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Low Complexity Precoding of BICMB-OFDM-SG for Wireless Broadband System

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ABSTRACT: Multi-Input Multi-Output(MIMO) techniques can achieve higher throughput and improved reliability in wireless broadband communications by exploiting spatial diversity in multiple-antenna wireless communications. By combining the spatial diversity and spatial multiplexing we can fully exploit the MIMO channel capacity. Bit-Interleaved Coded Multiple Beamforming (BICMB) can achieve both spatial diversity and spatial multiplexing for flat fading MIMO channels. For frequency selective fading MIMO channels, BICMB with OFDM (BICMB-OFDM) can be employed to provide both spatial diversity and multipath diversity, making it an important technique. Full diversity of BICMB-OFDM with Subcarrier Grouping (BICMB-OFDM-SG) can be achieved within the condition $R_cSL \leq 1$, where R_c, S, and L are the code rate, the number of parallel streams at each subcarrier, and the number of channel taps, respectively.

The full diversity condition implies that if S increases, R_c may have to decrease to maintain full diversity. As a result, increasing the number of parallel streams may not improve the total transmission rate. In this paper, the precoding technique is employed to overcome the full diversity restriction issue of $R_cSL \leq 1$ for BICMB-OFDM-SG. First, the diversity analysis of precoded BICMB-OFDM-SG is carried out. Based on the analysis, a full diversity condition related to the combination of the precoding matrix, the Low density parity check codes, and the bit interleaver is provided. Then, the full-diversity precoding design is developed with the minimum achievable decoding complexity. Thus provides a sufficent method to guarantee full diversity, better performance and higher throughput while minimizing the increased decoding complexity .

KEYWORDS: MIMO systems, frequency division multiplexing, singular value decomposition, diversity methods, subcarrier multiplexing, Low density parity check codes.

I. INTRODUCTION

In recent years spatial diversity techniques are under investigation to increase the robustness as well as the throughput of multi-input multi-output (MIMO) wireless systems, employing N transmit and M receive antennas. These systems can be grouped into two. The first group requires the channel state information (CSI) at the receiver, but not at the transmitter. Space-time (ST) codes are a subset of these systems. The second group requires perfect or partial CSI at both the transmitter and the receiver. When perfect CSI is available at both ends, two techniques that can be used are single and multiple beamforming. These techniques utilize singular value decomposition (SVD) which separates the MIMO channel into parallel subchannels. When only the subchannel with the largest gain is used for transmission, the technique is called single beamforming. MIMO systems can also be used to enhance the throughput of wireless systems.When more than one subchannel is used to improve the capacity, the technique is called multiple beamforming. In other words, multiple beamforming is a special case of spatial multiplexing in which SVD-based linear processing is employed at the transmitter and the receiver sides. It is known that an SVD subchannel with larger singular value provides larger diversity gain. During the simultaneous parallel transmission of the symbols on the diagonalized subchannels, the performance is dominated by the subchannel with the smallest singular value, resulting in losing the full diversity order. To overcome the degradation of the diversity order of multiple beamforming, bit-interleaved coded multiple beamforming (BICMB) was proposed. This scheme interleaves the codewords through the multiple subchannels with different diversity orders, resulting in better diversity order.

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When the channel has frequency selective fading, the result is Inter-Symbol Interference (ISI) for the transmitted symbols. Orthogonal Frequency Division Multiplexing (OFDM) is commonly used to combat ISI caused by multipath propagation.The combination of MIMO and OFDM has been incorporated for all broadband wireless communication standards, i.e., WiFi, WiMAX, and LTE. For frequency selective MIMO channels, combining beamforming with OFDM can 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 can be an important technique for broadband wireless communication. The diversity analysis of BICMB-OFDM require subcarrier grouping technique to overcome the performance degradation caused by subcarrier correlation and offer multi-user compatibility.The full diversity of BICMB-OFDM with Subcarrier Grouping (BICMB-OFDM-SG) can be achieved as long as the condition $R_cSL \le 1$ is satisfied, where S is the number of streams transmitted at each subcarrier and L is the number of channel taps.

In this paper, the main contribution is that the precoding technique is employed to solve the full diversity restriction issue of $R_cSL \le 1$ for BICMB-OFDM-SG proposed in. First, diversity analysis of precoded BICMB-OFDMSG is carried out. Based on the analysis, a full diversity condition related to the combination of the precoding matrix, the convolutional code, and the bit interleaver is provided.Then, the full diversity precoding design is developed. This design provides a sufficient method to guarantee full diversity while minimizing the increased decoding complexity.

II. BIT INTERLEAVED CODED MULTIPLE BEAMFORMING (BICMB): SYSTEM MODEL

BICMB is a combination of BICM and multiple beamforming.The output bits of a binary convolutional encoder are interleaved and then mapped over a signal set $\chi \subseteq \mathbb{C}$ of size χ = 2m with a binary labeling map μ: 0,1 $m \rightarrow \chi$ [1-3]. The minimum Hamming distance of the convolutional encoder, dfree, should satisfy dfree $\geq$ S. The interleaver is designed such that the consecutive coded bits are

1. Mapped over different symbols.
2. Transmitted over different subchannels that are created by beamforming.

Gray encoding is used to map the bits onto symbols. During transmission, the code sequence c is interleaved by π, and then mapped onto the signal sequence $X \in \chi$.

A. Beamforming

Beamforming is implemented by multiplying the symbol(s) with appropriate beamforming vector(s) both at the transmitter and the receiver [4]. In this paper, we assume that CSI is available at both ends. In such a case, the beamforming vectors used at the transmitter and the receiver can be obtained by the SVD of the MIMO channel. Beamforming separates the MIMO channel into parallel subchannel. Let's denote the quasi-static Rayleigh flat fading $N \times M$ MIMO channel as H, where N is the number of transmit antennas and M is the number of receiver antennas [5].

Then, the SVD of H can be written as

$$H = U\Lambda V^{H} \qquad (1)$$

where Λ is a $N \times M$ matrix with singular values, {λi} min(N,M) i=1 , in decreasing order on the main diagonal. U and V are two unitary matrices of size $N \times N$ and $M \times M$, respectively [6]. By using SVD, MIMO channel is divided into independent and parallel subchannels.A commonly employed MIMO approach is known as beamforming via singular value decomposition (SVD) of the MIMO channel matrix. This approach enables spatial multiplexing enabling increased data rates. It can also enhance system performance. This technique requires the channel state information (CSI) to be available at both the transmitter and receiver. For flat fading MIMO channels, it has been shown that employing beamforming with only one spatial channel, or transmitting one symbol at a time, achieves the full diversity order provided by the channel [7].

In addition, employing a MIMO beamformer with more than one spatial channel without any channel coding results in the loss of full diversity. On the other hand, employing Bit Interleaved Coded Modulation (BICM) together with SVD beamforming restores full diversity. Such a system was analyzed and called Bit-Interleaved Coded Multiple Beamforming (BICMB). The channel coding technique employed has been convolutional codes [8-9]. The output of the convolutional code is then interleaved through the multiple subchannels with different diversity orders.

B. Single Beamforming

Only one symbol is transmitted over the subchannel with the largest gain. The optimal vectors to be used at the transmitter side and receiver side are the first columns of *U* and *V* corresponding to the largest singular value of *H* [10]. Then, the received signal can be represented by

$$y = x u_1^H H v_1 + \eta v_1 = \lambda_1 x + n \qquad (2)$$

where λ_1 is the largest singular value of *H*, *x* is the transmitted symbol, $n = \eta v_1$, and η is complex additive white Gaussian noise (AWGN) vector of size $1 \times M$ with zero mean and variance $N_0 = 1/SNR$. The elements of *H* are modeled as complex Gaussian random variables with zero mean and 0.5 variance per complex dimension [11]. Note that, the average total transmit power at the transmitter is assumed to be 1.Therefore, the received signal-to-noise ratio is *SNR* with the given channel and noise models.

C. Multiple beamforming

Multiple symbols are simultaneously sent over different parallel independent subchannels with equal power allocation [12]. If L subchannels are used, the input-output relation for the kth subchannel becomes

$$y_k = \frac{1}{\sqrt{L}} \lambda_k x_k + n_k \qquad (3)$$

where λk is the kth largest singular value of H and $nk = \eta vk$**.** The resulting system achieves almost the same performance as precoded BICMB while reducing the decoding complexity substantially, for MIMO dimensions 2 and 4.

III. BICMB-OFDM

In order to combat the ISI in frequency selective channels, we combined BICMB with OFDM and named the system as BICMB-OFDM [13].

A. System Model

The system model of BICMB-OFDM is similar to BICMB with few minor differences as given in this section. The interleaver is designed such that the consecutive coded bits are

1. Interleaved within one MIMO-OFDM symbol to avoid extra delay requirement to start decoding at the receiver.
2. Mapped over different symbols.
3. Transmitted over different subcarriers of an OFDM symbol.
4. Transmitted over different subchannels that are created by beamforming.

By adding cyclic prefix (CP), OFDM converts the frequency selective channel into parallel flat fading channels for each subcarrier. For frequency selective MIMO channels, BICMB-OFDM provide both spatial diversity and multipath diversity. Orthogonal Frequency Division Multiplexing (OFDM) is commonly used to combat ISI caused by multipath propagation [14]. OFDM transmits data in a parallel fashion on closely spaced subcarriers. The subcarriers satisfy an orthogonality property inorder to reduce bandwidth. OFDM is robust against ISI. It achieves this by using equalization in the frequency domain with the advantage of avoiding the computational burden and the long convergence time requirements associated with time domain equalization. Therefore, OFDM can adapt to severe channel conditions [15].

In addition, OFDM has high spectral efficiency, efficient implementation using Fast Fourier Transform (FFT) and Inverse FFT (IFFT), and low sensitivity to time synchronization errors. With OFDM, multipath diversity can be achieved by adding channel coding.

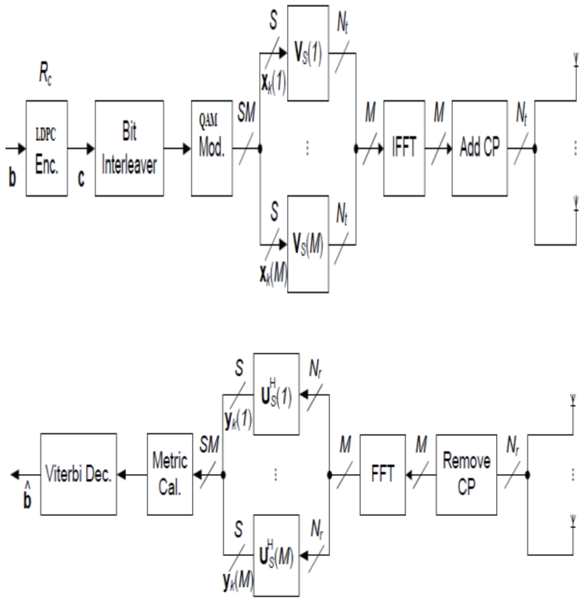

Figure 1. Structure of BICMB-OFDM

Figure 1. presents the structure of BICMB-OFDM. First, the bit codeword c is generated from the information bits by the convolutional encoder of code rate $R_{c,}$ which is possibly combined with a perforation matrix for a high rate punctured code. After that, a random bit interleaver is applied to generate an interleaved bit sequence, which is then modulated, e.g., quadrature amplitude modulation (QAM), to a symbol sequence. The number of transmit and receive antennas are denoted by N_t and N_r respectively [16].

Assume that M subcarriers are employed to transmit the symbol sequence, and $S \leq \min\{N_t, N_r\}$ parallel streams realized by SVD in the frequency domain for each subcarrier are transmitted at the same time. Hence, an $S \times 1$ symbol vector $\mathbf{x}_k(m)$ is carried on the mth subcarrier at the kth time instant with $m = 1, . . ., M$. The length of Cyclic Prefix (CP), which is employed for OFDM to combat ISI caused by multipath propagation, is assumed to be L_{cp} where $L_{cp} \geq L$ with L denoting the number of channel taps [17]. The L-tap frequency selective fading MIMO channel is assumed to be Rayleigh quasi-static and known by both the transmitter and receiver, which is denoted by $\mathrm{H}\ (l) \in C^{Nr \times Nt}$ with $l = 1, . . ., L$ where C stands for the set of complex numbers. When S streams are transmitted for each subcarrier at the same time, the first S columns of $\mathrm{U}(m)$ and $\mathrm{V}(m)$, i.e., $\mathrm{U}_S(m)$ and $\mathrm{V}_S(m)$, are chosen as beamforming matrices at the receiver and transmitter for the mth subcarrier respectively.For each subcarrier, the multiplications with beamforming matrices$\mathrm{V}_S(m)$ and $\mathrm{U}^H S(m)$ are carried out at each subcarrier before executing IFFT and adding CP at the transmitter, and after executing FFT and removing CP at the receiver, respectively [18]. As a result, OFDM is well-suited for broadband data transmission, and it has been selected as the air interface for the Institute of Electrical and Electronics Engineers (IEEE) 802.11 Wireless Fidelity (WiFi) standard, the IEEE 802.16 Worldwide Interoperability for Microwave Access (WiMAX) standard, as well as the Third Generation Partnership Project (3GPP) Long Term Evolution (LTE) standard.

Therefore, the input-output relation of BICMB OFDM for the m_{th} subcarrier at the kth time instant is

$$y_{s,k}(m)=\lambda_s(m)x_{s,k}(m)+n_{s,m}(m) \qquad (4)$$

for $s = 1, \ldots, S$, where $y_{S,k}(m)$ and $x_{s,k}(m)$ are the sth element of the $S \times 1$ received symbol vector $\mathbf{y}_k(m)$ and the transmitted symbol vector $x_k(m)$ respectively, and $n_{s,k(m)}$ is the additive white Gaussian noise with zero mean and variance $N_0 = N_t/\gamma$ with γ denoting the received signal- to - noise ratio (SNR) over all the receive antennas. Note that the total transmitted power is scaled by N_t in order to make the received SNR γ.The location of the coded bit c'_k within the transmitted symbol is denoted as $k' \rightarrow (k,m,s,j)$, meaning that the coded bit c'_k is mapped onto the jth bit position on the label of $x_{s,k}(m)$. Let χ denote the signal set of the modulation scheme, and let χ_j b denote a subset of χ whose labels have $b \in \{0, 1\}$ at the jth bit position. By using the location information $k' \rightarrow (k,m,s,j)$ and the input-output relation in the receiver calculates the Maximum Likelihood (ML) bit metrics. In the diversity analysis of BICMB-OFDM was carried out. According to the analysis, the maximum achievable diversity of BICMB-OFDM was derived and the full diversity restriction of $R_cSL \leq 1$ was proved. The performance degradation due to subcarrier correlation was investigated, which showed that although the maximum achievable diversity is the same when SNR is relatively high, strong subcarrier correlation can result in significant performance loss for SNRs in the practical range [19-20].

B. Subcarrier Grouping

The performance degradation of BICMB-OFDM caused by subcarrier correlation, the subcarrier grouping technique was employed. Instead of transmitting one stream of information through all subcarriers of OFDM, subcarrier grouping technique transmits multiple streams of information through multiple group of subcarriers, which was also suggested for multi-user interference elimination, Peak-to-Average Ratio (PAR) reduction, and complexity reduction. For BICMB-OFDM-SG, assuming that $G = M/L \in \mathbb{Z}$ where Z denotes the set of integer numbers, then G streams of bit codewords are carried on G different groups of L uncorrelated or weakly correlated subcarriers at the same time [21].

IV. BICMB-OFDM-SG WITH PRECODING

BICMB-OFDM-SG is obviously a much better choice than BICMB-OFDM without subcarrier grouping because it provides better performance with the same transmission rate and decoding complexity while also offers multi-user compatibility. Therefore, the precoding technique discussed in the following parts of this paper is employed on top of BICMB-OFDM-SG [22]. Since the G groups of bit streams are transmitted separately in the frequency domain for BICMB-OFDM-SG and the only difference is the corresponding singular values of subchannels the precoding technique can be applied to each subcarrier group independently. Therefore, it is sufficient to consider one subcarrier group to illustrate the system model.

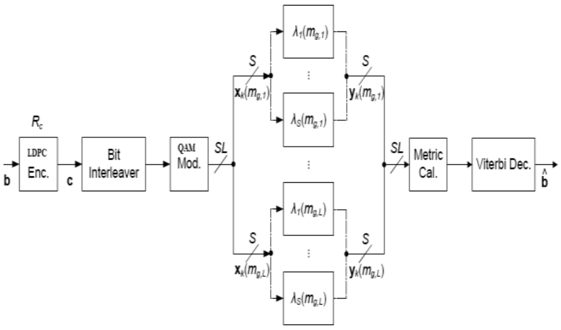

Figure 2. Structure of BICMB-OFDM-SG

Figure 2. illustrate the structre of BICMB-OFDM-SG in the frequency domain for one bit stream transmission of the gth subcarrier group with $g \in \{1, \ldots, G\}$, and the associated subcarrier index for the lth subcarrier of the gth

group is denoted in the figure as $m_g,l = (l-1)G+g$ with $l = 1, \ldots, L$. Compared to BICMB-OFDM without subcarrier grouping, BICMB-OFDM-SG achieves better performance with the same transmission rate and the same decoding complexity while also provides multi-user compatibility [23].

BICMB-OFDM-SG without precoding as shown in Figure 2. the channel coding, bit interleaver, and modulation remain the same while two more precoding blocks are added at the transmitter for BICMB-OFDM-SG with precoding. In BICMB-OFDM-SG with precoding before the SVD beforming precoding technique can be applied to each subcarrier group independently.

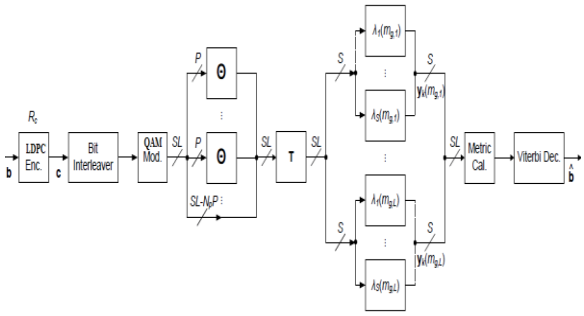

Figure 3. Structure of BICMB-OFDM-SG with precoding

Figure 3. presents the structure of BICMB-OFDM-SG with precoding in the frequency domain for one bit stream transmission of the gth subcarrier group. Specifically, Θ is defined as a P ×P precoding matrix where $P \leq SL$ denotes the dimension of Θ, which is applied to precode P of SL subchannels employed for the gth subcarrier group. The P precoded subchannels are defined as one precoded subchannel set. Let N_p denote the number of precoded subchannel sets employed for the gth subcarrier group, where $N_pP \leq SL$. As a result, N_pP subchannels are precoded while the remaining $N_n = SL-N_pP$ subchannels are non-precoded.

The selections of precoded subchannel sets and non-precoded subchannels are predefined by a permutation matrix T. Note that there are L subcarriers of each group and each subcarrier includes S subchannels realized by SVD. For the sth subchannel at the lth subcarrier for the gth group, its singular value is $\lambda_s\,(m_{g,l})$ where $m_{g,,l} = (l-1)G+g$. Since the G subcarrier groups are independent, the group index is omitted for brevity in the following, and $\lambda_s\,(m_{g,l})$ is rewritten as $\lambda_{l,s}$ where the two-dimensional index $\{l, s\}$ denotes the sth subchannel at the lth subcarrier. For the sake of convenience, the two-dimensional index is further converted to a single dimensional one following the rule $\{l, s\} \rightarrow q = (l - 1)S + s$ with $q \in \{1, \ldots, SL\}$, and the corresponding inverse conversion is $q \rightarrow \{l, s\} = \{[\lfloor (q - 1)/S \rfloor + 1]\,, [(q - 1) \bmod S + 1]\}$. Define $\eta^z = [\eta_1^z \ \ldots \eta_P^z]$ as a vector whose elements η_P^z denote the subchannel indices of the zth precoded subchannel set with $z \in \{1, \ldots, N_p\}$, and are ordered increasingly such that $\eta_u^z < \eta_v^z$ for $u < v$. In the same way, $\boldsymbol{\omega} = [\omega_1 \ldots \omega_{Nn}]$ is defined as an increasingly ordered vector whose elements are the indices of the non-precoded subchannels.

At the kth time instant, after modulation,the serial-to-parallel coverter of the transmitter organizes the $SL \times 1$ symbol vector x_k and the received symbol vector y_k of the q_{th} sub channel is written as

$$y_k = \breve{\Lambda}\breve{\Theta}x_k + n_k \tag{5}$$

where $\breve{\Lambda}$ denotes a $SL \times SL$ block diagonal matrix $\breve{\Lambda} = diag[\breve{\Lambda}_{\eta^1} \vdots \ldots \vdots \breve{\Lambda}_{\eta^{N_p}} \vdots . . \vdots \breve{\Lambda}_{\omega}]$ with diagonal singular matrices defined as $\breve{\Lambda}_{\eta^z} = diag\left[\lambda_{\eta_1^z} \ldots . \ldots . \lambda_{\eta_P^z}\right]$, $\breve{\Theta}$ is a $SL \times SL$ block diagonal matrix $\breve{\Theta}$=diag[$\Theta \vdots \ldots \vdots \Theta \vdots\, I_{N_n}$] with I_{N_n} defined as the $N_n$dimensional identity matrix and n_k denoting the additive white Gaussian noise with zero mean and variance $N_0 = Nt/\gamma$ at the qth subchannel.. As a result, the input-output relation can be decomposed into N_p + 1 equations as

$$y_{\eta^z,k} = \breve{\Lambda}_{\eta^z}\Theta x_{\eta^z},k + n_{\eta^z},k, \quad (6)$$

$$y_{\omega,k} = \breve{\Lambda}_{\omega}X_{\omega,K}. + n_{\omega,k} \quad (7)$$

In a similar way to BICMB-OFDM introduced the location of the coded bit $c_{k'}$ within the transmitted symbol is denoted as $k' \rightarrow (k, q, j)$, which means that ck' is mapped onto the jth bit position on the label of $x_{q,k}$.

V. FULL-DIVERSITY PRECODING OF BICMB-OFDM-SG

The precoding design satisfying the full diversity condition $\rho l,1 \neq 0, \forall l$ of all error events may not be unique. In this section, a sufficient method of precoding design is developed for BICMB-OFDM-SG which guarantees full diversity while minimizing the increased decoding complexity caused by precoding.

A. Choice of Precoding Matrix

An upper bound of PEP for BICMB-OFDM-SG without precoding can be written as in a similar form as only with different weights of

$$\tilde{p}_{l,s} = d^2_{min}\,\alpha_{l,s} \quad (8)$$

where d_{min} is the minimum Euclidean distance in the constellation, and $\alpha_{l,s}$ denotes the number of distinct bits transmitting through the sth subchannel of the lth subcarrier for an error path. The diversity can be derived in a similar fashion to the full diversity condition is $\alpha_{l,1} \neq 0, \forall l$ for all error events. As proved in the full diversity condition can be achieved only if the condition of $R_cSL \leq 1$ is satisfied. Otherwise, full diversity cannot be provided. The reason is that, in the case of $R_cSL > 1$, there always exists at least one error path with no errored bit of the error event transmitted through the first subchannel of a subcarrier.

It is obvious that when $\alpha_{l,1} = 0$, then $\rho_{l,1} = 0$, if the $\{l, 1\}$th subchannel is non-precoded. However, if the $\{l, 1\}$th subchannel is precoded, $\rho_{l,1}$ could be non-zero even if $\alpha_{l,1} = 0$. Therefore, BICMB-OFDM-SG with precoding could achieve full diversity even if $R_cSL > 1$ by proper precoding design. When designing the precoding matrix, it is inconvenient to consider all error events which could be large in number.

B. Minimum Effective Dimension of Precoding Matrix

The weights can be simplified by applying the precoding matrices, which is given as

$$\rho_q = d^2_{min}\beta_q \quad (9)$$

An upper bound with a form similar to be derived with the simplified weights. Compared to the weights of BICMB-OFDM-SG without precoding, m the weights of the N_n non-precoded subchannels are the same. For the N_pP precoded subchannels, each weight now depends on the α elements of the P precoded subchannels of the corresponding set instead of only one subchannel. Therefore, if an errored bit is transmitted through a precoded subchannel, then all weights in for the P precoded subchannels of the corresponding set is non-zero. However, if no errored bit is transmitted through a precoded subchannel set, then all weights of the P precoded subchannels are zero, which are the same as BICMB-OFDM-SG without precoding. The precoding design requirement is that at least an errored bit of each error event is transmitted through each precoded subchannel set.

The aforementioned precoding design requirement is related to the LDPC code, the bit interleaver, and the dimension of the precoding matrix. In fact, if $P = SL$, which means all subchannels are precoded by only one $SL \times SL$ precoding matrix Θ, the requirement can be easily satisfied. However, a larger dimension for Θ results in higher complexity for calculating the metrics associated with the precoded bits. The minimum effective dimension of Θ should be found. Assume that $N_b = R_cSLJ$ information bits are transmitted, then J coded bits are transmitted by each of the SL parallel subchannels. Hence, PJ coded bits are transmitted by a precoded subchannel set. Note that N_b information bits can provide 2^{N_b} different bit codewords. Hence, if PJ is smaller than N_b, there always exists at least a pair of bit codewords whose PJ coded bits transmitted by a precoded subchannel set are the same.

The reason is that the total possible number of bit sequences for a precoded subchannel set, which is $2PJ$, is smaller than the total possible bit codewords 2^{N_b} . As a result, the precoded subchannel set is non-effective. Therefore, PJ cannot be smaller than N_b, which implies that $P \geq R_c SL$. Since P is an integer, the minimum effective dimension of Θ is $P = \lceil R_c SL \rceil$. Note that $P = \lceil R_c SL \rceil$ is only proved in this subsection to be a necessary condition because the requirement, i.e., at least an errored bit of each error event is transmitted through each precoded subchannel set, is also related to the convolutional code and the bit interleaver.

C. Selection of Precoded Subchannels

The diversity of BICMB-OFDM-SG with precoding also depends on the α-spectra of BICMB-OFDM-SG without precoding. In fact, the α-spectra are related with the bit interleaver and the trellis structure of the convolutional code, and are independent of the precoding matrix. Note that the α-spectra can be derivedby a similar approach to BICMB in the case of flat fading MIMO channels presented in or by computer search.Based on the α-spectra for a certain combination of the convolutional code and the bit interleaver, the selection of precoded subchannels should be properly designed in order to satisfy the condition of $\rho_{l,1} = 0, \forall l$ for all error events.

VI. SIMULATION RESULTS

A. COMPARISION OF FULL DIVERSITY PERFORMANCE WITH AND WITHOUT PRECODING

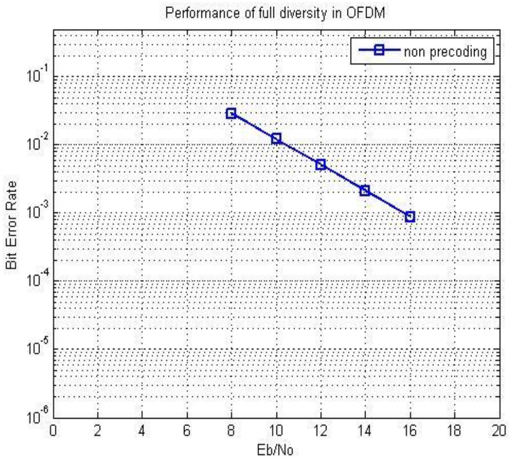

Figure 4.1 Full Diversity performance without precoding

Figure 4.1 shows the full diversity performance without precoding design. In this case the bit error rate get reduced in a small rate for the increasing data rate. For 15 E_b/N_O the BER is 10^-3 i.e. the error rate is more.

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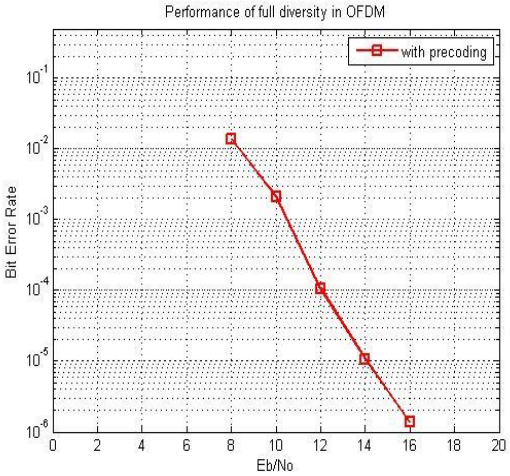

Figure 4.2 Full Diversity performance with precoding design

Figure 4.2 shows the full diversity performance with precoding design when we use the precoding matrix at E_b/N_O 14 the BER is 10^-5 its optimal.

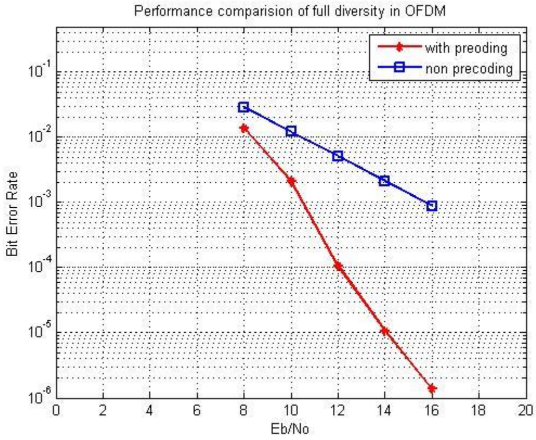

Figure 4.3 Comparison of full diversity with and with out precoding

Figure 4.3 shows the comparison of full diversity with and with out precoding design when we use the precoding matrix at E_b/N_O 14 the BER is 10^-5 but with out precoding design the BER is 10^-3 at 15.

VII. CONCLUSION

In this project BICMB-OFDM-SG with precoding design provides a sufficient method to guarantee full diversity while minimizing the increased decoding complexity. With this method, more choices are offered with different trade-offs among performance, transmission rate, and decoding complexity. The bit error rate of the precoded system is greatly reduced for the increasing data rate compared to the system without precoding. As a result, BICMB-OFDM-SG becomes a more flexible broadband wireless communication technique.

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