Various Modulation Options for OFDM in 5G System: A Comparative Approach

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Abstract*: *The loss of information and signal quality degradation is the major issue in wireless communication due to multipath fading. The 'multi-input multi-output (MIMO)' antenna system can be used to minimize the signal fading which alternatively reduces the error rates but at the cost of hardware complexity, power consumption. The most critical issue in wireless communication is the availability of bandwidth, and signal quality. These issues can be resolved satisfactorily with the employment of 'orthogonal frequency division multiplexing (OFDM)' system. The significant functional element of the OFDM system is the kind of modulation technique employed. Various modulation techniques are employed in the OFDM system to enhance the data rates as well as to reduce the error rates. This article focuses on the error rate behavior of different PSK and QAM modulation techniques used in the OFDM system.

***Keywords*: Wireless communication, Modulation schemes, Error rates, Interference**

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I. Introduction

In the last decade, mobile and wireless communication has made remarkable development to interconnect the world with high speed. Now the world is switching towards 5G with the huge requirement of the wireless networks to fulfill the gap between the application requirement and technology, we need to introduce the next frontier technology which will stand in the future to serve the data speed requirement. In all aspects, the use of software-defined radio, new error control scheme, new modulation scheme, and spectrum utilization. Mobile / wireless terminals should be capable to adopt a different technology. The limitations of 4G motivate the inventors to introduce the 5G wireless network. The transformation of the current generation (4G) to next-generation (5G) has so many challenges such as novel wireless technology platforms, protocols, etc. The aim of the new system design is to create a useful solution for future requirements, and to design receivers with minimal complexity with the integration of various technologies. To minimize the limitations in the current system MIMO-OFDM systems are playing a key role as well as in the next generation too [1-3]. Today, Multimode network integration is a basic practice that can access different network platforms simultaneously. These are such platforms that accommodate smart phones, wireless gadgets, Wi-Fi modules, 3G & 4G LTE systems. Also, while integrating the different platform technology it is capable of handling the user's mobility [4]. 5G uses OFDM schemes on both uplink and downlink. Carrier spacing in 5G NR is flexible (e.g. 15 kHz, 30 kHz, 60 kHz, 120 kHz, 240 kHz, 480 kHz) and has up to 3300 subcarriers. Subcarriers can be modulated using the M-PSK or M-QAM constellations [5]. This paper introduces the error rates characteristics of various M-PSK and M-QAM modulation schemes.

This paper is planned under the following headings. Section-I gives brief introduction of the next generation wireless technology and the use of OFDM scheme with various modulation techniques. Section- II explores the literature review. Section-III gives a brief introduction to the MIMO-OFDM system model, describes the MIMO antenna system along with OFDM modulation. Section-IV describes various modulation techniques. Section-V comprises the simulation results and discussion. And section-VI gives the conclusion of the article.

II. Literature review

S. Thangamayan et al. (2022) carried out the simulation approach for the comparison of various modulation techniques that may be used in 5G communication network. The main objective of the article was to analyze the performance of wireless network such as BER, Capacity, spectral efficiency, and PAPR. Various modulation techniques including QPSK and M-QAM have been analyzed by the author on the SNR range of -10dB to 20dB. It was observed that for QPSK modulation negligible BER, higher capacity and about 3dB PAPR is measured. However at the SNR above 10 dB 256-QAM techniques is found performing better than QPSK. On the other hand on negative SNR the performance of 256-QAM was worst compared to QPSK. Y. Xu et al. (2020) analyzed Turbo codes and Quadrature Amplitude Modulation (QAM) scheme. For further enhancement in the spectral efficiency of 5G system, code like LDPC (Low Density Parity Check) from 5G new radio (NR) standard and novel non-uniform constellations (NUCs) are utilized in this research to replace Turbo codes and QAM respectively. R. T. Kamurthi et al. (2020)

suggested that in UFMC withholding orthogonality using Quadrature Amplitude Modulation (QAM) scheme which is also suitable for MIMO technology. In this article authors have chosen 256-QAM and 1024-QAM techniques. After simulation they observed better PAPR values compared to other modulation schemes. B. Chirag et al. (2017) examined different modulation techniques such as FSK, MSK, BPSK, QPSK, QAM, MPSK and MQAM for the BER performance, error probability, and rate distortion. Authors suggested employing certain modulation schemes under the presence of certain levels of noise in the communication channel. At lower range of SNR the use of BPSK or QPSK is found better regarding BER performance, where as at the high SNR range it is seen that M-QAM modulation schemes performing better for BER with high data rate as well. On the contrary at lower range of SNR the performance of M-QAM scheme is poor.

III. MIMO-OFDM SYSTEM MODEL

The concatenation of OFDM system and the MIMO system forms the most effective MIMO-OFDM system model for wireless communication system.

A. The MIMO antennas system

It is a fundamental technology in 4G/5G network, offers big advantage towards the spectrum utilization. The spectrum efficiency can effectively improve with multiple transmitting and receiving antenna. Also, the additional antennas at receiver or transmitter lead to increase the signal power. This could be successful way to maximizing the received power.

A MIMO antenna system having ‘M’ & ‘N’ antenna at transmitter and receiver respectively, approach is illustrated in fig. 1. Through the same channel, each antenna of receiver accepts the direct as well as the indirect components anticipated for the neighboring antennas [5-7]. By adopting multiple antennas system at transmitter (Tx = 2, 3, 4) and receiver (Rx = 2, 3, 4) respectively, results in to a remarkable improvement in system performance in terms of throughput or capacity and BER [8]. The spatial multiplexing attains a linear growth in channel capacity along with the number of antennas increases.

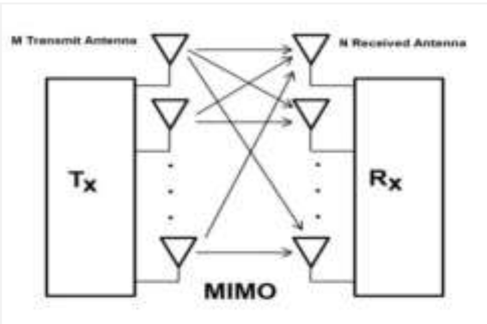

Fig.1 Multi Input Multi Output antenna system

B. The MIMO-OFDM System

A basic OFDM equipped with MIMO antenna system for wireless communication shown in fig. 2. The process begins with the modulation of message signal (using BPSK / QPSK / QAM, etc.). At this point, the outputs are complex numbers and they are in serial form. At this stage serial to parallel converter is used to provide parallel complex data. Using the N-point IDFT or IFFT, frequency separation (at rate 1/Ts) of samples of the overall signal to be transmitted over N sub-carriers can be obtained [9]. Now the data transformed using IFFT are grouped in to blocks as per requirement of transmission sub-carriers. CP (Cyclic pre-fix) is added in each block of data. The objectives of adding the CP is to overcome inter symbol interference ISI between OFDM symbols. After adding the CP in each block data again converted into serial using parallel to serial converter. At this stage, the data are OFDM modulated and made ready for final transmission. Before transmission DAC is used to convert digital output into analog in time domain. Radio Frequency modulation is carried out on the output signal from DAC and the signal is up-converted to transmission frequency [10].

The MIMO antenna systems employ multiple transmitter (Tx) and receiver antennas (Rx) as shown in figure 1. MIMO antenna system is used to provide antenna diversity, to have a reliable communication and to enhance the system’s reliability and throughput or capacity. After the transmission of OFDM signal through MIMO antenna system with or without transmitter antenna selection,

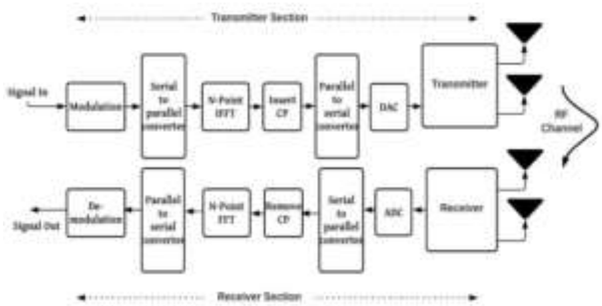

Fig. 2 Basic MIMO-OFDM system

the signals go through wireless channel. After receiving the signal through MIMO receiving antennas, the received signal is converted into digital domain using ADC. After ADC conversion, timing synchronization of symbols is obtained. The output signal of ADC is converted back to parallel using serial to parallel converter. At this stage CP from each block is removed and the resulting signal is fed to FFT block to convert signal in to time domain. Before demodulation of the OFDM signal parallel time domain signal is converted in to serial form using parallel to serial converter and then it is demodulated to obtain original information [6-10].

IV. MODULATION SCHEMES FOR OFDM SYSTEM

The signal quality performance of a wireless communication system mainly depends upon the types of modulation techniques used in the OFDM system and the channel environment. This article is investigating the error performance of different modulation schemes over the Gaussian channel [11]. For the proper modulation scheme and channel environment, the probability of error has been observed as negligible. The modulation schemes used in wireless communication must be power efficient as well as spectral efficient. The OFDM system is the best example of such a modulation scheme where various 'M-array phase shift keying (M-PSK)' and 'M-array quadrature amplitude modulation (M-QAM)' constellations can be used as a primary element. Examples of PSK modulations are BPSK, QPSK, 8-PSK, 16-PSK, etc. and the examples of QAM modulations are 4-QAM, 8-QAM, 16-QAM, and so on [12-14]. As we go on increasing the order M the data rate can be notably increased but at the cost of an increase in error rates, which can be seen for the simulation results in the result section.

A. Error rates for M-PSK Modulation

The error probability of base band and pass band is similar. The BER for BPSK modulation over AWGN channel is given by

$$\mathrm{BER} = \mathrm{Q}\sqrt{\frac{2\mathrm{E_b}}{\mathrm{N_0}}} \tag{1}$$

Where Q factor and is given by

$$Q(x) = \frac{1}{\sqrt{2\pi}}\int_x^\infty e^{\frac{-x^2}{2}}\, dx \tag{2}$$

The probability of BER over AWGN channel is given by

$$P_b = \frac{1}{2}\, erfc\left(\sqrt{\frac{E_b}{N_0}}\right) \tag{3}$$

And the probability of BER over Rayleigh fading channel is given by

$$P_b = \frac{1}{2}\left(1 - \sqrt{\frac{E_b/N_0}{1+E_b/N_0}}\right) \tag{4}$$

The QPSK modulation comprises two BPSK constellations; one is in phase while another in quadrature as shown in fig.3. In QPSK modulation the BER for each phase is similar and equal to the probability of BER in BPSK modulation.

$$P_b = Q\sqrt{\frac{2E_b}{N_0}} \tag{5}$$

The probability of 'Symbol error rates (SER)' is nothing but the probability that each phase of QPSK has BER, and is given by,

$$P_s = 1 - [1 - P_b]^2 \tag{6}$$

At the high SNR the error occurs only for the nearest constellation point and the $\mathrm{P_b}$ can be approximated as $\mathrm{P_s}/2$. Similarly the error rates probability for the M-PSK constellation can be approximated as,

$$P_s \approx 2Q\left(\sqrt{2\gamma_s}\, sin(\pi/M)\right) \tag{7}$$

Where $\gamma_s = \frac{2E_b}{N_0}$ and the probability of BER is given by

$$P_b \approx \frac{2}{log_2 M} Q\left(\sqrt{2\frac{E_b}{N_0} log_2 M}\ \ sin(\pi/M)\right) \tag{8}$$

B. Error rates for M-QAM constellations

In the case of M-PSK modulation, only phases are changed while amplitudes are constant, whereas in M-QAM modulation both amplitudes and the phases are changed. The constellation diagram for 16-QAM is shown in fig.4 in which the neighboring constellation point are equidistance from each other. The SER probability for M-QAM modulation over the AWGN channel is given by

$$P_s \leq 1 - \left[1 - 2\left(1 - \frac{1}{\sqrt{M}}\right).\, Q\left(\sqrt{\frac{3log_2 M\, E_b}{(M-1)N_0}}\right)\right]^2 \tag{9}$$

$$P_s \leq 1 - \left[1 - \left(1 - \frac{1}{\sqrt{M}}\right).\, erfc\left(\sqrt{\frac{3log_2 M\, E_b}{2(M-1)N_0}}\right)\right]^2 \tag{10}$$

and the probability of BER for M-QAM modulation is given by

$$P_b \approx \frac{4}{log_2 M}\, Q\left(\sqrt{\frac{3^{E_b/N_0} log_2 M}{M-1}}\right) \tag{11}$$

$$P_b \approx \frac{2}{log_2 M}\, erfc\left(\sqrt{\frac{3E_b log_2 M}{2(M-1)N_0}}\right) \tag{12}$$

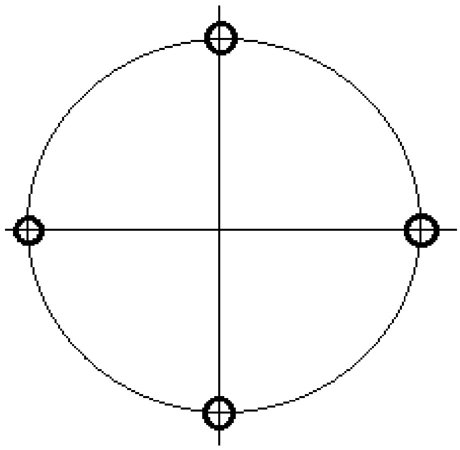

Fig.3 QPSK constellation

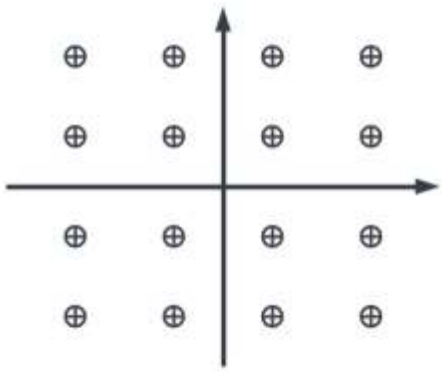

Fig. 4 16-QAM constellation

V. RESULT AND DISCUSSION

The simulation has been carried out using MATLAB tools in which 10^5 number of symbols has been used for simulation of error rates of various modulation schemes. Fig. 5 shows the Bit error rate for BPSK modulation, where it is seen that, the BER is exponentially decaying up to 8 dB SNR, and after that it falls rapidly. At 9 dB SNR the BER of 10^{-5} for BPSK modulation has been measured. The results for Symbol error rate (SER) versus SNR (Eb/N0 (dB)) for M-PSK modulation is shown in fig. 6 and SER versus SNR for M-QAM modulation is shown in fig. 7. The simulated results of SER for M-PSK modulation is exactly matching with theoretical results. Where as for M-QAM modulation the simulated results are some what deviated from the theoretical results. From fig 6 and 7 it is very clear that the M-PSK modulation performing better compared to M-QAM modulation in terms of SER.

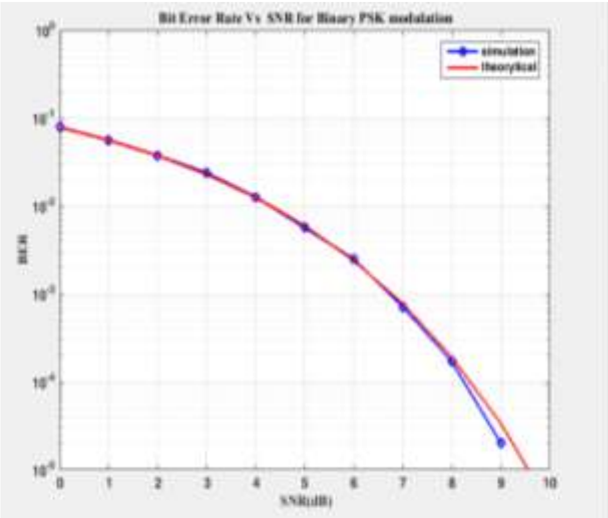

Fig.5 Bit error rate Vs SNR for BPSK modulation

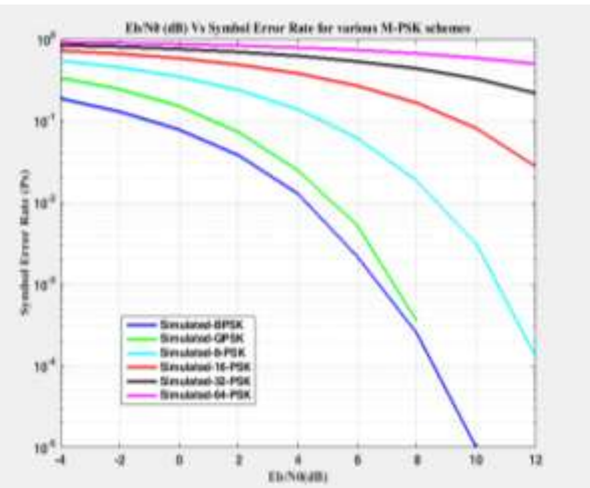

Fig. 6 Symbol error rates for M-PSK modulation schemes

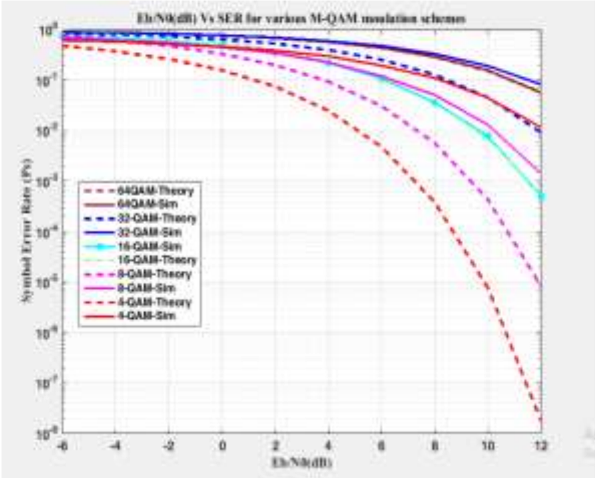

Fig. 7 Symbol error rates for M-QAM modulation schemes

Table 1 shows the SER values at the SNR of 10 (dB) for various PSK and QAM modulation schemes. Here we observed that the probability of SER is less in the case of lower order modulation schemes of PSK as well as lower-order QAM modulation, for example in the case of BPSK, QPSK & 8-PSK in PSK modulation and 4-QAM, 8-QAM & 16-QAM in QAM modulation schemes.

TABLE 1 SER VALUES AT 10 DB SNR FOR M-ARRAY MODULATION SCHEMES

M-PSK Modulation	**SER at SNR=10 (dB)**	**M-QAM Modulation**	**SER at SNR=10 (dB)**
BPSK	1×10^{-5}	--	--
QPSK	1×10^{-5}	4 QAM	4.47×10^{-2}
8 PSK	3.13×10^{-3}	8 QAM	1.3×10^{-2}
16 PSK	7.9×10^{-2}	16 QAM	7×10^{-3}
32 PSK	3.2×10^{-1}	32 QAM	2.0×10^{-1}
64 PSK	5.9×10^{-1}	64 QAM	1.7×10^{-1}

VI. CONCLUSION

In this article, the performance of different modulation techniques has been analyzed from the perspective of symbol error rates. Although the higher order modulation provides high data rates, but at the same time quality of the signal is degraded due to an increase in bit errors and symbol error rates. Upon simulation of different modulation techniques using MATLAB, it is found that in the case of lower order modulation schemes the symbol error rate is under satisfactory level, and as the order of modulation increases beyond 16 (M=16), the probability of symbol error increases considerably which is not good for a future wireless communication system. It is concluded that the PSK modulation up to order 8 (M=8) e.g. BPSK, QPSK, and 8-PSK, and QAM modulation up to order 16 (M=16) e.g. 4-QAM, 8-QAM, and 16-QAM are best suitable for OFDM system to be used in the next-generation wireless system. As far as data rates along with quality in future 5G wireless communication systems, the QPSK, 8-PSK and 16-QAM modulation schemes are most suitable.

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