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Bit Error Rate Reduction Using Orthogonal Frequency Division Multiplexing with Index Modulation

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Abstract:
This paper provides a novel orthogonal frequency division multiplexing (OFDM), called orthogonal frequency division multiplexing with index modulation (OFDM-IM). In this scheme the information is conveyed not only by M-ary signal constellations but also by the indices of the sub carriers. The error performance analysis is provided for this scheme operating under ideal channel conditions. Then the same procedures are applied for the realistic channel conditions such as imperfect channel state information and very high mobility cases. The Error performance analysis is provided for both zero mobility and very high mobility cases. This scheme provides better error performance than classical OFDM because in this scheme the information bits are carried by the indices of the subcarriers. It is shown via computer simulations.

***Key words**: Bit error rate, mobility, multiple input multiple output, Orthogonal frequency division multiplexing*

1. Introduction

Multicarrier transmission is used for wideband digital communications and hence it improves high data rate communications. Orthogonal frequency division multiplexing is one of the multicarrier transmission techniques where a single data stream is transmitted over a number of lower rate subcarriers.

In wireless communication, concept of parallel transmission of symbols is used to achieve high throughput and better transmission quality. The idea of Orthogonal frequency division multiplexing (OFDM) is split the total transmission bandwidth into a number of orthogonal subcarriers in order to transmit the symbols using these subcarriers in parallel. Orthogonal frequency division multiplexing (OFDM) provides high data rate, allowable bit error rate and maximum delay.

In frequency selective fading channels with mobile terminals reaching high vehicular speeds, the sub channel orthogonality is vanished due to rapid variation of the wireless channel throughout the transmission of the OFDM block, and this leads to inter-channel interference (ICI) which affects the system implementation and performance considerably. As a result, the design of OFDM systems that work effectively under high mobility conditions is a challenging problem since mobility support is one of the key features of next generation broadband wireless communication systems.

Multiple-input multiple-output (MIMO) transmission techniques have been implemented in many practical applications due to their benefits over single antenna systems. Multiple-input multiple-output system achieves high data rate due to transmission of multiple data symbols simultaneously using multiple antennas. It also achieves better bit error rate (BER) compare to single antenna systems at the same SNR.

This paper taking a different approach, we propose a novel transmission scheme called orthogonal frequency division multiplexing with index modulation (OFDM-IM). In this scheme the information is conveyed not only by M-ary signal constellations as in classical OFDM, but also by the indices of the subcarriers. Different mapping and detection methods are proposed for the new scheme. First use a look-up table method to map the incoming information bits to the subcarrier indices and a maximum likelihood detector is employed at the receiver. But this method is infeasible in the case of increasing number of transmitted bits. Then we go for another method called combinatorial method and log-likelihood ratio (LLR) detector is employed at the receiver. A theoretical error performance analysis based on pair wise error probability (PEP) calculation is provided for the new scheme operating under ideal channel conditions.

In the next section, the proposed scheme is investigated under realistic channel conditions. First, an upper bound on the PEP of the proposed scheme is derived under channel estimation errors in which a mismatched ML detector is used for data detection. Second, the proposed scheme is substantially modified to operate under channel conditions in which the mobile terminals can reach high mobility. Considering a special structure of the channel matrix for the high mobility case, three novel ML detection based detectors, which can be classified as interference unaware or aware, are proposed for the OFDM-IM scheme. In addition to these detectors, a minimum mean square error (MMSE) detector, which operates in conjunction with an LLR detector, is proposed. The new scheme detects the higher number of transmitted information bits successfully in the spatial domain.

The rest of the paper can be summarized as follows. Section II introduces the basic OFDM-IM system model. Section III proposes different implementation approaches for OFDM-IM. The theoretical error performance of OFDM-IM is investigated. Section IV presents simulation results and we conclude the paper in Section V.

2. System Model

Consider an OFDM-IM scheme operating over a frequency-selective Rayleigh fading channel. A total of m information bits are enter to the OFDM-IM transmitter for the transmission of each OFDM block. Each group of m bits are then split into g groups each containing p bits. i.e., $m = pg$. Each group of p bits is mapped to an OFDM sub block of length n where $n = N/g$ and N is the number of OFDM subcarriers. This mapping operation is not only performed by means of modulated symbols as in classical OFDM, but also by the indices of the subcarriers. For each sub block, only k out of n available indices are employed and they are determined by using a selection procedure. For the selection procedure we use two different mapping methods. First, use a simple look-up table method which provides active indices for corresponding bits. In the case of large number of information bits transmitted, the use of a look-up table becomes infeasible. Then we go for a simple and effective technique based on combinatorial number theory to map the information bits to the subcarrier indices. We set the symbols corresponding to the inactive subcarriers to zero, and therefore, we do not transmit data with them. The remaining $p_2 = k \log_2 M$ bits of this sequence are mapped onto M-ary signal constellation, therefore we have $p = p_1 + p_2$. In other words, the information is conveyed by both of the M-ary signal constellation symbols and the indices of the subcarriers that are modulated by these constellation symbols. We compensate the loss in total number of bits transmitted by transmitting additional bits in the index domain of the OFDM block.

Fig. 1.Shows the block diagram of the OFDM- IM transmitter. For each sub block β, The incoming p1 bits are transferred to the index selector, which chooses k active indices out of n available indices , where the selected indices are given by

$I_\beta = \{ i_{\beta,1} , \ldots , i_{\beta,k} \}$ (1)

Where $i_{\beta,\gamma}$ $[1 , \ldots , n]$ for $\beta = 1 , \ldots , g$ and $\gamma = 1 , \ldots , k$.

The vector of the modulated symbols at the output of the M-ary mapper is given by

$\mathbf{s}_\beta = [s_\beta (1) , \ldots , s_\beta (k)]$ (2)

The OFDM block creator creates all of the sub blocks and it then forms N x 1 main OFDM block

$\mathbf{X}_F = [x (1)\ x (2) \ldots x (N)]^T$ (3)

After this, the same procedures of the classical OFDM are applied. The OFDM block is processed by the inverse FFT (IFFT) algorithm

$\mathbf{X}_T = \frac{N}{\sqrt{k}} \text{IFFT} \{\mathbf{X}_F\} = \frac{1}{\sqrt{k}} \mathbf{W}_N^H \mathbf{X}_F$ (4)

Where $\mathbf{X}_T$ is the time domain OFDM block, $\mathbf{W}_N$ is the discrete Fourier transform (DFT) matrix with $\mathbf{W}_N^H \mathbf{W}_N = N\mathbf{I}_N$ and the term $N/\sqrt{k}$ is used for the normalization.

3. Implementation of the OFDM-IM

This section provides different implementation methods to index selector and index demapper. Index selector block maps the incoming bits to a combination of active indices out of $C(n, k)$ possible candidates. Index demapper is used to provide an estimate of these bits. Instead of dealing with a single OFDM block with higher dimensions, we split this block into smaller sub blocks to ease the index selection and detection processes at the transmitter and receiver sides, respectively. Different two mappers are proposed for the new scheme

3.1. Look-Up Table Method

In this method first create a look-up table of size c to use at both transmitter and receiver side. At the transmitter, the look-up table provides the corresponding indices for the incoming bits for each sub block, and it performs the opposite operation at the receiver. A look-up table for n = 4, k = 2, and c = 4 is shown in Table I. Since C (4, 2) = 6, two combinations out of six are discarded.

Bits	Indices	Sub blocks
[0 0]	{ 1 , 2 }	$[s_\chi\ s_\zeta\ 0\ 0]^T$
[0 1]	{ 2 , 3 }	$[0\ s_\chi\ s_\zeta\ 0]^T$
[1 0]	{ 3 , 4 }	$[0\ 0\ s_\chi\ s_\zeta]^T$
[1 1]	{ 1 , 4 }	$[s_\chi\ 0\ 0\ s_\zeta]^T$

Table 1: Look-Up Table For N= 4, K = 2 And P_1 = 2

Although a very efficient and simple method for smaller c values, this mapping method is not feasible for higher values of and due to the size of the table. We employ this method with the ML detector since the receiver has to know the set of possible indices for ML decoding, i.e., it requires a look-up table. On the other hand, a look-up table cannot be used with the LLR detector since the receiver cannot decide on active indices if the detected indices do not exist in the table.

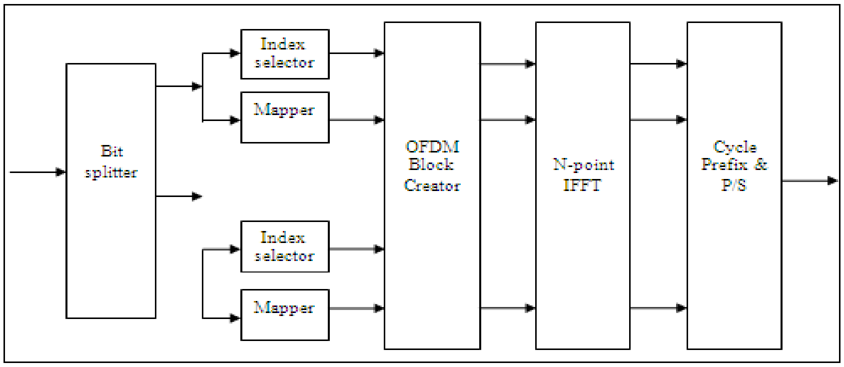

Figure 1: Block diagram of OFDM-IIM transmitter

3.2. Combinatorial Method

The combinational number system provides a one-to-one mapping between natural numbers and *k* combinations, for all *n* and *k*. i.e., it maps a natural number to a strictly decreasing sequence J = {c_k ,………., c_1}, where c_k > ….> $c_1 \geq 0$. In other words, for fixed n and k, all Z can be presented by a sequence J of length k, which takes elements from the set {0, . . . , n-1} according to the following equation:

$Z = C(c_k, k) + ... + C(c_2, 2) + C(c_1, 1)$ (5)

An example for n = 8, k = 4, C (8, 4) = 70, the following J sequences can be calculated as

$69 = C(7, 4) + C(6, 3) + C(5, 2) + C(4, 1)$ J = {7, 6, 5, 4}
$68 = C(7, 4) + C(6, 3) + C(5, 2) + C(3, 1)$ J = {7, 6, 5, 3}

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.

$32 = C(6, 4) + C(5, 3) + C(4, 2) + C(1, 1)$ J = {6, 5, 4, 1}
$31 = C(6, 4) + C(5, 3) + C(4, 2) + C(0, 1)$ J = {6, 5, 4, 0}

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$1 = C(4, 4) + C(2, 3) + C(1, 2) + C(0, 1)$ J = {4, 2, 1, 0}
$0 = C(3, 4) + C(2, 3) + C(1, 2) + C(0, 1)$ J = {3, 2, 1, 0}

In our scheme, for each sub block, we first convert the p_1 bits entering the index selector to a decimal number Z, and then feed this decimal number to the combinatorial algorithm to select the active indices as J+1. At the receiver side, after determining active indices, we can easily get back to the decimal number using (5). This number is then applied to a p_1 bit decimal-to-binary converter. We employ this method with the LLR detector for higher c values to avoid look-up tables

4. Simulation Results

In this section, we present simulation results for the OFDM-IM scheme with different configurations and make comparisons with classical OFDM, ESIM-OFDM and the ICI self-cancellation OFDM scheme. The BER performance of these schemes was evaluated via Simulations. We investigate the error performance of OFDM-IM under ideal and realistic channel conditions.

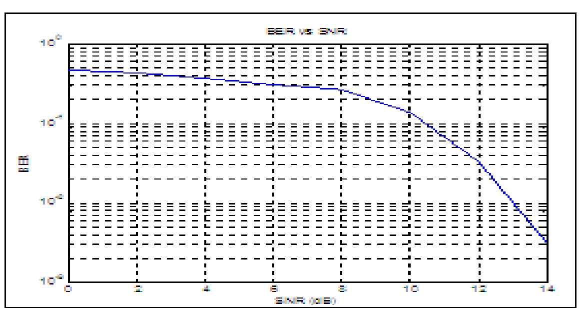

Figure 2: Performance of classical OFDM

Fig. 2.Shows the performance of classical OFDM. The graph plotted Bit error rate versus signal to noise ratio (SNR) in dB. As the signal to noise ratio (SNR) increases the bit error rate (BER) decreases. It is shown via simulation results as shown in Fig. 2.

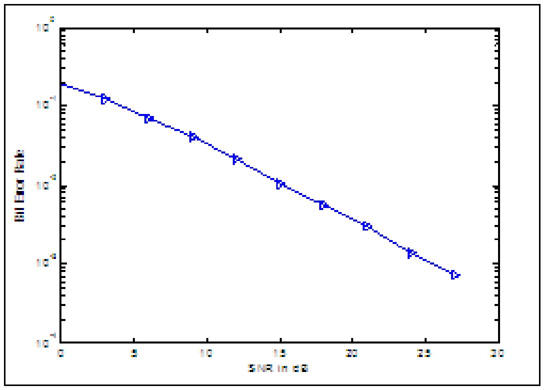

Figure 3: Performance of OFDM-IM

Performance of OFDM with index modulation is shown in Fig. 3. The graph plotted bit error rate (BER) versus signal to noise ratio (SNR) in dB. Compare with classical OFDM, this graph shows a steep decrease in bit error rate (BER) as signal to noise ratio (SNR) increases

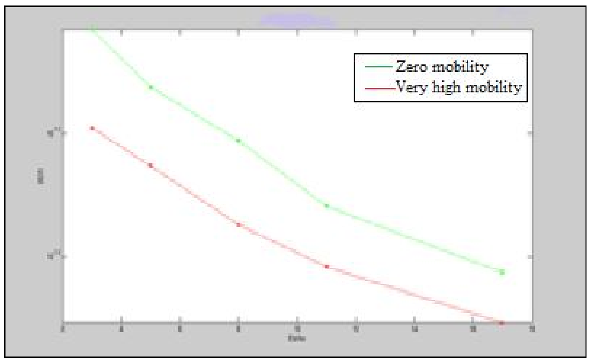

Figure 4:Performance comparison

Fig. 4. Shows the error performance analysis for zero mobility and very high mobility case. Green plot represents zero mobility and red plot represents very high mobility. The above graph plotted bit error rate (BER) versus signal-to-noise ratio (SNR). In very high mobility case at 3 dB SNR, the bit error rate (BER) is $10^{-1.3}$. Very high mobility achieves better BER compared to zero mobility case.

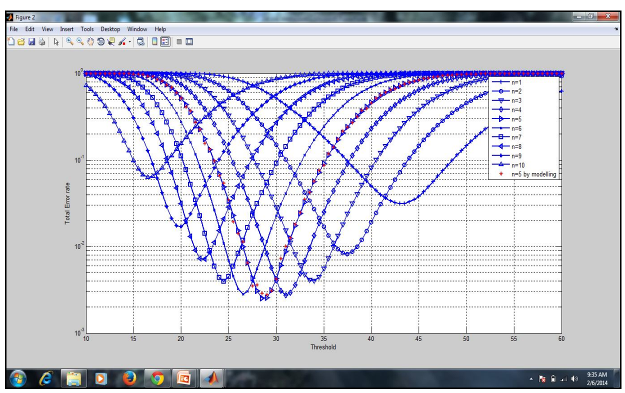

Figure 5: Performance comparison based on Threshold

Fig. 5. Shows the performance comparison based on threshold value. In this figure X-axis represents the threshold values and Y-axis represents the total error rate. This figure represents the total error rate for number of subcarriers from n=1 to 10 and choose the threshold value be from 10 to 60. Figure shows the error rate for different threshold values.

5. Conclusion

A novel Orthogonal frequency division multiplexing called orthogonal frequency division multiplexing with index modulation (OFDM-IM) is proposed in this paper. In this scheme, motivated by the recently proposed Spatial Modulation concept, the incoming information bits are transmitted in a unique fashion to improve the error performance as well as to increase spectral efficiency. The performance comparison graphs are shown via computer simulations. It compares the bit error rate with classical

OFDM. The error performance for zero mobility and very high mobility case is also implemented in this paper. It has been shown that the proposed scheme achieves significantly better BER performance than classical OFDM under different channel conditions.

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