BICM-OFDM System with Power Allocation and Bit Loading

Rupali Hande
ME(Computer Engg.)
Second Year Student
Department of Computer Engineering
MGM's College of Engineering and Technology,
Navi Mumbai, University of Mumbai, India

Prof. D. R. Ingle
PROFFESOR
Department of Computer Engineering,
Bharati Vidyapith College of Engineering,
Navi Mumbai, University of Mumbai, India

Abstract-The OFDM has many advantages such as high bandwidth efficiency, robustness to the selective fading problem, use of small guard interval, and its ability to combat the ISI problem. But in an OFDM system, the information is converted to N parallel sub channels and sent at lower rates. The combination of bit-interleaved coded modulation (BICM) with orthogonal frequency division multiplexing (OFDM) provides a low-complexity nearly-optimal performance approach to the broadband transmission in multipath scenarios. Caire, Taricco and Biglieri presented a detailed analysis of bit interleaved coded modulation, a simple and popular technique used to improve system performance, especially in the context of fading channels. This paper deals with transmission schemes for BICM-OFDM system. In the BICM-OFDM scheme, nearly optimal performance can be achieved by bit loading and power allocation, i.e. assigning a different constellation (number of bits) and different power to each subcarrier and each channel access according to the channel frequency response.

Keywords – BICM, OFDM, Mutual information, bit loading, power allocation.

I. INTRODUCTION

The OFDM has many advantages such as high bandwidth efficiency, robustness to the selective fading problem, use of small guard interval, and its ability to combat the ISI problem. So, simple channel equalization is needed instead of complex adaptive channel equalization. The combination of bit-interleaved coded modulation (BICM) with orthogonal frequency division multiplexing (OFDM) provides a low-complexity nearly-optimal performance approach to the broadband transmission in multipath scenarios. On the one hand, the paradigm of channel code and modulation separation by means of a bit interleaver introduced by BICM has been proved a versatile approach to spectrally efficient transmission in fading channels. BICM allows a large flexibility in constellation selection and channel coding design at the expense of minor performance losses. On the other hand, the use of OFDM allows to get rid of inter-symbol interference converting the frequency selective channel into a set of parallel non-interfering channels thanks to the use of multicarrier transmission. The good performance vs. complexity trade-off provided by BICM-OFDM has motivated a broad interest in this transmission scheme, as well as its introduction in many standards like IEEE802.11a/g, IEEE802.16. This paper deals with transmission schemes for BICM-OFDM systems subject to slow-fading. In low-mobility scenarios the channel state can be accurately tracked by both the transmitter and the receiver and the performance can be improved adapting the signalling to the instantaneous channel spectral shape. In the BICM-OFDM scheme, nearly optimal performance can be achieved by bit loading and power allocation, i.e. assigning a different constellation (number of bits) and different power to each subcarrier and each channel access according to the channel frequency response. Probably the most well-known criterion for power allocation is the maximization of the channel capacity under an average power constraint. The solution for the additive white Gaussian noise (AWGN) channel is known as waterfilling. Unfortunately, this solution assumes a continuous and Gaussian modulation so it is not optimum for practical systems using discrete constellations, since the bit rate assignments are constrained to be integer. In this case, if the bit loading has been previously determined, the power allocation that maximizes the mutual information is provided by the mercury/ waterfilling policy (MWF).

Taking into account that state of the art channel codes can achieve performance very close to the Shannon limit, the mutual information provides a good criterion for system design without taking into account the specific channel code employed. However, since MWF only optimizes the power allocation, a bit loading algorithm is also required. Unfortunately, mutual information cannot be employed as the optimization criterion for bit loading design when typical constellations (e.g. m-QAM, m-PSK) and optimum transceivers are considered, since for a fixed SNR the largest constellation always provides the largest mutual information. In other words, the mutual information is maximized employing the largest constellation available at any SNR. Therefore, other methods have been proposed in the literature that introduces practical constraints related to the bit error rate (BER) performance, either for the uncoded or coded case. However, this situation may change if we take account of the mutual information loss introduced by suboptimum transceivers. In the case of BICM, the magnitude of this loss depends on the constellation, its labelling and the SNR. As it is well known, for QAM constellations with Gray labelling the MI of small constellations surpasses that one of larger ones at low SNR's. Hence, when BICM schemes are considered, mutual information provides a meaningful criterion for joint optimization of bit loading and power allocation that can be applied to design transceivers with nearly optimal performance.

In this paper, we propose a bit loading and power allocation algorithm for BICM-OFDM systems that maximizes the mutual information under an average power constraint. We rely on irregular modulation to formulate the problem in the framework of a convex optimization. The proposed algorithm does not provide significant gains in terms of spectral efficiency increase, but rather provides a new tool for joint bit loading and power allocation that maximizes the mutual information while it maintains the computational complexity of mercury / waterfilling.

The rest of the paper is organized as follows. The project architecture is explained in section II, followed by result in section IV and detailed explanation of algorithm is provided in section III

II. SYSTEM ARCHITECTURE

This section describes the system set-up in which the proposed bit loading and power allocation policy will be employed in OFDM system implementation. The system design is based on the application of irregular modulation and power allocation to a BICM scheme in scenarios which makes use of multiple parallel sub channels.

Figure 1 depicts the system block diagram, including the coding, interleaving, mapping and power allocation stages. Following a BICM scheme, the coded bits are bit-interleaved and delivered to the modulation and power allocation stages.

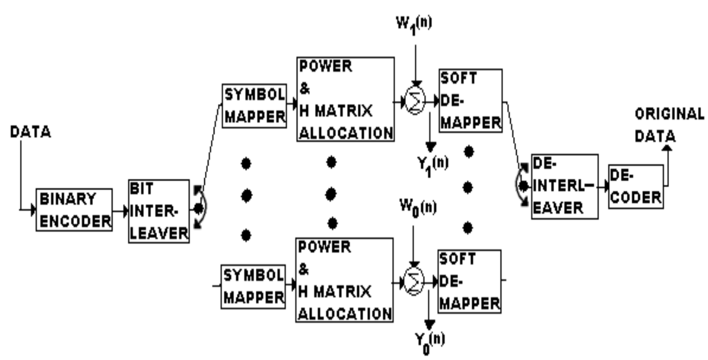

Figure 1 System Architecture

Consider Q parallel sub channels with coefficients $\{H_{1,\dots,}H_Q\}$. $p_n(n)$ is the power allocated to and by $x_q(n)$ the unit-power symbol transmitted through the qth sub channel in the nth channel access. The symbol belongs to one of the N available constellations, $\{C_{1,\dots}C_N\}$, with $\{m_{1,\dots}m_N\}$ bits per symbol respectively and possibly different labeling. Then, the received signal is

$$y_q(n) = H_q\sqrt{p_q(n)}x_q(n) + w_q(n)$$

$$q = 1, \ldots \ldots, Q \qquad (1)$$

where $w_q(n)$ is the additive complex white Gaussian noise term of zero mean and variance σ^2, independent among sub channels. At the receiver, the suboptimum detector computes the bit log-likelihood ratios (LLR's) of the transmitted bits, de interleaves and delivers them to the decoder. According to the irregular modulation and power scheme, we allow the transmission of symbols belonging to different constellations with different allocated power within the same sub channel, and we let this configuration to be different for each sub channel. If more than one constellation is used within a sub channel, the order in which the bits are mapped to them is predefined and, therefore, known at both transmitter and receiver

III. ALGORITHM

In order to implement the Power allocation we propose implementation using following algorithm which only needs the primary assumption of sharing of channel state information (CSI) between the receiver and transmitter, leading to maximization of the mutual information being communicated.

A system with *K* users and *N* subcarriers is considered. A subset of *N* subcarriers is assigned to a user, and the number of bits is also determined on downlink transmission. $\{h_{n,k}\}$ denotes the channel gains over all *N* subcarriers for the k^{th} user at subcarrier *n*. The number of bits of the n^{th} subcarrier assigned to user *K* is $r_{n,k}$. The required received power f_k at a particular data error rate is a function of bits per symbol $r_{n,k}$. The power of noise is normalized to one. If the *n*th subcarrier is used by the k^{th} user, the required transmit power for the specified BER at $r_{n,k}$ bits per symbol is equal to

$$p_{n,k} = \frac{f_k\left(r_{n,k}\right)}{h_{n,k}^2} \qquad (2)$$

In multiuser OFDM systems under consideration, we do not allow more than one user to share a subcarrier. To formulate the allocation problem, we define

$$\rho_{n,k} = \begin{cases} 1 \; if \;\; r_{n,k} \neq 0 \\ 0 \; if \;\; r_{n,k} = 0 \end{cases} \qquad (3)$$

The constraint is expressed as

$$p = \sum_{k=1}^{K} \rho_{n,k} \qquad (4)$$

The required transmit power can be expressed as

$$p = \sum_{n=1}^{N} \sum_{k=1}^{K} \frac{f_k\left(r_{n,k}\right)}{h_{n,k}^2} \rho_{n,k} \qquad (5)$$

Data rates $\{R_1, R_2, \ldots \ldots, R_K\}$ are predetermined parameters for each user. The bit error rate must be ensured at a certain level to meet the service quality. The subcarrier, bit, and power allocation problem for the minimization of total transmit power is formulated as

$$\min_{r_{n,k}, \rho_{n,k}} \sum_{n=1}^{N} \sum_{k=1}^{K} \frac{f_k\left(r_{n,k}\right)}{h_{n,k}^2} \rho_{n,k}$$

$$subject\ to \sum_{k=1}^{K} \rho_{n,k} = 1, for\ n = 1,2, \ldots .N$$

$$\sum_{n=1}^{KN} r_{n,k} = 1, for\ k = 1,2, \ldots .k \qquad (6)$$

A. Subcarrier Allocation Algorithm

Each single user is initially supposed to be able to use all subcarriers. The optimal bit allocation is obtained by the water-filling method. In this algorithm there is no need to be pre-determined number of subcarriers for each user.

1. For each user
   a. Apply the single user subcarrier and bit allocation algorithm to allocate subcarriers and bits to the user.
   b. The transmit power of each user on each subcarrier is computed.
   c. Subcarrier is checked for confliction.
2. If there is no conflicting subcarrier,
   a. Then the optimal allocation solution for multiuser OFDM systems is found.
   b. Otherwise
      i. The conflict of desired subcarriers needs to be resolved. Suppose a conflicting subcarrier *k* is in the desired list of M users $\{n_1, n_2, \ldots \ldots . n_M\}$. Define the total transmit power on subcarrier k as the sum of each user's transmit power on this conflicting subcarrier.
      ii. Arrange the conflicting subcarriers in the order of decreasing total transmit power of the subcarrier.
3. The conflicting subcarrier with the largest power is chosen to start.
   a. The conflicting subcarriers are assigned to users in turn. Once a conflicting subcarrier is assigned to a user, other users are required to reallocate the bits which are allocated to this subcarrier currently.
   b. The required total transmits power after re-assigning of bits is re-computed.

4. The user providing the minimum total transmit power increase of the bit reassignment is selected to use the conflicting subcarrier. Then, the subcarriers and the bits are reallocated according the water-filling method. New conflicting subcarriers may be generated during the process. The procedure is performed iteratively until there is no conflicting subcarrier.

IV. Simulation Results

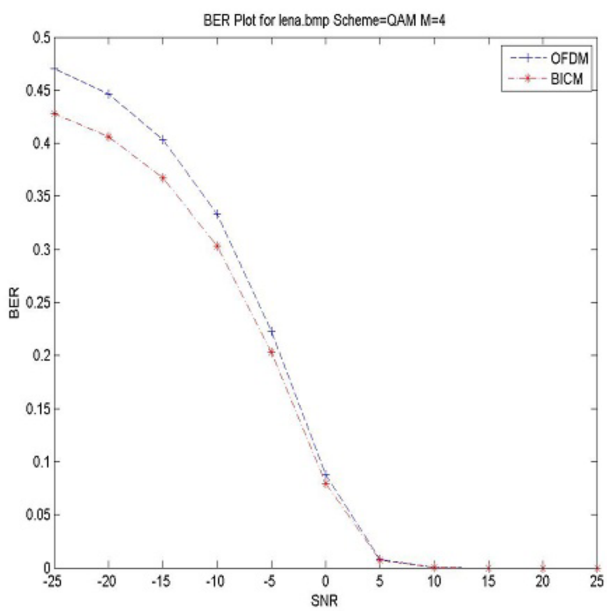

Figure 2BER Plot M=4

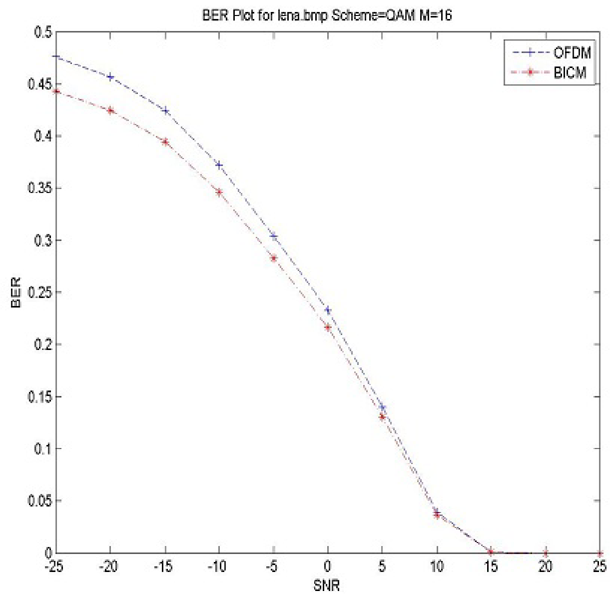

Figure 3 BER Plot M=16

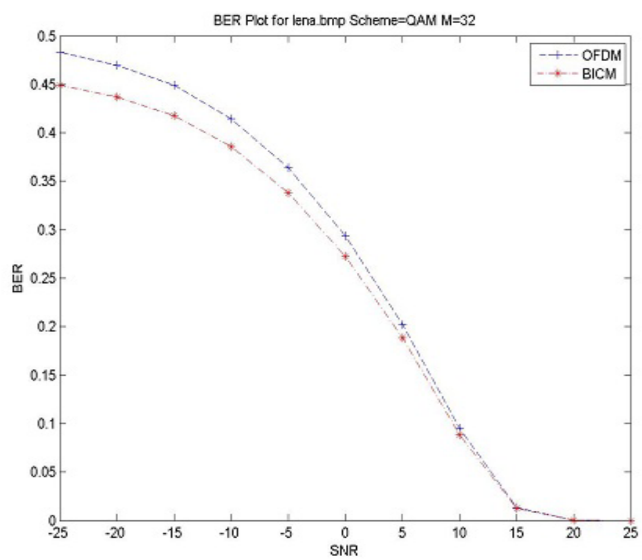

Figure 4 BER Plot M=32

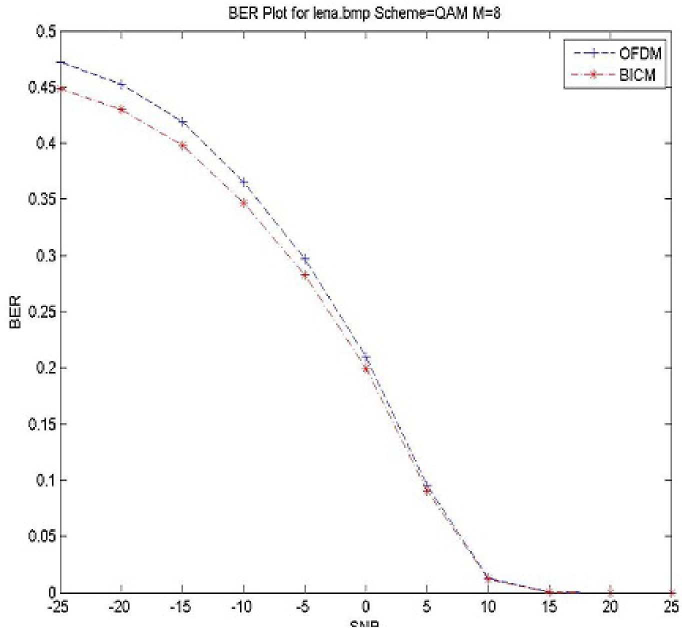

Figure 5 BER Plot M=8

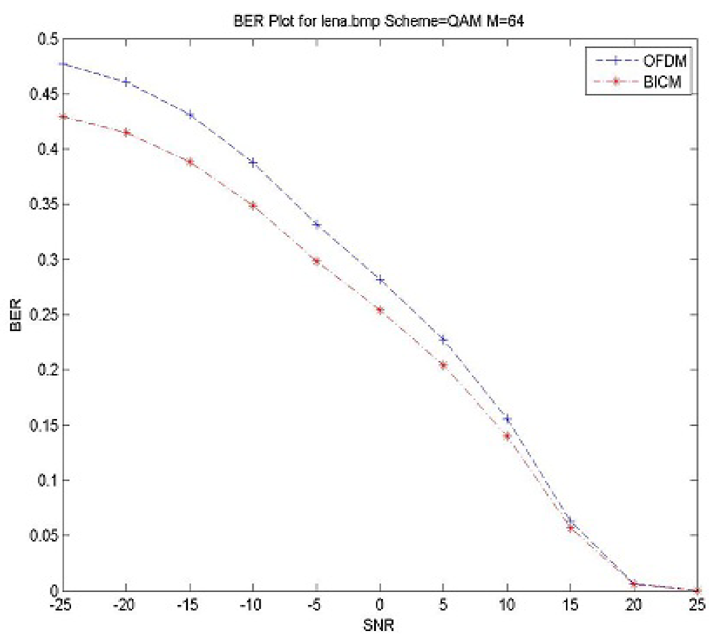

Figure 6 BER Plot M=64

V. CONCLUSION

In this work, the concepts of orthogonal frequency division multiplexing (OFDM) and bit interleaved coded modulation (BICM) in digital transmission system are explored. BICM-OFDM scheme, nearly optimal performance can be achieved by bit loading and power allocation, i.e. assigning a different constellation (number of bits) and different power to each subcarrier and each channel access according to the channel frequency response. In particular, we have focussed on BER minimization using bit and power allocation and code selection. Although the algorithm is proposed for a BICM-OFDM transmission, it could be employed in any other scenario where parallel sub channels arise (e.g. multiple antenna transmission where the MIMO channel is diagonalized through the use of linear pre/post-filtering based on its singular value decomposition) and where the transmission scheme results in mutual information vs. SNR curves that overlap for different configurations.

REFERENCES

[1] Miloˇs Jakovljevi´c1, Santiago Zazo1,Jos´e Luis Pe˜na2 "New approach to bit loading and power minimization using mercury/waterfilling" EUSIPCO 2009.

[2] Joakim Jald´en, Peter Fertl, Gerald Matz "On the Generalized Mutual Information of BICM Systems with Approximate Demodulation" 2010 IEEE Information Theory Workshop.

[3] Sanjay Singh, M Sathish Kumar, and H. S Mruthyunjaya "Effect of Peak-to-Average Power Ratio Reduction on the Multicarrier Communication System Performance Parameters" International Journal of Electrical and Computer Engineering 4:12 2009

[4] S. H. Han and J. H. Lee, "An overview of peak-to-average power ratio reduction techniques for multicarrier transmission," *IEEE Wireless Commun.*, vol. 12, pp. 56-65, Apr. 2005.

[5] E. Biglieri, G. Caire, and G. Taricco, "Bit-interleaved coded modulation," *IEEE Trans. Inf. Theory*, vol. 44, pp. 927-946

[6] Mohammad Mohammadnia-Avval, Alireza Kenarsari-Anhari, and Lutz Lampe "Adaptive Bit- Interleaved Coded OFDM" University of British Columbia, Vancouver, BC, Canada.

[7] Nikolaos Papandreou, and Theodore Antonakopoulos, "A New Computationally Efficient Discrete Bit-Loading Algorithm for DMT Applications" IEEE transactions on Communications , vol. 53, no. 5, may 2005.

[8] David Matas and Meritxell Lamarca "Optimum Power Allocation and Bit Loading for BICM Systems" IEEE transactions on communications, vol. 58, no. 8, august 2010. Jun Tan, *Member, IEEE,* Gordon L. St¨uber, *Fellow, IEEE* "Analysis and Design of Symbol Mappers for Iteratively Decoded BICM ".

[9] Fernando P´erez-Cruz,.Miguel R. D. Rodrigues, Sergio Verd´u "Generalized Mercury/Waterfilling for Multiple-Input Multiple-Output Channels" *Conference* on Advanced Communication Technology, 2007.

[10] M. Tulino, A. Lozano, and S. Verdu, "Optimum power allocation for parallel Gaussian channels with arbitrary input distributions," *IEEE Trans. Inf. Theory*, vol. 52, pp. 3033-3051, July 2006

[11] F. Rey, M. Lamarca, and G. Vazquez, "Robust power allocation algorithms for MIMO-OFDM systems with imperfect CSI," *IEEE Trans.Signal Process.*, vol. 53, pp. 1070-1085, Mar. 2000.

[12] Francesc Rey, Meritxell Lamarca and Gregori Vazquez*, Senior Member, IEEE* "Robust Power Allocation Algorithms for MIMO OFDM Systems With Imperfect CSI" IEEE transactions on signal processing, vol. 53, no. 3, march 2005.

[13] S. Krongold, K. Ramchandran, and D. L. Jones, "Computationally efficient optimal power allocation algorithms for multicarrier communication systems," *IEEE Trans. Commun.*, vol. 48, pp. 23-27, Jan. 2000.

[14] Enis Akay and Ender Ayanoglu "Bit Interleaved Coded Modulation with Space Time Block Codes for OFDM Systems" IEEE CONF. 26-29 Sept. 2004

[15] G. D. Forney Jr. and G. Ungerboeck, "Modulation and coding for linear Gaussian channels," *IEEE Trans. Inf. Theory*, vol. 44, pp. 2384-2415, Oct. 1998.

[16] T. S. Rappaport, "Wireless Communications: Principles and Practice," Prentice Hall, New Jersey, 2002

[17] B. Saltzberg, "Performance of an Efficient Parallel Data Transmission System," *IEEE Trans. on Commun.*, vol 15, no. 6, pp. 805-811, Dec. 1967.

[18] S. Weinstein and P. Ebert, "Date transmission by frequency-division multiplexing using the discrete fourier transform," *IEEE Trans. on Commun.*, vol. 19, no. 5, pp. 628-634, Oct. 1971.

[19] J. G. Proakis, "Digital Communications", McGraw-Hill, New York, 1995.

[20] A. Peled and A. Ruiz, "Frequency domain data transmission using reduced computational complexity algorithms", in *Proc. IEEE ICASSP-80*, Denver, CO, 1980, pp. 964- 967.