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Diversity Analysis of Bit-Interleaved Coded Modulation with Orthogonal Frequency Division Multiplexing

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Abstract: Multiple input and multiple output orthogonal frequency division multiplexing (MIMO-OFDM) is a high-flying technology for fourth generation mobile radio communication. OFDM is a multi-carrier-modulation (MCM) technique that divides the high data rate input bit streams into large number of lower rate sub streams and each sub stream is transmitted over orthogonal subcarriers. The main benefit of MIMO-OFDM system is the resourceful deployment of bandwidth, multipath delay spread tolerance and alleviation of inter symbol interference (ISI) in frequency selective fading channels. Bit-Interleaved Coded Modulation (BICM) can improve spatial diversity for flat fading MIMO channels. For MIMO channels, the diversity analysis was carried out for various combinations of antennas and the better antenna configuration of MIMO systems which gives the low probability of errors was selected and then Bit-Interleaved Coded Modulation (BICM) was introduced in that MIMO systems. The BICM-OFDM system improves spatial diversity of the MIMO channels. The performance degradation arises due to the correlation among subcarriers. For that the subcarrier grouping technique is employed to combat the performance degradation and the pre coder technique is used to improve the diversity.

Keywords**: MIMO systems, frequency division multiplexing, singular value decomposition, diversity methods, convolution codes, correlation, subcarrier multiplexing**

Introduction

In a MIMO system, beam forming techniques exploiting Singular Value Decomposition (SVD) can be [19] employed to achieve spatial multiplexing and thereby increase the data rate, or to enhance performance, when the Channel State Information (CSI) is available [5] at both the transmitter and receiver. For flat fading MIMO channels, single beam forming carrying only one symbol at a time achieves full diversity. However, spatial multiplexing without channel coding results in the loss of the full diversity order. To overcome the performance degradation, Bit-Interleaved Coded Multiple Beam forming (BICMB) [11],[12],[13] was proposed. BICMB systems studied so far employ convolution codes as channel coding, and interleave the coded bit code words through the multiple sub channels with different diversity orders. If the channel is in frequency selective fading, Orthogonal Frequency Division Multiplexing (OFDM) can be used to combat the Inter-Symbol Interference (ISI) caused by multipath propagation. In particular, multipath diversity can be achieved by adding channel coding. Beam forming can be combined with OFDM for frequency selective MIMO channels to combat ISI and achieve spatial diversity. Moreover, both spatial diversity and multipath diversity can be achieved by adding channel coding, e.g., BICMB with OFDM (BICMB-OFDM) [10]. Therefore, BICMB-OFDM can be an important technique for broadband wireless communication.

However, the diversity analysis of BICMB-OFDM is a difficult challenge. In, an initial attempt to investigate the diversity of BICMB-OFDM was based on two over-optimistic assumptions. First, the s th singular values realized by SVD at all subcarriers were assumed to be independent and identically distributed, which is not practical in general. Second, the bit interleave was assumed to satisfy the condition that at least one error bit of each error event is carried on the sub channels with each index s, which is not always valid. In this paper, the diversity analysis of BICMB-OFDM is carried out with more reasonable assumptions than, and the relation between the diversity and the combination of the bit interleaver and the convolution code is better investigated as in First, the maximum achievable diversity is derived and the important α-spectra directly determining the diversity are introduced. Based on the analysis, a sufficient and necessary full

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diversity [10] condition, $RcSL \leq 1$ where S is the number of streams transmitted at each subcarrier and L isthe number of channel taps, is proved. Then, the performance degradation caused by the correlation among subcarriers is investigated. To overcome the performance degradation, the subcarrier grouping technique which also provides multi-user compatibility, is employed and the precoder technique is applied to improve the diversity.

II. MIMO DIVERSITY ANALYSIS

Each pair of transmit-receive antennas provides a signal path from transmitter to receiver. By sending the SAME information through different paths, multiple independently-faded replicas of the data symbol can be obtained at the receiver end. Hence, more reliable reception is achieved.

In MIMO, analysis the antenna diversity with various combination of transmitting and receiving antennas. Form that to find the multi-input multi-output maximum-ratio-transmission/maximum-ratio-combining (MRT/MRC) of antenna which provide the maximum diversity. The analysis reveals a simple connection with system parameters, providing good insights for the design of MIMO [2] diversity systems.

Using diversity reception is a well-known technique to mitigate the effects of fading over a communications link. However, it has mostly been relegated to the receiver end. In, Alamouti proposes a transmit diversity scheme that offers similar diversity gains, using multiple antennas at the transmitter.

For an (M_R,M_T) system, the total number of signal paths is $M_R M_T$

$$1 \leq d \leq d_{max} = M_R M_T \qquad (1)$$

d-diversity
d_{max}-maximum diversity
M_R-Maximum No of Receiving antenna
M_T-Maximum No of Receiving antenna

III. BIT INTERLEAVED CODED MODULATION OFDM

In a MIMO system, beam forming techniques exploiting Singular Value Decomposition (SVD) [9] can be employed to achieve spatial multiplexing and thereby increase the data rate, or to enhance performance, when the Channel State Information (CSI) is available at both the transmitter and receiver. For flat fading MIMO channels, single beam forming carrying only one symbol at a time achieves full diversity. However, spatial multiplexing without channel coding results in the loss of the full diversity order. To overcome the performance degradation, Bit-Interleaved Coded Modulation (BICM) was proposed.

BICM systems employed convolution codes as channel coding, and interleave the coded bit code words through the multiple sub channels with different diversity orders. If the channel is in frequency selective fading, Orthogonal Frequency Division Multiplexing (OFDM) can be used to combat the Inter-Symbol Interference (ISI) caused by multipath propagation. In particular, multipath diversity can be achieved by adding channel coding. Beam forming can be combined with OFDM for frequency selective MIMO channels to combat ISI and achieve spatial diversity. Moreover, both spatial diversity and multipath diversity can be achieved by adding channel coding, e.g., BICM with OFDM (BICM-OFDM). Therefore, BICM-OFDM can be an important technique for broadband wireless communication.

IV. SYSTEM MODEL

A BICMB system employing N_t transmit and N_r receive antennas, a convolution code of code rate R_c, and transmit-ting S parallel data streams has the maximum diversity order of

$$D=(N_r-R_cS+1)(N_t-R_cS+1) \qquad (2)$$

BICMB-OFDM was proposed to achieve both spatial diversity and multipath diversity for MIMO frequency selective channels. The structure of BICMB-OFDM is presented in Fig. 1. First, the convolutional encoder of code rate Rc , possibly combined with a perforation matrix for a high rate punctured code , generates the bit codeword c from the information bits. Then, an interleaved bit sequence is generated by a random bit interleaver before being modulated, e.g., Quadrature Amplitude Modulation (QAM), to a symbol sequence. Assume that the symbol sequence is transmitted through M subcarriers, and $S \leq \min\{N_t,N_r\}$ streams are transmitted for each subcarrier at the same time. Hence, an $S \times 1$ symbol vector $X_k(m)$ is transmitted through the m th subcarrier at the K th time instant with m =1,...,M. The length of Cyclic Prefix (CP), which is employed by OFDM to combat ISI caused by multipath propagation, is assumed to be Lcp where Lcp ≥ L with L denoting the number of channel taps.

For each subcarrier, the multiplications with beam forming matrices are carried out before executing the Inverse Fast Fourier Transform (IFFT) and adding CP at the

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transmitter, and after executing the Fast Fourier Transform (FFT) and removing CP at the receiver, respectively

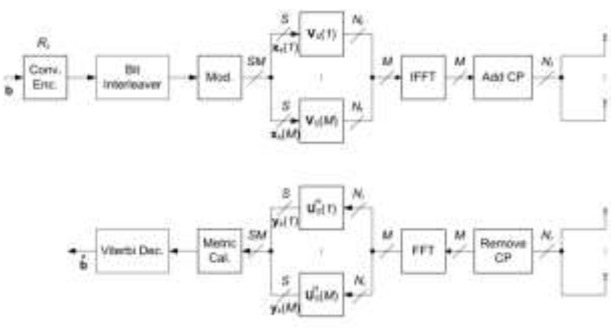

Fig 1 BICM-OFDM System

. Therefore, the system input-output relation for the m^{th} subcarrier at the k^{th} time instant is

$$y_{k,s}(m) = \lambda_s(m) X_{k,s}(m) + n_{k,s}(m) \quad (3)$$

where s =1,...,S ,$y_{k,s}(m)$ and $x_{k,s}(m)$ are the s^{th} element of the S × 1 received symbol vector $y_k(m)$ and the transmitted symbol vector $x_k(m)$ respectively, and $n_{k,s}(m)$ is the additive white Gaussian noise with zero mean and variance

In that performance degradation produced due to the correlation among subcarriers. The BICM –OFDM was increased the spatial diversity, the disadvantage is that in increases the bit error rate. Due to the increase of subcarriers, the correlation is produced among the sub carriers, it increases the bit error rate. There by applying the subcarrier grouping to reduce the bit error rate and by using pre coders to improve the diversity.

V. SUBCARRIER GROUPING

The idea of subcarrier grouping technique is to transmit multiple streams of information through multiple group of sub-carriers of OFDM. It was suggested for multi-user interference elimination [14], Peak-to-Average Ratio (PAR) reduction [15], and complexity reduction [8]. In this paper, the subcarrier correlation technique is applied to overcome the performance loss caused by subcarrier correlation. As a result, the subcarrier grouping technique can be applied to transmit multiple streams of bit codewords through these *G* different groups of uncorrelated subcarriers, instead of transmitting one stream of the bit codeword through all the correlated subcarriers.

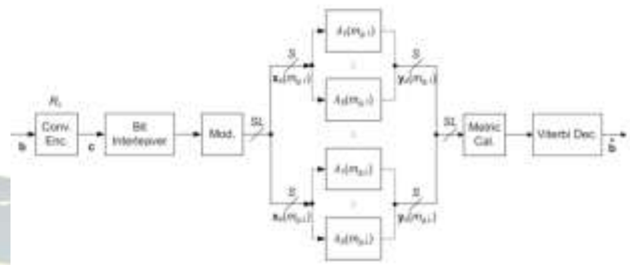

Fig.2. Structure of BICMB-OFDM with subcarrier grouping in the frequency domain for one bit stream transmission of the gth subcarrier group.

As a result, the negative effect of subcarrier correlation is completely avoided, and the maximum achievable diversity is thereby achieved. Note that the best choice of the number of subcarriers in one group is *L*, since smaller choice results in less diversity while larger choice causes subcarrier correlation which degrades performance.

VI. SIMULATION RESULTS

In this part, MATLAB simulations are performed for various combinations of transmitted and received antenna in MIMO system. From that the best combination of antennas which provides low error rate is chosen. Then apply the bit interleaved coded modulation in the selected combination of antenna to increase the diversity.

A. MIMO system analysis

An MIMO system was simulated for 3 various combinations transmitting and Receiving antennas as No Diversity (1Tx, 1Rx), Alamouti (2Tx, 1Rx), Maximal-Ratio Combining (1Tx, 2Rx). Then the simulation results shows in Fig.2.

The simulation covers an end-to-end system showing the encoded and/or transmitted signal, channel model, and reception and demodulation of the received signal. It also provides the no-diversity link (single transmit- receive antenna case) and theoretical performance of second-order

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diversity link for comparison. It is assumed here that the channel is known perfectly at the receiver for all systems. Then run the simulation over a range of Eb/No points to generate BER results that allow us to compare the different systems.

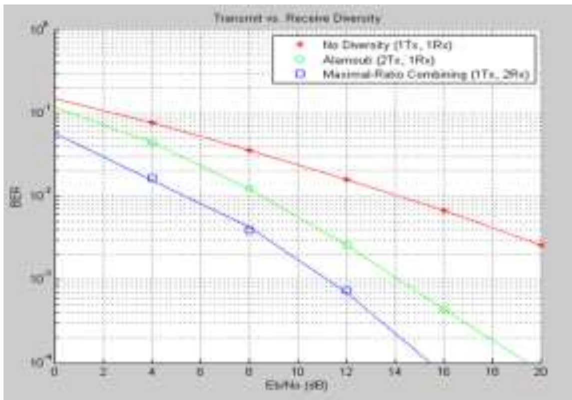

Fig. 3. MIMO Transmitting and Received Antenna Diversity

The simulation figure 7.1 results show that using one transmit antenna and two receive antennas provides the same diversity order as the maximal-ratio combined (MRC) system of one transmit antenna and two receive antennas. It is observed that transmit diversity has a 3 dB disadvantage when compared to MRC receive diversity.

B. BICM-OFDM System Analysis

From the analysis of MIMO system the 2x1 antenna combination gives a minimum bit error rate. Then in that combination implement the BICM-OFDM system and the diversity of the system was analyzed.

C. Role of interleaver

The interleaver is used to add the redunency bits in on OFDM signal in order to spread the errors out in the bit-stream that is presented to the error correction decoder, because when such decoders are presented with a high concentration of errors the decoder is unable to correct all the bit errors, and a burst of uncorrected errors occurs.

	Number of error bits	Error rate
Without interleaver	0	0
With interleaver	4	0.0020

Table.1 Error rate comparison of with and without interleaver

From table.1 shows that the interleaver was transmitted the bits with zero error rate and then the error rate is increased to 0.0020 in without the interleaver.

D. BICM-MIMO Diversity analysis

From the MIMO diversity analysis, the antenna configuration of (2 transmitters and 1 receiver) Maximum ratio combiner was provide a low bit error rate. So in that combination the Bit Interleaved Coded Modulation was implemented and the simulation result was shown in Fig.4.

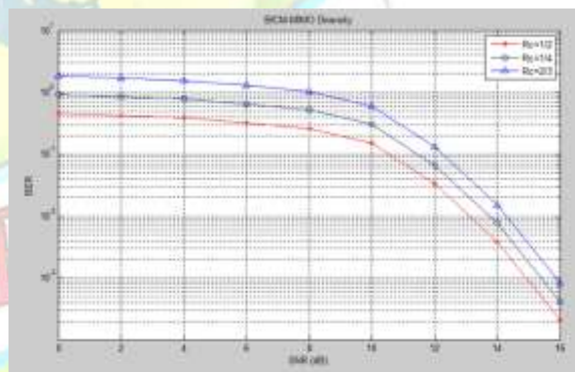

Fig.4 BICM-MIMO Diversity analysis

The BICM implementation simulated for the different code rates as ½, ¼, 2/3. The results shows that the amount of diversity is increased up to 4, (i.e).the subcarriers are further divided into 4 sub channels. So it gives the advantages of BICM implementation.

The disadvantage is that in increases the bit error rate (Eb/No) into 0.01 to 0.1. Due to the increase of subcarriers, the correlation is produced among the sub carriers, it increases the bit error rate.

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There by applying the subcarrier grouping to reduce the bit error rate and by using precoders to improve the diversity.

E. Sub carrier grouping

After the BICM was applied in the system then the bit error rate will be increased, because the more number of diversity will produce sub carrier correlation. So here applied an sub carrier grouping for convert it form 64 to 32 sub carriers.

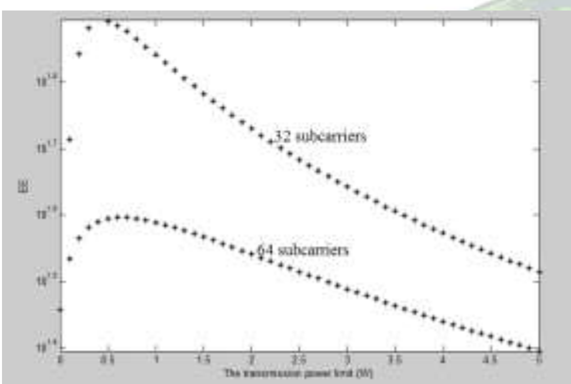

Fig.5 Energy efficiency comparisons with sub carrier grouping

In Fig.5 shows that the sub carrier grouping from 64 sub carrier to 32 sub carrier was improved 20 % energy improvement.

VII.CONCLUSION

In this work the diversity analysis was carried out for various combinations of antennas in the MIMO System. From that the better antenna configuration of MIMO systems which gives the low probability of errors was selected and then Bit-Interleaved Coded Modulation (BICM) was introduced in that MIMO systems. The BICM-OFDM system improves spatial diversity of the MIMO channels. Then, the performance degradation was occurred due to the correlation among subcarriers. The BICM-OFDM implementation simulated results shows that the amount of diversity is increased up to 4 as the subcarriers are further divided into 4 sub channels. So it produces improvement in the diversity but it also increases the bit error rate (Eb/No) into 0.01 to 0.1. Due to the increase of subcarriers, the correlation is produced among the sub carriers, it increases the bit error rate. Then by applying the subcarrier grouping ,the sub carrier correlation was reduced and hence the energy efficiency improved 20 % and reduce the bit error. In future work the pre coders to improve the diversity.

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BIOGRAPHY

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University, Chennai, in 2013. Now he is pursuing his Post Graduate (M.E) in Communication Systems at Kongu Engineering College (2013-2015) and his research works include the areas OFDM and wireless networks

S.Venkatachalam is guiding my project. He obtained his Bachelor's Degree in ECE from Bharathiar University, Coimbatore, in 1988. Later he purused **his M.Tech**. in Telecommunication Systems Engineering from IIT Kharagpur in 1999. He has presented more than 25 papers in National and International Conferences. Published many articles in International journals. Organised many programmes for the faculty including a course on Cellular Mobile communication in 2003.