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Low Complexity Post-Coded MIMO OFDM Systems: Design and Performance Analysis

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LOW COMPLEXITYPOST-CODEDMIMOOFDMSYSTEMSDESIGNANDPERFORMANCEANALYSIS

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Low Complexity Post-Coded MIMO OFDM Systems: Design and Performance Analysis

Sanjeev Kumar[α] & Dr.Amita Soni[σ]

Abstract - This paper discuss the Low Complexity Post-Coded MIMO OFDM (PC-MIMO OFDM) Systems: Design and performance analysis. The signal is propagating from the transmitter to receiver along number of different paths, referred as multipath in wireless environment. Path loss, macroscopic fading and microscopic fading are propagating signal power drops. Orthogonal Frequency Division Multiplexing (OFDM) provides a viable solution to communicate over selective fading channels. OFDM offers several advantages like resilience to multipath fading in intersymbol interference, low complexity and others. Multiple input multiple output (MIMO) utilizes spatial diversity by having several transmit and receive antennas.

The combination of MIMO and OFDM has been designed to improve the data rate and Quality of service (QoS) .The wireless system utilizes the multiplexing gain and/or diversity gain which is a major problem in communication. The combination MIMO-OFDM is very natural and beneficial, since OFDM enables support of more antennas and large bandwidths. Coded or precoded OFDM systems are generally employed to overcome the symbol recovery problem in uncoded OFDM systems. The post coded OFDM systems introduce frequency diversity by manipulating the OFDM systems in time domain so that the computational complexity of the system can be significantly reduced.

We discuss the design principle of PC-MIMO OFDM system transmitter that uses up sampling operation and spreading codes to introduce frequency diversity .We also describe the design of low complexity receiver for PC-MIMO OFDM systems to minimize error performance.

The main advantages of this scheme are reduce system complexity by having a simple encoder/decoder ,smaller size inverse fast Fourier transform/fast Fourier transform (IFFT/FFT)modules, and lower clock rates in the receiver and transmitter leading to be lower energy consumption. The proposed system is found to be equally good over Gaussian and Fading channels where it achieves the maximum diversity gain of the channel. Simulation results show that PC-MIMO OFDM performs better than existing precoded OFDM systems.

Indexterms : Multiple input multiple output (MIMO), Orthogonal frequency division multiplexing (OFDM), precoding,postcoding,spreading codes, frequency diversity, coding gain, diversity gain.

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I. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) has been proven to be a viable technique to overcome multipath fading in wireless channels.OFDM offers several advantages like resilience to multipath fading, intersymbol interference, low complexity and others. It has been adopted in many wireless standards, such as digital audio/video broadcasting, the HIPERLAN/2 standard, the IEEE 802.11a and g standards for wireless local area network (WLAN). The need for high rate data services is growing, especially as multimedia applications are gaining popularity, as they require higher data rate with good quality of service (QoS). Thus, new wireless systems have to be designed considering the need for data and multimedia services [1].

In wireless technology biggest challenge is to overcome the effect of Rayleigh fading channel. The multipath nature of the channel leads to inter symbol interference (ISI) and as the bandwidth occupied increases, the ISI severity is pronounced.

To combat the ISI problem due to the multipath nature of the channel, equalizers are used. In a single carrier system, the equalizer is generally a linear filter whose purpose is to combine the signal components arriving at various time delays. The computational effort required for implementing an equalizer increases with data rate and the problem becomes more challenging when there is a time varying multipath channel in which case it need tracking. The orthogonal frequency division multiplexing (OFDM) transmission scheme is an efficient technique to combat ISI.In a conventional serial data system, the symbols are transmitted sequentially, with the frequency spectrum of each data symbol allowed to occupy the entire available bandwidth. As the data rate increases, the time a single symbol (one or several bits) is “on air” is decreased. In case of impulse noise or other short period noise with high energy, it is likely that a symbol gets distorted to such a high extent that it cannot be recovered. The shorter the period in which the symbol is available, the higher is the probability that the symbol is fully destroyed by bursts of noise [2].

But in OFDM instead of using a single carrier that occupies the whole available frequency band, several orthogonal subcarriers are employed within the available frequency band. The data is divided into several parallel data streams or channels, one for each sub-carrier.Each sub-carrier is modulated with a conventional modulation scheme (such as quadrature amplitude modulation or phase shift keying) at a low symbol rate, maintaining total data rates similar to conventional single-carrier modulation schemes in the same bandwidth [3]. The key idea of the OFDM transmission is to make the symbol period long with respect to the delay spread of the channel. In the frequency domain this can be viewed as the subcarrier BW becoming smaller compared with the coherence BW of the channel, i.e., the individual subcarriers experience flat fading, which requires a simple one tap equalizer. The orthogonality of the carriers means that each carrier has an integer number of cycles over a symbol period. Due to this, the spectrum of each carrier has a null at the centre frequency of other carriers in the system. This result is no interference between the carriers [4].

To cope with this problem of multipath channel, various techniques have been and continuously are being proposed by the researchers of system modeling. Orthogonal frequency division multiplexing is one of the widely used such techniques. The aim of this work to design a system to reduce the complexity without any performance loss and the overall computational cost of the system significantly reduced.The idea of precoded OFDM system for single and multiple antennas has designed already and post coded system for single antenna system has also designed. But if the idea of post-coding scheme from single antenna is extended to multiple antenna systems.The proposed Post-coded MIMO-OFDM system results low complexity in design, since number of IFFT blocks required by the system reduces to one in contrast to the traditional systems used in which this requirement equals number of transmit antenna. The post-coded system achieves this low complexity objective by manipulating the OFDM symbols in time domain.

It compared the computation cost of single and multiple antenna post-coded system with precoded systems and observed that for same system constraints, that is, for same structure of spreading code and modulation scheme used, the post-coded systems provide cost efficient system design. In short,PC-OFDM systems introduce frequency diversity by spreading the information symbols across all the subcarriers in the efficient manner so that the overall computation cost of the system is significantly reduced. The computation saving in PC-OFDM come from two sources: 1) smaller size IFFT and FFT are used as compared to frequency domain precoding and 2) the special structure of encoding matrices is exploited resulting in $O(N)$ operation instead of $O(N^2)$ operations [5].

II. MIMO System

Multiple-Input-Multiple-Output (MIMO) systems use multiple antennas at the transmitter and receiver ends in a wireless communication system.

Multiple-Input-Multiple-Output systems are increasingly being adopted in communication systems for the possible gains in capacity.

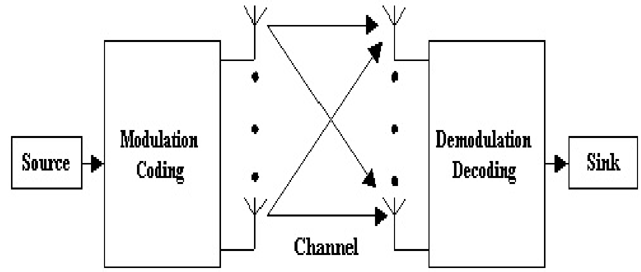


Figure 1 : Block Diagram of MIMO system

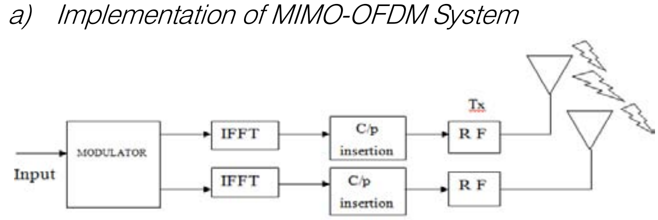
In Multiple-Input-Multiple-Output (MIMO) system, multiple antennas use the spatial dimension in addition to the time and frequency ones, without changing the bandwidth requirements of the system. For a communications link, it focuses on transmit diversity in lieu of traditional receive diversity. Let h be the channel coefficient between the T^{th} transmit antenna and R^{th} receive antenna.Let S =[S1 S2 S3………SN] be the transmitted data and Y=[Y1 Y2 Y3 …….YN] be the received data .Then the relation is given by

$Y = Hs + n$

III. MIMO-OFDM System

MIMO-OFDM systems provide higher data rates, improve communication performance, support a large number of users with flexibility in Quality of Service (QoS) and provide high quality transmission in comparison with the existing ones. Also coding is being done on OFDM symbols to achieve further improved performance from the systems. But in order to fulfil these requirements some constraints have to be very well addressed such as limited availability of frequency spectrum, availability of total transmit power and nature of wireless channels. Also all these advantages come at the cost of high complexity in the system. Main tool for increasing the transmission rate with multiple transmit antennas system consist of transmitting more independent streams or layers of data from all available transmit antennas simultaneously [6].

a) Implementation of MIMO-OFDM System



(a) Transmitter

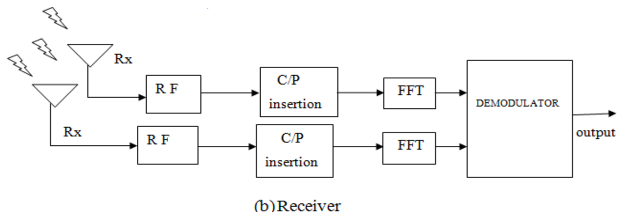


Figure 2 : Block Diagram of MIMO-OFDM Transceiver

The general transceiver structure of MIMO-OFDM is presented in Figure2. The system consists of N transmit and M receiver antennas, the cyclic prefix is assumed to be longer than the channel delay spread [6]. The OFDM signal for each antenna is obtained by using inverse Fast Fourier Transform (IFFT) and can be detected by Fast Fourier Transform (FFT).

The received MIMO-OFDM symbol of n[th] subcarrier and the m[th] OFDM symbol of i[th] receive antenna after FFT can be written as

$$A_i[n,m] = \sum_{j=1}^{N} k_{i,j}\,[n,m] R_j\,[n,m] + W_i[n,m], \text{ i=1,2,3......M} \quad (3.1)$$

Where $R_j\,[n,m]$ is the transmitted data symbol on n[th] carrier and m[th] OFDM symbol, $W_i[n,m]$ is the adeptive noise contribution at i[th] receive antenna for the corresponding symbol in frequency domain and $K_{i,j}\,[n,m]$ is the channel coefficient in the frequency domain between the j[th] transmit antennas and i[th] receive antennas [9].

$$K[n,m] = \sum_{i=0}^{I-1} k_i[m] e^{-j2\pi t_i n/T}, \text{ n=0,1,2,3......N -1} \quad (3.2)$$

Where I is the number of channel taps in time domain and $k_i[m]$ is modulation as an independent zero-mean random Gaussian process [7].

IV. Pc Mimo-Ofdm System

In Post-coded MIMO-OFDM system the spreading and encoding has to be performed in time domain, that is, after IFFT operation, in contrast to the precoded systems as discussed earlier, in which it is done in frequency domain. A MIMO-OFDM system with two transmitting antennas is considered. It uses Alamouti code for encoding the spread symbols as it considered in the precoded system. Since now it is to be performed in time domain, so instead of performing encoding separately, it include the effect of Alamouti coding in the modulated symbols and spreading matrix. It is to be noted that proposed structure of spreading matrix and modulated symbol vector is valid only for MIMO system with two transmitting antennas.

a) *System Model for Post Coded MIMO OFDM System*

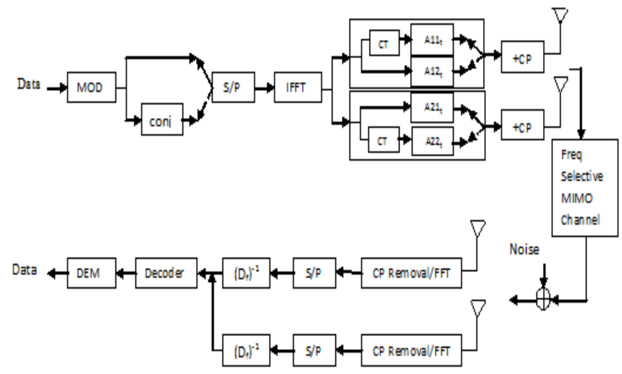


Figure 3 : Block Digram Of Post-coded MIMO-OFDM system model

The structure of the spreading matrix and modulated symbol vector is modified in such a way that symbols generated after time domain spreading operation are equivalent to symbols which are spread as well as encoded in frequency domain and then transformed to time domain, that is, the precoded symbols.

The block diagram of Post-coded MIMO-OFDM system with two transmit and two receive antenna is as shown in figure 3 (CT represent time domain operation that is equivalent to conjugation in frequency domain).To include the effect of alamouti coding to the symbols, instead of directly transforming the symbols to time domain, it, the $N \times 1$ vector of modulated symbols in frequency domain.Indirectly, the part of alamouti coding is separately applied to modify the modulated symbols. Since, the system are required two transmit antennas is being considered, so two modified forms of the modulated symbol vector are required. If the original modulated symbol vector is,

$$b = \begin{bmatrix} b_1 & b_2 & b_3 & \cdots & b_N \end{bmatrix}^T \quad (4.1)$$

Then the first modified form required to include the encoding effect is,

$$b_{m1} = \begin{bmatrix} b_1 & b_2^* & b_3 & \cdots & b_N^* \end{bmatrix}^T \quad (4.2)$$

These modified symbols can now be transformed to time domain by IFFT operation,

$$s = F_N^H b_{m1} \quad (4.3)$$

The second modified form required is,

$$b_{m2} = \begin{bmatrix} b_1^* & b_2 & b_3^* & \cdots & b_N \end{bmatrix}^T \quad (4.4)$$

which is nothing but,

$$b_{m2} = b_{m1}^* \quad (4.5)$$

Now to obtain time domain equivalent of b_{m2} instead of using another IFFT block it use complex conjugate property of IFFT, that is,

$$s_{conj}(1) = (s(1))^* \quad (4.6)$$

$$s_{conj}(i+1) = (s(N+1-i))^* \quad (4.7)$$

Where i=1….N.

The $N \times 1$ vector s_{conj} is the time domain equivalent of the vector b_{m2} or b^*_{m1}. This operation is represented by block CT in figure 3.The time domain equivalent of the symbol vectors, s and s_{conj} is now has to be spread using modified spreading matrix which generates post-coded symbols, equivalent to precoded time domain symbols. The same structure and design criterion is used for constructing spreading matrix and then it is modified to include the effect of encoding. For each transmitting antenna different form of spreading matrix is required [8].

b) Receiver

The transmitting symbols, generated from proposed post-coding technique for MIMO-OFDM system, are equivalent to precoded MIMO-OFDM symbols [9]. After removing CP and performing FFT operation, the data in frequency domain at Receiver is

$$U_{k.j} = \sum_{i=1}^{M_t} H^k_{j,i} x_{k,i} + W_{k,j} \quad (4.25)$$

c) Computational Complexity

In pre coded MIMO-OFDM systems, each transmit antenna requires one IFFT block, so total real multiplications and additions will be,

Real multiplication:

$$Mt \times 2N \log_2 N = 2MtN \log_2 N \quad (4.26)$$

Real additions:

$$Mt \times (5/2)N \log_2 N = (5/2)MtN \log_2 N \quad (4.27)$$

The Post-coded OFDM system requires only one IFFT block. As the complexity of one ordinary IFFT is $(N/2)\log_2 N$ complex multiplications and $N \log_2 N$ additions, and one complex multiplication is 4 real multiplications and 3 additions, so one ordinary IFFT has $2N \log_2 N$ real multiplications and $(5N/2)\log_2 N$ additions. Since the post-coded MIMO-OFDM system require single IFFT block, so the total number of real multiplications and additions required still remains $2N \log_2 N$ and $(5N/2)\log_2 N$ respectively.

V. Simulation Results

In this section are presented simulation results for comparing the performance of both the schemes. Graphs are plotted between bit error rates (BER) and signal to noise ratio (SNR). For all simulations it defines SNR as signal to noise ratio per bit and compute it as ε_b / N_0 where ε_b is the bit energy and $N_0/2$ is the noise variance. Simulations are performed to compare the performance of Post-coded single antenna OFDM system with different spreading codes and with precoded system.

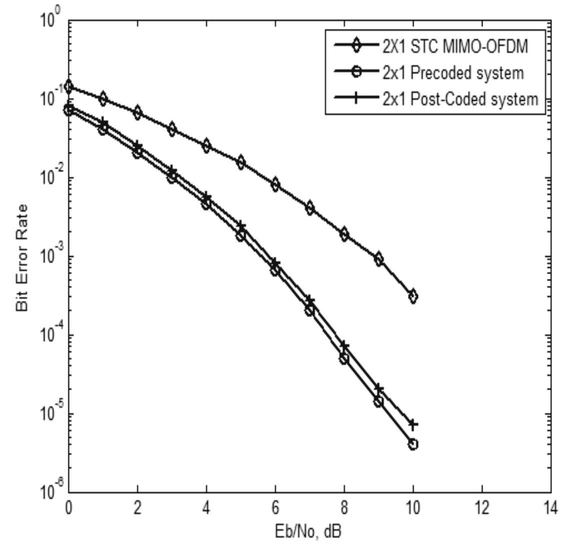


Figure 4 : BER of different coded MIMO-OFDM systems for 2Tx/1Rx antenna and BPSK constellation

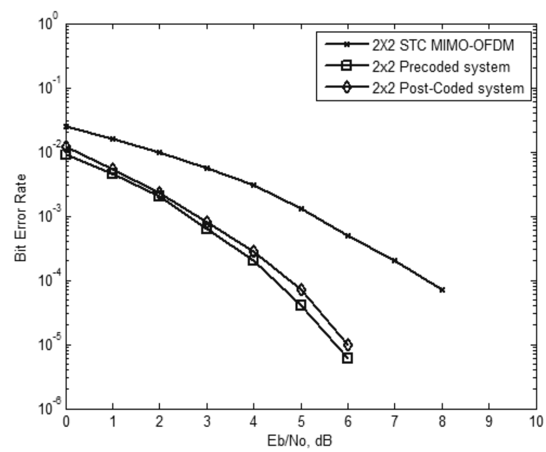


Figure 5 : BER of different coded MIMO-OFDM systems for 2Tx/2Rx antenna and BPSK constellation

VI. Conclusion

In this paper to design a system to reduce the complexity without any performance loss and the overall computational cost of the system significantly reduced. The proposed Post-coded MIMO-OFDM system results low complexity in design, since number of IFFT blocks required by the system reduces to one in contrast to the traditional systems used in which this requirement equals number of transmit antenna. The post-coded system achieves this low complexity objective by manipulating the OFDM symbols in time domain. It compared the computation cost of single and multiple antenna post-coded system with precoded systems and observed that for same system constraints, that is, for same structure of spreading code and modulation scheme used, the post-coded systems provide cost efficient system design.

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