast and receive weight vectors. Therefore, without the use of TDL (tap-delay line) equipment, the approach is to find the best transmit and receive weight vectors for MIMO systems with frequency-selective fading. Spatial filters are used in the weight vector determination process for both the transmitter and the receiver in MIMO beamforming in a configuration where the transmitter has M antenna elements and the receiver has N antenna elements. These filters maximize the output Signal-to-Interference-plus-Noise Ratio (SINR) while reducing co-channel interference and intersymbol interference. In contrast, as compared to MIMO systems with TDL structure in the transmitter either receiver; our suggested technique can achieve quicker convergence rates and minimize computing complexity.

2. MIMO Systems

As technology advances, so do the performance requirements for next-generation wireless systems. The performance standards for modern-day wireless systems are stated below.

- Small size
- Higher data rate
- High bandwidth
- Good gain

The implementation of MIMO (Multiple Input Multiple Output systems) in current wireless networks is one technique to attaining the above-mentioned goals. This term refers to the usage of numerous antennas for both the transmitter (multiple input) and the receiver (multiple output). Because of the advantages of MIMO technology, future wireless technologies will have multiple antennas. MIMO technology requires uncorrelated antennas. The correlation coefficient, which was specified as a parameter in the previous chapter, determines the frequency range over which the MIMO antenna will operate. Figure 1.2 shows MIMO technology with the best throughput and data rates. The words and approaches utilized in MIMO communication are categorized into two basic categories are spatial multiplexing and space time coding.

MIMO systems have several advantages compared to SISO system. Some of the principle advantages are Increased channel capacity, Reduced transmitting power, Higher link gain, Faster data rate, Better reliability, Improve network throughput, Improve coverage without requiring additional bandwidth. [4]

3. Generations of Mobile communication

Digital transmission via radio links was first used in the early 1990s to usher in the second generation of mobile communication. Voice services were the main emphasis of early mobile communication systems. But the introduction of digital transmission brought about a big change. Emergence of second-generation (2G) technologies includes CDMA-based IS-95, D-AMPS (Digital AMPS), PDC (Personal Digital Cellular), and GSM (Global System for Mobile communication). Of them, GSM was the most widely used and finally dominated the global 2G market. Because of GSM's success, mobile phone service went from being a specialized offering to becoming a necessity for most people on the planet. Even with the later advent of third- and fourth-generation technology, GSM is still widely used in many areas today. The arrival of 3G (third generation) marked a pivotal moment, enabling high-quality mobile broadband and fast wireless internet access.This was especially enabled by the 3G evolution known as High Speed Packet Access [1][5]. While earlier mobile-communication technologies had all been designed for operation in paired spectrum.

Table 1: Mobile communication's several generations

The foundation of mobile telephony	Mobile telephony for everyone	The foundation of mobile broadband	Enhanced mobile broadband
1G	**2G**	**3G**	**4G**
AMPS TACS NIMT	GSM D-AMPS PDC IS-95	WCDMA/HSPA cdma2000	LTE
~1980	~1990	~2000	~2010

FDD 3G also saw the first introduction of mobile communication in unpaired spectrum based on the china-developed TD-SCDMA technology based on Time Division Duplex (TDD). We currently reside in the fourth-generation (4G) era of mobile communication, characterized by LTE technology. LTE builds upon the foundation laid by HSPA, offering higher efficiency and an improved mobile broadband experience. Key enhancements include wider transmission bandwidths facilitated by OFDM-based transmission and advanced multi-antenna technologies. Unlike 3G, which relied on specific radio-access technologies (such as TD-SCDMA) for unpaired spectrum communication, LTE seamlessly supports both Frequency Division Duplex (FDD) and Time Division Duplex (TDD) operations within a unified radio-access framework. As a result, LTE has become the global standard for mobile communication, adopted by virtually all mobile-network operators and applicable across paired and unpaired spectra. Notably, the evolution of LTE has extended its reach into unlicensed spectra.

4. Beamforming using MIMO Systems

A new standard for information transit in Wi-Fi conversation frameworks in MIMO systems is being established by many approaches. The Wi-Fi channel saves differential impedance to the communicated channel and signal response. Between the sender and the destination, it results in the sign taking many routes. The receiver perceives delayed versions of the same signal. Delays can be driven by diffraction, reflection, shadowing, refraction, and other reasons. because of the weather, mugginess, buildings, trees, aircraft, and other elements. There may be variations in the strength of the signals or the output of the change stage. The effects of multipath include profile delays and reductions, output reduction, distorted data recipients, and channel effectiveness. MIMO utilizes the multipath effect to enhance system capacity. Transitions in the Rayleigh fading output are randomly shifted between Zero and 2, and these rotations occur on a regular basis. The signal is believed to be received following free behavior in each of the several pathways it crosses. Even if LOS is diminishing in Rician, one of the collection strategies is far more reliable. The visible pathway signal stage and a delay form indication must change or contrast in phase. Any of these indications that show a covering or troughing pattern are a sign of constriction or high normal energy. As a result, the computation might end up in a distorted sign for the recipient [6].

5. Hybrid Precoding

Hybrid precoding, also known as hybrid beamforming, enables the use of massive MIMO antenna arrays at a lower cost and with less power. With hybrid precoding, each stream requires a dedicated RF chain, whereas in a traditional antenna array, each antenna requires a separate RF chain to transmit and receive each data stream. As a result, there are fewer RF lines overall, reducing power and cost. Each chain's analog outputs are combined to form a network of phase shifters and analog RF gains, which are then linked to a massive antenna array, multiplying the number of streams and antennas.

Hybrid precoding, also known as hybrid beamforming, is a method for using enormous MIMO antenna arrays in a more power-efficient and cost-effective manner. In a typical antenna array, each antenna requires a separate RF chain to transmit and receive data streams; with hybrid precoding, each stream requires its own RF chain. This significantly decreases the number of RF links, lowering cost and power. Each chain's analog outputs are merged to form a network of analog RF gains and phase shifters that are linked to a huge antenna array, where the number of antennas and streams are determined. These analog units cannot change weights fast, but calculated RF weights do vary slowly over time since they are principally governed by receiver spatial locations. Digital baseband precoding weights may vary from symbol to symbol due to smaller-scale multipath effects, as well as from subcarrier to subcarrier to allow for frequency-selective fading [7].

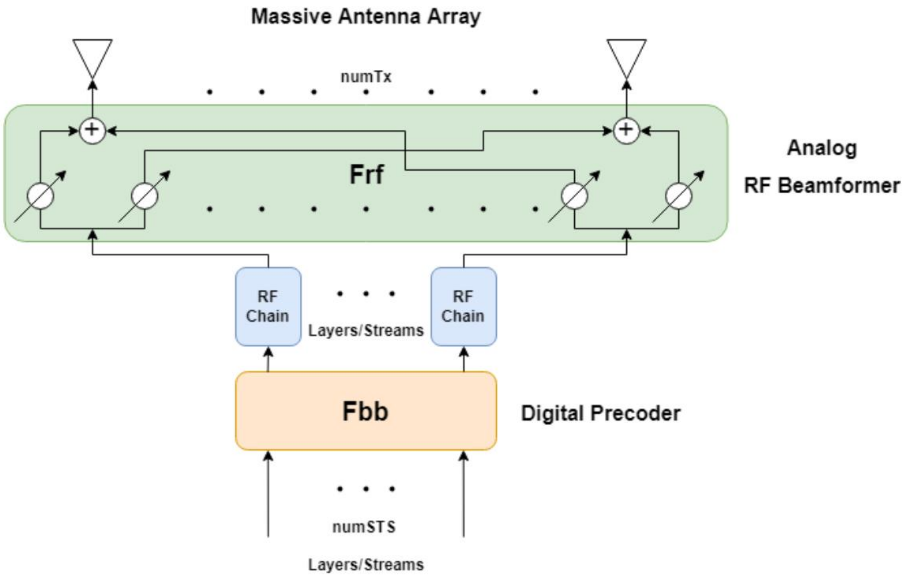

Figure 1: Shows the Precoding with phased array using MIMO system

In order to demonstrate the division of the necessary precoding across its digital baseband and RF analog elements at the transmitter end, a single-user or multi-user MIMO-OFDM system is provided in this study. The system estimates the digital baseband Fbb and RF analog Frf precoding weights for the selected configuration using the orthogonal matching pursuit (OMP) method for a single user system with the joint spatial division multiplexing (JSDM) approach for a multi-user system. Expanding upon the MIMO-phased array precoding system observed in Figure 1, describes the transmit-end precoding matrices and how they are applied to a MIMO-OFDM system. After the beams are produced, users throughout each group are orthogonalized employing the calculated digital precoding weights [8].

Instead than using the output from the antenna array, these precoding weights are dependent on the user's channel state information of the effective channel as observed from the RF chains' output. In 5G networks, these beam-based measurements are carried out. It is assumed that the RF weights apply to all subcarriers since the analog RF boosts and phase shifters are implemented at the antennas. The digital precoding weights, however, can be used for each subcarrier. Digital precoding weights are applied by each subcarrier based on their CSI calculations.

Table 2: Parameters utilized for the proposed work

S. No.	Parameter	Value
1	Frequency	28 GHz
2	Sampling Rate	110Msps
3	Noise Figure	8
4	Modulation Technique	16 QAM, 64 QAM, 256 QAM

Results for the proposed system using different modulation techniques have been presented in the form of transmit array pattern. For better performance the directions of beam should correlate closely with the spatial positions of the users, and the beam magnitude should correlate with the number of streams being sent in that direction.

In the presented beamforming simulation setup the implementation part of the system description is set for five users. The frequency for the system was selected at 28 GHz. Three modulation techniques were selected i.e. 16-QAM, 64-QAM, and 265-QAM, and using 10 OFDM symbols. The number of bits, root mean square (RMS), bit error rate (BER), error vector magnitude (EVM), and the number of errors were calculated for each user. The results are presented in table 2.

Table 2: Computed EVM and Bits given techniques

	256 QAM			64 QAM			16 QAM [10]		
User#	EVM %	BER	No. of Bits	EVM %	BER	No. of Bits	EVM %	BER	No. of Bits
User 1	0.00051236	0	24954	0.00052408	0	18714	0.00050242	0	12474
User 2	0.0005329	0	18714	0.00053621	0	14034	0.00050148	0	9354
User 3	0.00058017	0	12474	0.00063307	0	9354	0.00064067	0	6234
User 4	0.00073366	0	24954	0.00071659	0	18714	0.00073312	0	12474
User 5	0.00051405	0	18714	0.00055102	0	14034	0.00052299	0	9354

6. Conclusion

The presented work demonstrated the effectiveness of different QAM modulation techniques in enhancing the performance of beamforming in 5G MIMO systems. The results highlight the significant impact of modulation schemes on error rates, offering practical insights for optimizing 5G communication systems. The presented study provides valuable insights into the optimization of beamforming techniques in 5G networks, which are crucial for enhancing data transmission efficiency and reducing error rates in modern wireless communications.

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