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Enhanced MIMO-OFDM System for Wireless Communication

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ABSTRACT: Orthogonal Frequency Division Multiplexing (OFDM) is a powerful technique employed in communication systems suffering from frequency selectivity. However, it has got some limitations. The objective of our paper is to study and improve the OFDM system using Multi-Input Multi-Output technology (MIMO) technology supported with reduction of Inter Symbol Interference (ISI), Inter Carrier Interference (ICI) and Peak to Average Power Ratio (PAPR). Furthermore, the Bit Error Rate (BER) can also be reduced by Convolution Coding. Different techniques are employed viz. Cyclic Prefix for ISI, Maximum Likelihood Estimation for ICI and Clipping for PAPR to overcome the associated drawbacks.

KEYWORDS: Orthogonal Frequency Division Multiplexing (OFDM), Multi-Input Multi-Output technology (MIMO), Inter Symbol Interference (ISI), Inter Carrier Interference (ICI), Peak to Average Power Ratio (PAPR)

I. INTRODUCTION

OFDM is sometimes called multicarrier or discrete multi-tone modulation. It is a modulation technique used for digital TV in Europe, Japan and Australia. It can be seen as either a modulation technique or a multiplexing technique for UWB systems. OFDM's spread spectrum technique distributes the data over a large number of carriers that are spaced apart at a precise frequency. This spacing provides the "orthogonality" in this technique which prevents the demodulators from seeing frequencies other than their own. The sidebands of individual carriers in an OFDM signal overlap and the signals are still received without adjacent carrier interference as the carriers are mathematically orthogonal.

However in an OFDM transmission system, each subcarrier is attenuated individually under the frequency-selective and fast fading channel. If the same fixed transmission scheme is used for all OFDM subcarriers, it results in high attenuation and hence poor performance. Multiple input multiple output (MIMO) communication systems when integrated with the OFDM system can obtain high data rate transmission over broadband wireless channels. Alamouti's Simple Transmit Diversity Technique is used for this purpose. By exploiting the multipath nature of wireless channels, a trait that inhibits traditional wireless system, capacity (bits per second/ Hertz) can increase linearly with the number of transmit & receive antennas, while still maintaining the same total transmission power as a traditional single transmit/receive antenna system. This remarkable technique implies that at a given receiver SNR, total transmission power and Bandwidth, one can increase the aggregate data rate by simply adding more antenna and avoid channel delay spread too.

Furthermore, OFDM for MIMO is considered for wideband transmission to mitigate Inter Symbol and InterCarrier Interference and enhance system code. Intersymbol interference (ISI) can be caused by multi-path fading as signals are transmitted over long distances and through various mediums. As a result, they can interfere with the following or preceding transmitted symbols. This is avoided by using Cyclic Prefix. Also, due to carrier frequency offsets like Doppler Shifts due to time channel variations, channel delay, sampling frequency offsets, interference between the carriers of different symbol takes place. Different reduction techniques are employed for this purpose.

Also it is important to make the system immune to errors or inherently detects/corrects errors. Different coding techniques like Channel coding, source coding, (at the transmitter) and error detecting and correcting codes (at the

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receiver) are used for this purpose. Source coding converts the analog information into raw digital data. Channel coding, for instance, convolutional coding adds redundancies, that is it adds more bits per bit.

Furthermore, OFDM systems has a very basic disadvantage of a high Peak to Average Power Ratio (PAPR). This makes the system inefficient since the system often runs in non-linear region and also the need for a large battery back-up power. Thus different techniques are used for reducing PAPR. Thus we would like to propose a system that would deal with the reduction of ICI, ISI, PAPR reduction and also reduce Bit Error rate (BER) by using Convolution Coding.

II. FOURTH GENERATION (4G)

4G is short for fourth-generation cellular communication system. The approaching 4G mobile communication systems are projected to solve still-remaining problems of 3G (third generation) systems and to provide a wide variety of new services, from high-quality voice to high-definition video to high-data-rate wireless channels. The 4G systems not only will support the next generation of mobiles service, but also will support the fixed wireless networks.

A. Objectives of 4G:

To cater the quality of service and rate requirements set by the forthcoming applications like wireless broadband access, Multimedia Messaging Service, video chat, mobile TV, High definition TV content, DVB and minimal service like voice and data at anytime and anywhere, 4G is being developed.

III. ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING (OFDM)

Frequency division multiplexing (FDM) extends the concept of single carrier modulation by using multiple subcarriers within the same single channel. The total data rate to be sent in the channel is divided between the various subcarriers. FDM systems usually require a guard band between modulated subcarriers to prevent the spectrum of one subcarrier from interfering with another. However in OFDM, no guard band is required and saving of bandwidth takes place as shown in figure 2.1

One view of the DFT is that the transform essentially correlates its input signal with each of the sinusoidal basis functions. If the input signal has some energy at a certain frequency, there will be a peak in the correlation of the input signal and the basis sinusoid that is at that corresponding frequency. This transform is used at the OFDM transmitter to map an input signal onto a set of orthogonal subcarriers, i.e., the orthogonal basis functions of the DFT. Similarly, the transform is used again at the OFDM receiver to process the received subcarriers.[17]

Thus in short, Orthogonal frequency-division multiplexing (OFDM), also sometimes called discrete multi-tone modulation (DMT), is a complex modulation technique for transmission based upon the idea of frequency-division multiplexing (FDM) where each frequency channel is modulated with a simpler modulation. In OFDM the frequencies and modulation of FDM are arranged to be orthogonal with each other which almost eliminates the interference between channels.

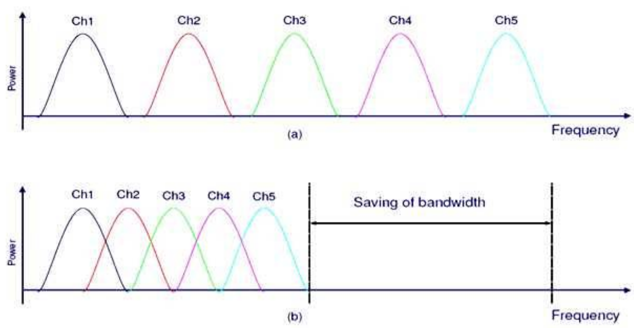

Fig 2.1 Graph Comparison of OFDM with FDM

These guard bands lower the system's effective information rate when compared to a single carrier system with similar modulation.

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IV. MULTI INPUT MULTI OUTPUT (MIMO)-OFDM

Multiple Input Multiple output (MIMO) wireless technology in combination with orthogonal frequency division multiplexing (MIMO-OFDM) is an attractive air interface solution for next generation wireless local area networks (WLANs), wireless metropolitan air networks (WMANs) and fourth generation mobile cellular wireless systems.[18]

A. MIMO architecture:

The application of multi-antenna technology (MIMO) yields a unique physical layer capable of targeting the requirements of a second-generation non-LOS system. Herein, we discuss some key design and algorithmic choices made in implementation of the Airburst modem.

A.1 Transmit Diversity:

In this scheme, the signal sent from the second antenna is a delayed copy of the signal at the first antenna. The delay introduced at the transmitter results in frequency selectivity in the received channel sense. There are two types of coding. In space time coding, the same signal is encoded differently into different forms to be transmitted across multiple antennas. Block codes are attractive since they allow decoding at the receiver (e.g. the Alamouti's scheme). In linear precoding, the transmitted signals are linearly mapped onto multiple transmit antennas; depending on the slowly varying channel statistics such as transmit antenna correlation. Linear precoding can be used in conjunction with space-time codes to provide performance gains

A.2 Spatial Multiplexing:

It is possible to transmit two separately encoded data streams from the two base station antennas. A high-rate signal is multiplexed into a set of lower-rate streams, each of which is encoded, modulated, and transmitted at a different antenna, while using the same time and frequency slot. Each of the three receiving antennas receives a linear combination of the two transmitted messages that have been filtered by different channel impulse responses.[16]

The receiver separates the two signals using a spatial equalizer, and demodulates, decodes, and demultiplexes them to yield the original signal. Separation is possible as long as each stream induces a different spatial signature at the receiver (i.e., the channel matrix has full rank). Since most spatial equalizers use some form of channel matrix inversion, a unique solution is only possible if the number of receive antennas is greater than or equal to number of independent transmit signals

B. Alamouti's Simple Transmit Diversity Technique:

This technique is described to be applicable to two transmit antennas and one receiver antenna configuration. The scheme is defined by the following three functions:

- The encoding and transmission sequence of information symbols at the transmitter
- The combining scheme at the receiver
- The decision rule for maximum likelihood detection[19]

Alamouti's Simple Diversity Scheme can be seen in figure 3.1 and Encoding and Transmission sequence in figure 3.2.

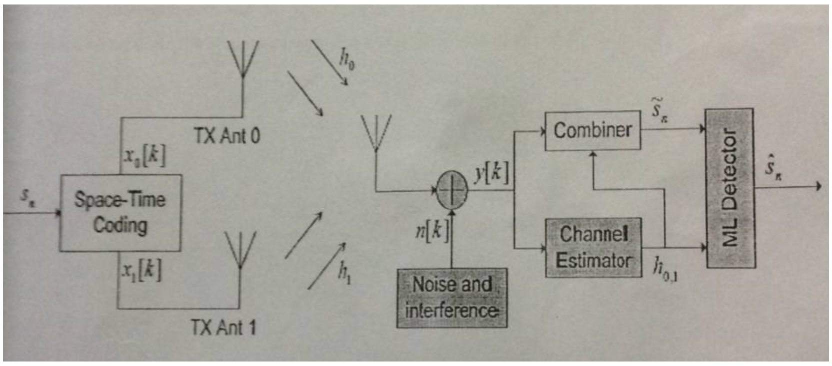

Fig 3.1 Alamouti's Simple Diversity Scheme

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	Antenna 0	Antenna 1
Time t	S_n	S_{n+1}
Time t+T	$-S^*_{n+1}$	S^*_n

Fig 3.2 The Encoding and Transmission Sequence for the Two-Branch Transmit Diversity Scheme

V. INTERSYMBOL INTERFERENCE (ISI)

In telecommunication, Intersymbol Interference (ISI) is a form of distortion of a signal in which one symbol interferes with subsequent symbols.. The spreading of the pulse beyond its allotted time interval causes it to interfere with neighbouring pulses.ISI is usually caused by multipath propagation or the inherent non-linear frequency response of a channel causing successive symbols to "blur" together. Therefore, in the design of the transmitting and receiving filters, the objective is to minimize the effects of ISI, and thereby deliver the digital data to its destination with the smallest error rate possible.

In order for the orthogonality of the OFDM sub-carriers to be preserved, typically in an OFDM system, a guard interval is inserted. The insertion of cyclic prefix is very simple. Assume the length of the guard interval is v, it is just pre-pended the last v samples to the original OFDM sample sequence at the transmitter. At the receiver the so-called guard interval is removed. The length of the cyclic prefix is required to be equal to or longer than the maximum channel delay spread to be free from ISI/ICI.[20] As already mentioned, this is simple, but it reduces the transmission efficiency of the information bits.[10] An example of Intersymbol Interference is shown in figure 4.1

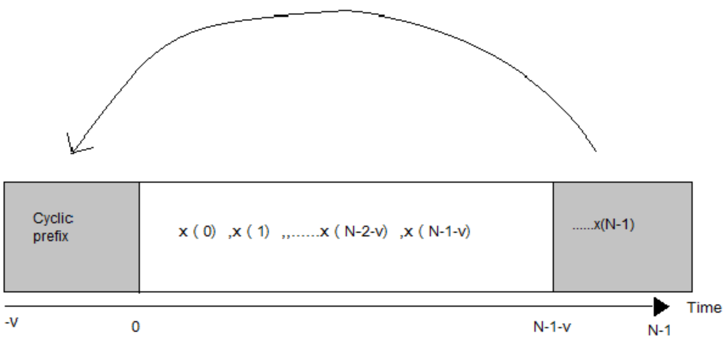

Fig 4.1 Structure of Cyclic Prefix

VI. INTERCARRIER INTERFERENCE (ICI)

The main disadvantage of OFDM is its susceptibility to small differences in frequency at the transmitter and receiver, normally referred to as frequency offset. This frequency offset can be caused by Doppler Shift due to relative motion between the transmitter and receiver, or by differences between the frequencies of the local oscillator at the transmitter and receiver. Here, the frequency offset is modelled as the multiplicative factor introduced in the channel.[12]

The received signal is given by,

$$y(n) = x(n)\, e^{\frac{j2\pi n\epsilon}{N}} + w(n) \qquad \text{Eq.5.1}$$

Here ϵ is the normalized frequency offset and is given as the frequency difference between the transmitted and received carrier frequencies and N is the subcarrier symbol period.

ICI results from other subchannels in the same data block of the same user. Even if only one user in communication, ICI might occur, yet the co channel interference will not happen. There are two factors that causes the

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ICI namely frequency offset and time variations. Some kinds of time variations of channels can be modelled as a white Gaussian random noise. When n is large enough, other time variations can be modelled as frequency offsets such as Doppler shifts.

A. **Multipath Fading:**

The influence of multipath fading on ICI is seldom discussed before. As a matter of fact, the multipath fading does not cause ICI but it will make the ICI problem worse since ICI cannot be neglected in practice. The impact of Multipath should be discussed. It is recognized that the cyclic prefix has been used to eliminate ISI entirely and therefore only ICI needs to be concerned.

There are three kinds of approaches used to reduce ICI:

1. ICI Self Cancellation scheme
2. Maximum Likelihood Estimation
3. Kalman Filter

One of the methods for frequency offset correction i.e. ML estimation in OFDM systems was suggested by Moose. This technique involves the replication of an OFDM symbol before transmission and comparison of the phases of each of the subcarriers between the successive symbols. The maximum likelihood estimate is a conditionally unbiased estimate of the frequency offset and can be computed by using received data. The maximum likelihood estimate of the normalized frequency offset is given by

$$\hat{\varepsilon} = \frac{1}{2\pi}\tan^{-1}\left[\frac{\sum_{k=-K}^{K} Im Y_2(k) Y_2^*(k)}{\sum_{k=-K}^{K} Re\, Y_2(k) Y_1^*(k)}\right]$$

Eq.5.5

Once the frequency offset is known, the ICI distortion in the data symbols is reduced by multiplying the received symbols with a complex conjugate of the frequency shift and applying the FFT. [8][14]

$$X(n) = FFT\{Y(n) e^{\frac{-j2\pi n\varepsilon}{N}}\}$$

Eq. 5.6

VII. PEAK TO AVERAGE POWER RATIO (PAPR)

One of the most important problems associated with the multicarrier systems like in MIMO-OFDM is high PAPR i.e. Peak to Average Power Ratio. It is a relationship between the maximum power of a sample in a OFDM symbol which is transmitted and it's average power. It can be given as

$$PAPR = 10\log_{10}\frac{P_{peak}}{P_{average}}\,(dB)$$

Eq. 6.1

In other terms, if x(t) is a signal to be transmitted, then it's PAPR is given as

$$papr = \frac{\max[x(t)x^*(t)]}{E[x(t)x^*(t)]}$$

Eq. 6.2

The cause of PAPR in such multicarrier systems like MIMO-OFDM is the superposition (IFFT operation) of multiple subcarrier signals. It is always desirable for a system to have a low PAPR due to many reasons. A high peak power results the transmitter Power Amplifier to run within a non linear operating region. This causes distortion at output of the amplifier. Also, it causes DAC to work at saturation. The inter-modulation between the different subcarriers causing distortion requires the Power Amplifier to operate with a large backup power, thus making it an inefficient operation. Hence different techniques are employed for reduction of PAPR in systems. Some of the

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techniques include Clipping, Block Coding, Tone Reservation, Tone Injection, Scrambling Techniques like Selected Mapping Technique, Partial Transmit Sequence and many more.[7]

The technique which is employed in the proposed system is Clipping which is a type of Signal Distortion technique. The operations like Clipping and Filtering come under this category. This is one of the most common technique generally employed where the signal at the transmitter is clipped or snipped so as to eliminate the appearance of high peaks above a certain level.[6]

VIII. CONVOLUTION CODING

For the successful working of any digital system, it is utmost importance to make the system immune to errors or design a system which inherently detects/corrects errors. Channel coding, source coding,(at the transmitter)and error detecting and correcting codes(at the receiver)are used for this purpose. Source coding converts the analog information into raw digital data. Channel coding, for instance, convolutional coding adds redundancies, that is it adds more bits per bit. This is done to make data the immune to errors introduced during transmission.

At the receiver side, the convolutional codes can be decoded using decoding algorithms such as Viterbi algorithm. The two important parameters that are used at the receiver are the bit error rate (BER) and signal to noise ratio (SNR) These parameters help to evaluate the efficiency of the system as a whole. [11]

A. Structure of a Convolution Code and its parameters

A convolutional code is described by three integers, n ,k and K, as shown in figure 7.1 where the ratio k/n has the same code rate significance (information per coded bit) that it has for block codes; however, n does not define a block or codeword length as it does for block codes. The integer K is a parameter known as constraint length; it represents the number of k-tuple stages in the encoding shift register. An important characteristic of the convolution codes ,different from block codes, is that an encoder has memory-the n-tuple emitted by the convolutional encoding procedure is not only a function of an input k-tuple, but is also a function of the previous K-1 input k tuples. In practice, n and k are small integers and K is varied to control the capability and complexity of the code.[11][15]

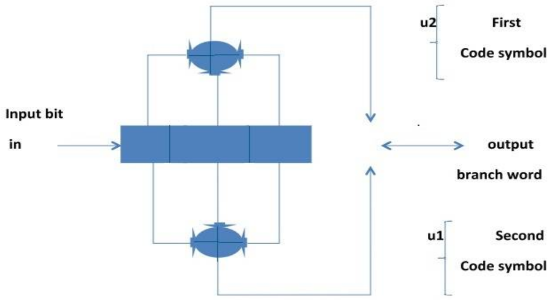

Fig 7.1 Convolution Encoder (rate ½ k=3)

IX. PROPOSED METHOD AND BLOCK DIAGRAM

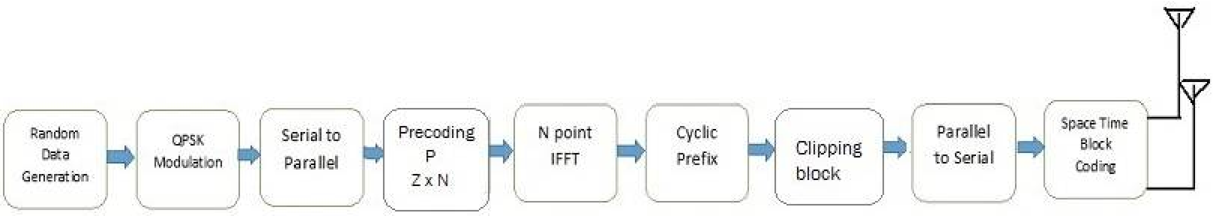

Fig 8.1 MIMO-OFDM transmitter block diagram

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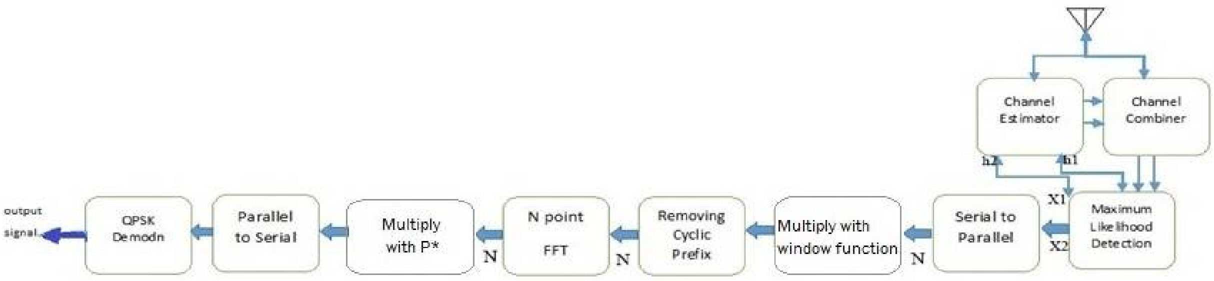

Fig 8.2 MIMO-OFDM receiver block diagram

A.1 Random Data Generator

The data to be transmitted is generated randomly or any data to be transmitted is given at this input. This uniformly distributed binary data is coded into symbols depending on the modulation scheme of implementation. This results in block of data symbols of particular length.

For e.g.: In QPSK-----2bits form a symbol
In 16QAM--- 4bits form a symbol
In BPSK--- ---each bit is a symbol

A.2 Modulation & Demodulation of Data

The data to be transmitted on each carrier is then encoded with previous symbols, then mapped into a modulation scheme. The data on each symbol is then mapped to a phase angle based on the modulation method.

For e.g.: For QPSK--- the phase angles used are 0, 90, 180, and 270 degrees. The use of phase shift keying produces a constant amplitude signal and was chosen for its simplicity and to reduce problems with amplitude fluctuations due to fading.

For 16QAM --- phase as well as amplitude modulation is done. And thus the data is coded in No phase and amplitude.

For BPSK--- the phases angles used are 0, 90. It proves to be the best modulation technique among the three.

The corresponding demodulation is then carried out at the receiver side to obtain the baseband data.

A.3 Serial to Parallel & Parallel to Serial Conversion

The whole block of data is then converted into blocks to obtain parallel data. This is padded with sufficient zeros at the start and end so that the length becomes equal. This is used to give to the N-Point IFFT block. While transmitting, the parallel data is again sent serially.

The corresponding blocks of received data are then made to obtain serially at the receiver through P to S converter. The S to P converter is used again to give the N-Point FFT block.

A.4 Pre-coding and Multiplying with P*

The parallel block of data is pre-coded with convolution coding to achieve low BER at the receiver.

Multiplying with P* i.e. the conjugate of pre-coded data at the receiver side enables to obtain the original data.

A.5 Inverse Fast Fourier Transform and Fast Fourier Transform

This N block of data is converted from frequency domain to the time domain using this IFFT block. N-Point IFFT is used for this purpose. After the required spectrum is worked out, an Inverse Fast Fourier transform is used to find the corresponding time waveform. The guard period is then added to the start of each symbol. Corresponding to this, a Fast Fourier Transform block FFT is used at the receiver side to obtain the original data.

A.6 Cyclic Prefix and its removal at the Receiver section

A fixed number of symbols are added at the start of each block of N data. This is the guard insertion or cyclic prefix addition of specific length ‘L’ to reduce Inter Symbol Interference i.e. ISI. This is done by copying the last 'L' symbols from each block of N and appending it to the start. This insertion is removed at the receiver section.

A.7 Clipping and Multiplying with Window Function

Clipping is done at the transmitter to reduce high PAPR by means of directly clipping the signal. The signal is then obtained at the Receiver side by multiplying the clipped version of signal by a pre-defined window function.

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A.8 Maximum Likelihood Estimation

The conditionally unbiased estimate of the frequency offset was compared using the received data. Once the frequency offset is known, the ICI distortion in the data symbols is reduced by multiplying the received symbols with a complex conjugate of the frequency shift and applying the FFT.

A.9 AWGN channel

This channel is considered to be a channel with no fading but only noise. Depending on the SNR and the power of the signal after fading, a controlled white Gaussian noise is added using AWGN function.

X. Conclusion and Future Work

OFDM is a robust technique which has greatly helped in improving the communications industry. Yet, there are many problems still associated which limit the performance of OFDM. Our project dealt with few of them like Inter Carrier Interference (ICI), Inter Symbol Interference (ISI), high Peak to Average Power Ratio (PAPR) and also considerable Bit Error Rate (BER). If efforts are taken to eliminate these completely, it will improve the performance of OFDM system extensively. Different methods are, however, available to reduce these problems. By employing these techniques to mitigate the distinct problems, a high performance or 'Enhanced' MIMO-OFDM system can be obtained.

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