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Analysis of Channel Capacity & PAPR in MIMO-OFDM System

Piyush Tiwari, Sachit Rathi

***Abstract*— Orthogonal frequency division multiplexing (OFDM) is a popular method for high data rate wireless transmission. OFDM may be combined with antenna arrays at the transmitter and receiver to increase the diversity gain and/or to enhance the system capacity on time-variant and frequency-selective channels, resulting in a multiple-input multiple-output (MIMO) configuration. This paper explores various physical layer research challenges in MIMO-OFDM system design, including physical channel measurements and modeling, analog beam forming techniques using adaptive antenna arrays, space–time techniques for MIMO-OFDM, error control coding techniques, OFDM preamble and packet design, and signal processing algorithms used for performing time and frequency synchronization, channel estimation, and channel tracking in MIMO-OFDM systems. Finally, the paper considers a software radio implementation of MIMO-OFDM**

***Index Terms*—MIMO-OFD, BE, PAP, Channel Capacity, Synchronization, Carrier offset.**

I. INTRODUCTION

MIMO is an acronym for 'Multiple Input Multiple Output'. In this technology, more than one antennais mounted at each end to improve the performance of a communication system. Multiple-input- multiple-output (MIMO) exploits spatial diversity by having several transmit and receive antennas [1]. This arrangement provides significant improvement in the data throughput and link range without increasing the input power and the bandwidth for transmission. On the other hand, OFDM (Orthogonal Frequency Division Multiplexing) is a technique for encoding the digital data on multiple carrier frequencies prior to transmission. The main advantage of OFDM is that it can overcome a lot of transmission losses like narrowband interference, high frequency attenuation, multi-path fading etc. When both of these technologies are combined together, new technique is emerged namely MIMO-OFDM [6],[7]. OFDM converts a frequency-selective channel into a parallel collection of frequency flat subchannels. The subcarriers have the minimum frequency separation required to maintain orthogonality of their corresponding time domain waveforms, yet the signal spectra corresponding to the different subcarriers overlap in frequency. Hence, the available bandwidth is used very efficiently. If knowledge of the channel is available at the transmitter, then the OFDM transmitter can adapt its signaling strategy to match the channel. Due to the fact that OFDM uses a large collection of narrowly spaced subchannels, these adaptive strategies can approach the ideal water pouring capacity of a frequency-selective channel. In practice this is achieved by using adaptive bit loading techniques, where different sized signal constellations are transmitted on the subcarriers The MIMO-OFDM technique is widely used in wireless communication in frequency selective fading channels due to its high spectral efficiency and its ability to divide a frequency selective fading channel into multipath flat fading sub-channel (subcarriers). This is the main reason for MIMO-OFDM technology being considered as the best technology for next generation wireless systems. The general block diagram [2] of a MIMO-OFDM system is given in figure 1.

Piyush Tiwari, M.Tech Scholar, Electronics and Communication Department, PDM College of Engineering, Bahadurgarh,Haryana
Sachit Rathi, Assistant Professor, Electronics and Communication Department, PDM College of Engineering, Bahadurgarh,Haryana

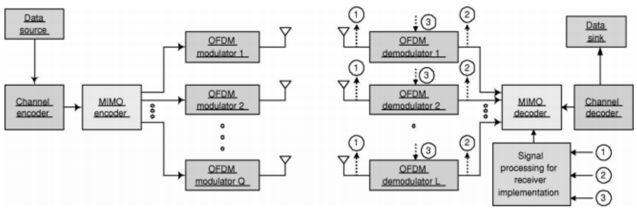


Figure 1: Block Diagram of Transmitter-Receiver

In this block diagram, it is shown that the high rate data stream is given to space-time processor where it is converted in to sub-streams through simple multiplexing or space-time coding for OFDM modulation and transmission through different antennas. Then, these space-time processed data streams after passing through OFDM modulators are transmitted through a number of antennas. A suitable technique is adopted for modulation depending upon the channel conditions and other transmission factors like available power and distance of transmission etc. Then, these transmitted data streams are received through a number of antennas at the receiving end. The number of antennas at both the ends may be same or different. Further, after OFDM demodulation, the data is present into its original form for further processing at the receiving end.

II. MIMO-OFDM SYSTEM MODEL

In recent years various smart antenna designs have emerged, which have found application in diverse scenarios and the four most wide-spread MIMO types are briefly summarized in Table which will provide during research work. The four MIMO schemes were designed for achieving various design goals. The family of Spatial Division Multiplexing (SDM) [1], [10] schemes aims for maximizing the attainable multiplexing gain, i.e., the throughput of a single user by exploiting the unique, antenna-specific channel impulse responses (CIRs) of the array elements. By contrast, SDMA arrangements [1] are close relatives of SDM schemes, but they maximise the number of users supported, as opposed to maximizing the throughput of a single user by sharing the total system. During the past decades, wireless communication has benefitted from substantial advances and it is considered as the key enabling technique of innovative future consumer products. For the sake of satisfying the requirements of various applications, significant technological achievements are required to ensure that wireless devices have appropriate architectures suitable for supporting a wide range of services delivered to the users.

III. Schemes

A. Synchronization

Since in a MIMO system, there are a number of transmitting as well as receiving antennas, hence all of these antennas have to be synchronized prior to the transmission of any kind of data through them. If there is lack of the synchronization then there will be undesired overlapping or destruction of the transmitted data symbols which eventually results in the degradation of the overall performance of the system as a whole.

B. Need of FFT units at the Transmitter & Receiver

Before transmission, the data stream is broken into many small data packets and then all of them are transmitted and then received through a number of antennas. For this procedure, at the transmitter, the FFT (Fast Fourier Transform) of the given data has to be carried out which requires an FFT unit, with the help of which the operation is accomplished. And similarly at the receiving end, the inverse phenomenon (i.e. IFFT) is carried out for the demodulation and recovery purpose. For all this, FFT and IFFT units are required at the transmitting and receiving ends which increase the overall cost of the system.

C. Sensitivity related Carrier Frequency Offset

Carrier Frequency Offset (CFO) [9] is one of the most common impairments found in a communication system. It is due to the mismatch between the carrier frequencies used by transmitter and receiver of the system. The main cause of carrier frequency offset is the Doppler shift of the channel and the difference between the transmitter and receiver local oscillator frequencies. In MIMO-OFDM systems, CFO destroys the orthogonality between subcarriers and causes inter-carrier interference (ICI). CFO must be accurately estimated and compensated to ensure good performance of a MIMO-OFDM system. For a collocated MIMO-OFDM system, periodic training sequences are used to estimate the CFO.

D. Analyzing Method

Almost all communication systems including MIMO-OFDM are employed with power amplifiers in order to obtain the necessary power level for transmission. To achieve the highest power efficiency, the High Power Amplifiers (HPAs) are operated at or near the saturation region which eventually leads to distortion and introduce inter-modulation products between different subcarriers. In MIMO-OFDM system, a number of high frequency carrier signals are used to transmit a number of narrow-band input signals. Therefore in time domain, a multi-carrier signal is the sum of many narrow band signals. This gives the peak value of the signal higher than average value. The higher value of PAPR reduces the power efficiency of the system. To minimize the value of PAPR, techniques like Selected Mapping (SLM) technique, Partial Transmit Sequence (PTS), Discrete Fourier Transform (DFT) spreading technique and Pulse Shaping technique are used [5].

E. Suitable Modulation Technique

If the data is to be transmitted up to a long distance, then it has to be modulated with some suitable method of modulation. Generally four modulation schemes are used:

B.P.S.K. (Binary Phase Shift Keying)

Q.P.S.K. (Quadrature Phase Shift Keying)

16-Q.A.M.(16-Quad. Amplitude Modulation)

64-Q.A.M. (64-Quad. Amplitude Modulation)

Sometimes, it becomes difficult to choose the appropriate modulation technique according to the given channel conditions and other input parameters.

F. Implementation Complexity

As explained earlier, a MIMO-OFDM system has a number of sub-systems with a number of transmitting and receiving antennas. The sub-systems include space-time processor, modulator, demodulator, power amplifiers, FFT and IFFT units at transmitter and receiver respectively. These all increase the complexity and cost of implementation of a MIMO-OFDM system which prove to be a major challenge in its practical implementation.

G. Size of Antenna Array

Although more number of antennas certainly improve the performance of a MIMO-OFDM system by reducing its BER and increasing channel capacity; but it also raises some issues like more power requirements, synchronization and higher value of PAPR etc. Therefore the size of antenna array has to be chosen by keeping all these factors in mind so that there may not be any compromise with the efficiency and fidelity of the MIMO-OFDM system under consideration.

IV. PERFORMANCE PARAMETERS OF A MIMO-OFDM SYSTEM

The performance of a MIMO-OFDM system depends upon a number of factors. There are certain parameters which decide the performance and efficiency of the wireless MIMO-OFDM system. Some of the most important parameters are briefly explained as follows:

A. Input Power (Pin)

The input power is a primary parameter to decide the performance of a MIMO-OFDM system. The range and efficiency of any system depend on its input power. In a MIMO system, it becomes important to feed all the antennas with the required power according to the type of modulation technique used and path of transmission of user data (or signal).

B. Number of Antennas

In a MIMO system, data is transmitted through a number of antennas. If number of antennas are used less then we require lesser power for transmission but there will be more bandwidth transmitted per antenna in this case. So the symbol duration will be less and hence inter-symbol interference (ISI) will be more. In the opposite case i.e. with more number of antennas, the power required will be more but also there will be less interference between the symbols and the complexity of the receiver is reduced.

C. Bit Error Rate (BER)

This is one of the major parameters for end-to-end performance measurement. It is basically the fractional relation between the number of output bits with errors and the total number of bits transmitted and may be defined as:

BER=No. of bits with errors/Total no. of bits

For better performance of any communication system, BER should be minimum (ideally zero). The maximum BER occurs when there is strong inter-symbol interference in the system.

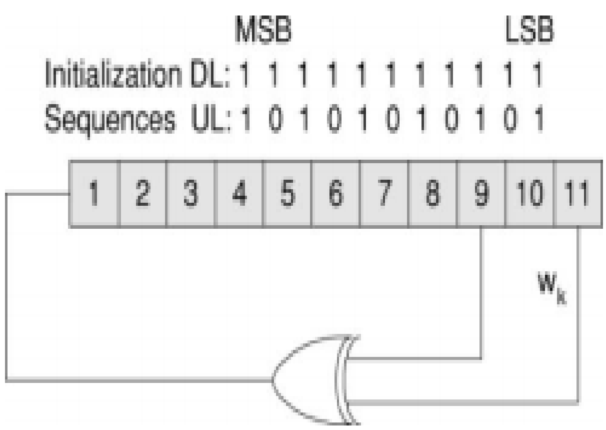
D. PAPR (Peak to Average Power Ratio)

The PAPR is defined as the ratio between maximum power and the average power of the complex pass-band signal. It may be given as [4]:

E. Information Analysis

It is the maximum amount of information that can reliably be transmitted over any communication channel at any given instant. It is denoted by 'C' and can be given as: where B= Bandwidth in Hz; C= Signal to Noise Ratio. Channel Capacity of the system increases with increase in SNR as well as with number of antennas in the system. Further, when number of transmitting and receiving antennas is increased in MIMO-OFDM systems, rate of increase in channel capacity also increases.

V. BRIEF ANALYSIS OF MIMO-OFDM SYSTEM PERFORMANCE



In this section, a brief analysis of the performance parameters obtained by the simulation of a MIMO-OFDM system has been covered. The system parameters considered for this analysis are given in table 1.

A.BER Analysis of MIMO-OFDM System

In figure 2, BER performance of a MIMO-OFDM system is analyzed by taking four transmitting and receiving antennas with different modulation techniques

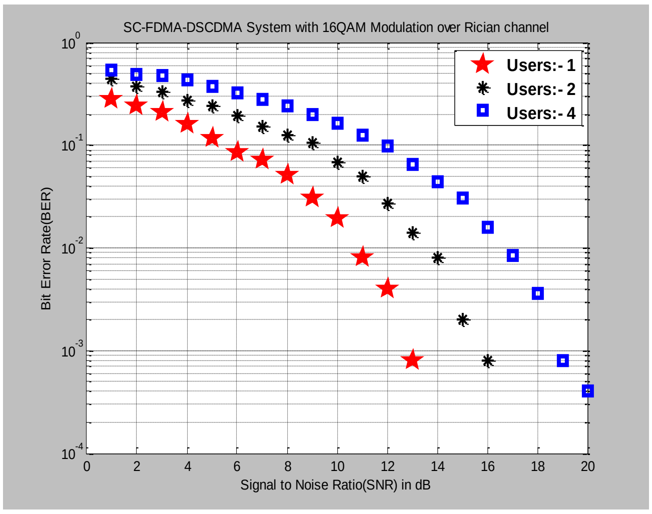


Figure 2BER Comparison of Different Users with 16QAM Modulation over Rician Channel

In fig.2, Rician channel is used for comparison with different modulation techniques. We can see in above fig. that at particular 10^{-3} BER, SNR is 12.8dB when user is 1; SNR is 15.7dB when users are 2; SNR is 18.8dB when users are 8. It has been observed that there is constantly increase in SNR value i.e. 3dB when users are increasing.

B. Probabilistic CCDF Analysis in MIMO-OFDM

The value of PAPR of a communication system has to be minimum for better power efficiency. The PAPR performance of any communication system is measured in terms of Complementary Cumulative Distribution Function (CCDF) which is defined as the amount of time spent by a waveform at (or above) a particular power level. CCDF is probabilistic in nature and may be mathematically given as:

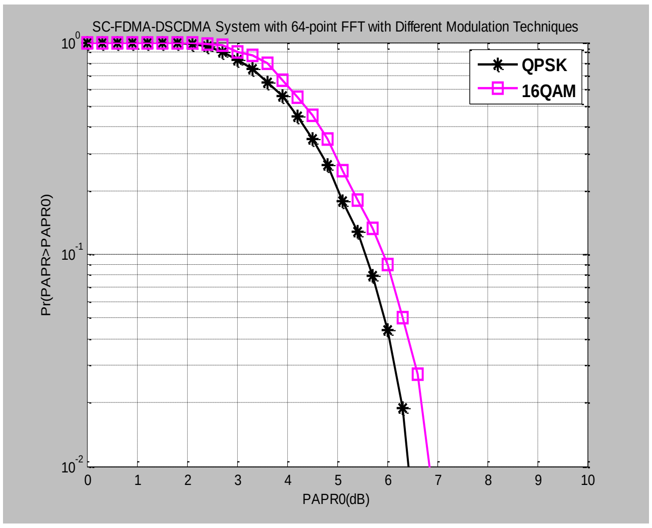


Figure 3 . CCDFs of PAPR for Same 64-point FFT with Different Modulation Techniques

which means the probability of PAPR being greater than a particular value of PAPR that is PAPR0. Figure 3 shows the CCDFs of PAPR with same FFT size i.e. 64-point with different modulation techniques (QPSK, 16QAM). As we go on lower modulation to higher modulation technique, PAPR increases which means high power amplifier is required at receiver side.

VI. CONCLUSION

Based on the solutions discussed throughout this paper, we demonstrated a number of significant benefits brought about by the GAs for wireless communications. It is worth pointing out that the proposed GAs may be further improved in various ways. For example, the value of the mutation probability can be adapted according to the number of users and/or the GA's generation index. Furthermore, the GA's population-based soft output [283], [284] can be improved, if the OSs of all meritorious individuals are stored throughout all generations, which may be used for improving the reliability of the GA's soft output. Additionally, the GA individual's symbol chromosome, which consists of the multiple users' hard-decoded symbol estimates, may also be represented by the soft bit estimates, enabling the GA to benefit from the soft information provided by the channel decoders during the external iterative processing. This is expected to improve the performance of the iterative GAs, such as those used in the IGA MUD of [281], [282] and in the GA-JCEMUD of [56], [324]. Moreover, the joint channel estimation and symbol detection approach of [56], [324] can also be further enhanced by introducing a soft-input soft-output mechanism. More specifically, not only the GA-optimized FD-CHTF estimates, but also the GA-optimized symbol estimates can be forwarded to the first-stage MUD for assisting in the initial symbol detection invoked in the next iteration.

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