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Adaptive Modulation and Coding Scheme for MB-OFDM UWB Systems

Houda CHIHI
Innov'COM
ENIT/SUP'COM
Tunis, Tunisia
houda.chihi@gmail.com

Raul DE LACERDA
DRE/EMG/LSS
SUPELEC
Gif-sur-Yvette, France
raul.delacerda@supelec.fr

Ridha BOUALLEGUE
Innov'COM
ENIT/SUP'COM
Tunis, Tunisia
ridha.bouallegue@ieee.org

***Abstract*—Energy Efficiency (EE) has become one of the main challenges for the development of wireless communication systems. Thus, many researchers are investigating new solutions to save power. For this reason, in this paper we apply a method based on modulation and coding scheme (MCS) for multiband orthogonal frequency division multiplexing (MB-OFDM) ultra wideband (UWB) systems. The MCS scheme is a powerful method known by its ability to improve the spectral efficiency. Our goal in this paper is to investigate the performance of MCS mechanism to diminish the transmitted power under some assumptions. Computer results show the throughput behavior in function of signal to noise ratio (SNR) for different selection of modulation and coding rate. Then, we draw the plot of bit error rate (BER) versus SNR and versus the energy per bit to noise power spectral density ratio (E_b/N_o).**

Keywords—MBOFDM; UWB; energy efficiency; MCS; throughput.

I. INTRODUCTION

Nowadays most of the research contributions focus in energy efficiency enhancement due to the great increase of wireless applications which require more consumed power. In particular, UWB which attracted the attention of many researchers especially in the domain of wireless personal area networks (WPAN) [1] and sensor. In 2002, the federal communications commission (FCC) [2] limits the power spectral density (PSD) into -41.3 dBm/MHz. The spectrum occupancy of UWB system is ranging from 3.1 GHz to 10.6 GHz. Furthermore, the institute of electrical and electronics engineers (IEEE) defined 802.15.3a group [3] for WPAN applications. Besides, MB-OFDM was appeared as the leading multiple access solution for UWB communications systems which is presented as a multicarrier approach described by the WiMedia proposal [4] and standardized by ECMA-368 [5] due to its robustness and flexibility against the selectivity of UWB channel.

Otherwise our aim in this paper is to investigate the performance of the MB-OFDM UWB (MB-UWB) system in terms of energy efficiency since power control is becoming an area of active search and was not well studied in WiMedia context. As a solution we apply adaptive modulation joint with coding rate which was frequently exploited in many systems in last decades such as WLAN, GSM, and IEEE 802.16 system. In fact, MCS could be employed for many reasons to overcome problems of interference and to increase the throughput but in our analysis we are interested in energy minimization. Furthermore, this idea has received much interest in previous research contributions [6]. At first adaptive modulation was proposed by *Steele and Webb* [7] to determine the capacity in Rayleigh channel.

Nevertheless, the MCS motivation is due to the contribution of Goldsmith in [8] where variable rate is joint with variable power. In [9] the author investigates adaptive bit loading approach to select the best MCS. In addition, the author in [10] exploits the features of MCS to draw a new adaptive modulation and coding (AMC) approach based on a learning algorithm managing the appropriate mapping choice in long term evolution (LTE) system. In [11] the author develops different MCS schemes to enhance the throughput of LTE in downlink status. Indeed, the AMC approach was also exploited in [12] for optical transceiver. The benefit of MCS in improving the spectral efficiency into satellite mobile system was discussed in [13]. Then, the AMC proposal was employed in the switching between M-ary pulse position modulation (M-PPM), M-ary pulse amplitude modulation (M-PAM) and low density parity check (LDPC) coding rate in [14].

The performance of changing AMC in worldwide interoperability for microwave access (WiMax) was described in [15]. A survey about adaptive coding scheme in MIMO scenario was presented in [16].

In [17] the author proposes adaptive modulation and variable power with antenna selection with different conditions of channel state information (CSI). In other hand, the paper in [18] presents AMC mechanism applied to exponential effective SNR for LTE and WiMax. Then, throughput performance results of LTE system using different adaptive modulation and coding propositions at each received channel quality indicator (CQI) was investigated in [19]. Additionally, Hayes in [20] shows the performance of transmitted information which is controlled by the receiver through the feedback in Rayleigh channel. The aim of this work is to manage the issue of power minimization regarding the advantages offered by MCS mechanism. The purpose is to evaluate the performance of the MB-UWB MCS systems in terms of EE improvement.

II. OVERVIEW OF MB-UWB SYSTEMS

In this section we present a brief overview of MB-UWB systems. At the beginning the generated data bits are encoded by a convolutional encoder having a rate of 1/3 with generator polynomials of [133_8, 165_8 and 171_8].

In addition, other coding rates could be derived from the convolutional coder due to puncturing. Next, the data will be interleaved. The interleaved data are modulated adaptively into a QPSK, 8QAM or 16QAM mapping according to different data rates given in [5]. Particularly for the data rates of 53.3 Mbps and 80 Mbps frequency domain spreading (FDS) is employed based on transmitting the subcarrier and his conjugate into the same OFDM symbol. Otherwise for data rates ranging from 53.3 Mbps to 200 Mbps [4] time domain spreading (TDS) is employed allowing the transmission of the same information over two OFDM symbols. The combination of guard subcarriers with pilot symbols form the framing block. After that inverse fast fourier transform (IFFT) process is applied with 128 subcarriers of length. Then, a zero padding component having 37 of length is added allowing mitigating inter-symbol interference (ISI). The hopping process is ensured by the time frequency code (TFC) pattern chosen according to [5]. In reception we find overlap and add (OLA) component restoring the samples of ZP pattern at the beginning of OFDM symbol after FFT processing.

Furthermore, the channel model adopted by MB-UWB systems is IEEE 802.15.3a composed of four channel models (CM1, CM2, CM3, CM4) which differ by reaching rate and the considered scenarios of line-of-sight (LOS) or non-line-of-sight (NLOS) where more details are given in [4]. The block diagram of MB-UWB systems is depicted in Fig. 1 in the next section.

III. MB-UWB MCS SYSTEMS DESCRIPTION

A. System model

In our analysis we consider a SISO MB-UWB communication system. The received signal Y_n at the nth sub-carrier is characterized by:

$$Y_n = H_n X_n + N_n. \quad (1)$$

where:

- H_n is the channel gain at the nth subcarrier.
- X_n is the transmitted signal in subcarrier n.
- N_n denotes the noise.

B. MB-UWB MCS systems principle

Adaptive coded modulation is known by its ability and efficiency to provide reliable transmission in wireless channels but the transmitter requires the information about the estimated channel at the receiver which could be possible with a feedback path. The received feedback enables the transmitter to manage the mapping size, coding rate and the transmitted power.

The mapping and coding choice is provided at each SNR. Particularly, when the channel conditions are good we obtain more power dedicated for transmission. It consists on choosing the appropriate MCS scheme for each received CSI. Moreover, we consider a convolutional encoder with 1/3 of coding rate and due to the adjustment with puncturing we obtain other coding rates (1/3, 1/2, 3/4, 5/8, 11/32) [5]. In addition, we consider adaptive modulation applying QPSK, 8QAM and 16QAM constellations. Table I specifies the supported MCS scheme.

The switching of the given modulation and coding rates specifies the amount of bits that could be sent and the suitable power to be transmitted. Furthermore, the transmitter employs the feedback to switch over the best MCS approach which provides a power gain where more details could be found in [21]. Indeed, the power is adjusted by adopting the accurate mapping size M and the coding rate r.

TABLE I. MCS TABLE OF MB-UWB SYSTEMS.

MCS	*Data rate(Mbps)*	*Coding rates (r)*	*Mapping (M)*
1	53.3	1/3	4
2	80	1/2	4
3	110	11/32	4
4	160	1/2	4
5	200	5/8	4
6	320	1/2	4
7	400	5/8	4
8	480	3/4	4
9	840	1/2	16
10	980	1/2	8

We focus in exploiting the features offered by MB-UWB systems for optimizing the application of MCS mechanism based on channel situation where the proposed model is depicted in Fig. 2.

The considered system is composed by an adaptive modulator and coding component with a separate feedback channel assumed with zero delay where the estimation's errors are relaxed. Therefore, the receiver measures the channel, selects an appropriate modulation and tells the transmitter to apply this MCS. Additionally, the transmitter measures the channel, selects an appropriate MCS and notifies the receiver about the used modulation. We must mention that we assume perfect channel knowledge at both transmitter and receiver.

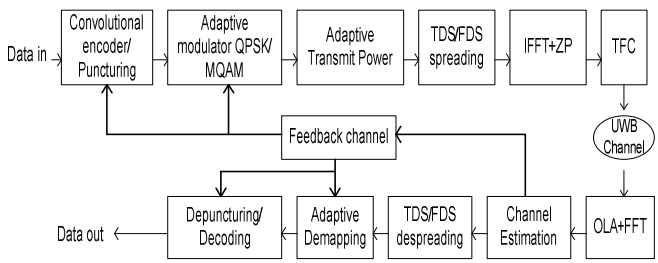

Fig.1. MB-UWB communication systems using MCS scheme.

The corresponding throughput of the MB-UWB MCS systems can be characterized according to the author in [22] by:

$$\gamma = (1\text{-BLER})\ L\ r \log_2(M) \qquad \text{(bps/Hz)} \qquad (2)$$

where:

- γ denotes the throughput expressed in (bps/Hz).
- r stands for the coding rate.
- M is the mapping size.
- BLER is the block error rate.
- L represents the length of the packet.

The adaptive selection of mapping and coding rate in terms of the SNR yields the throughput to vary at each BER.

C. Problem Formulation

To overcome the fading effects, power control is required to maintain heuristic system performance. Hence, MCS is the key of a flexible MB-UWB system enhancing the energy efficiency. The appropriate choice of MCS depends on the SNR received value. Additionally, the impact of latency in MCS mechanism is not considered in our work.

The efficiency of MCS approach depends on the channel estimation purpose. In fact, due to the channel variation the transmitter could be able to control the mapping size, coding rate under the purpose to accommodate the transmitted power allowing improving the EE. Previous studies depicted in [6] show that adaptive modulation is a required approach to improve the EE and to increase the throughput of wireless communication system. But the basic idea of this paper is to minimize the total transmitted power under the constraint of a given required data rate [23]. It turns out that our problem is a margin adaptive water-filling in time based on power minimization at the condition of providing the required data rate for each user. Nevertheless, the capacity of our MB-UWB MCS system at the nth subcarrier is expressed by:

$$C_n = \log_2\left(1 + \frac{1}{\Gamma} p_n \frac{|h_n|^2}{N_o}\right) \qquad (3)$$

where:

- C_n is the data rate at the nth subcarrier.
- p_n represents the power transmitted into the nth subcarrier.
- $|h_n|^2$ denotes the channel gain coefficient of the nth subcarrier.
- N_o is related to the density of noise.
- Γ refers to the SNR gap related to each QAM mapping at the nth subcarrier.

Hence, the power at the nth subcarrier is given by:

$$p_n = \Gamma\,(2^{C_n} - 1)\frac{N_o}{|h_n|^2} \qquad (4)$$

In other side, since our purpose is power minimization the optimization problem becomes:

$$\min \sum_{n=1}^{N} \Gamma\,(2^{C_n} - 1)\frac{N_o}{|h_n|^2}$$

$$\text{Under the constraint of}: \sum_{n=1}^{N} C_n = C\,. \qquad (5)$$

We must mention that C denotes the required data rate. Moreover, since our purpose is to determine the power p_n satisfying the required data rate C, we solve the optimization problem by applying the Lagrangian tools which implies to obtain:

$$L(\{C_n\},\{\lambda\}) = \sum_{n=1}^{N} \Gamma(2^{C_n} - 1)\frac{N_o}{|h_n|^2} - \lambda\left(\sum_{n=1}^{N} \log_2\left(1 + \frac{1}{\Gamma} p_n \frac{|h_n|^2}{N_o}\right) - C\right) \qquad (6)$$

where λ denotes the Lagrangian multiplier. Then, after applying partial derivative of $\frac{\partial L}{\partial C_n} = 0$ we obtain:

$$C_n^* = \log_2\left(\frac{1}{\Gamma}\frac{\lambda}{\ln 2}\frac{|h_n|^2}{N_o}\right) \qquad (7)$$

Next, the application of KKT condition leads to obtain:

$$\lambda\left(\sum_{n=1}^{N} \log_2\left(1 + \frac{1}{\Gamma} p_n \frac{|h_n|^2}{N_o}\right) - C\right) = 0 \qquad (8)$$

In other side, since $\lambda > 0$ we have:

$$\sum_{n=1}^{N} \log_2\left(1 + \frac{1}{\Gamma} p_n \frac{|h_n|^2}{N_o}\right) - C = 0 \qquad (9)$$

In addition, λ could be determined from the inequality condition in (5). By this way, it is expressed as:

$$\lambda = \ln 2\ \Gamma\, N_0 \frac{2^{C/N}}{\left(\prod_{n=1}^{N} |h_n|^2\right)^{1/N}} \qquad (10)$$

Yields, (7) is given by:

$$C_n^* = \frac{C}{N} + \log_2(|h_n|^2) - \frac{1}{N}\sum_{n=1}^{N} \log_2(|h_n|^2) \qquad (11)$$

IV. Performance Results

In this section we investigate the performance of the MB-UWB MCS systems over the first three sub-bands ranging from 3168 MHz to 4752 MHz. The simulation was performed over CM1 channel model by considering CSI at both transmitter and receiver with 100 channel realization and TFC pattern of {1,2,3,1,2,3} providing temporal and frequency diversity.

We consider the constellation of both QPSK following the standard [5] and MQAM where M ∈ {4, 8, and 16}. We must mention, that we consider only until 16QAM mapping to not complicating the system design. We assume a BER target of 10^{-4} over OFDM symbol period of 242 ns. We consider a parent convolutional encoder with 1/3 coding rate inducing a punctured code with a rate ranging from {1/2, 3/4, 5/8, 1/3 and 11/32}.

A. *Throughput Performance Results*

Herein, we show in Fig. 2 the throughput variation in function of the SNR:

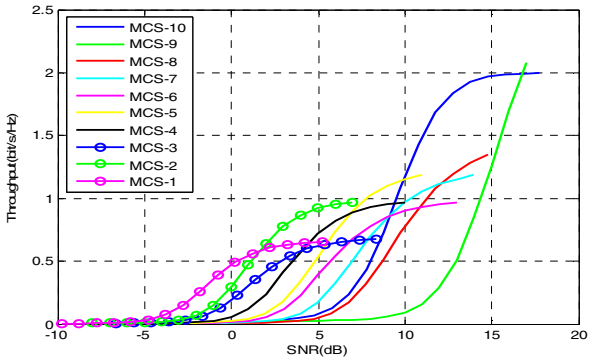

Fig. 2. Performance comparison of throughput versus SNR of MB-UWB MCS systems.

Fig. 2 illustrates the throughput variation (bps/Hz) when different modulation and coding rates are applied following Table I by exploiting the proprieties of MB-UWB proposal [4]. We must mention that the throughput is simulated according to (2). Indeed, the AMC approach allows the transmitter to predict the next step of transmission. Therefore, the power could be estimated in reception which implies selection of the constellation size allowing transmitted power management. Hence, according to the received SNR a given mapping and power could be chosen. In other hand, whenever SNR increases 16QAM and 8QAM are dominant.

B. *BER Performance Results*

To show the performance behavior of the MB-UWB MCS systems we illustrate in Fig. 3 the plot of BER = f (SNR):

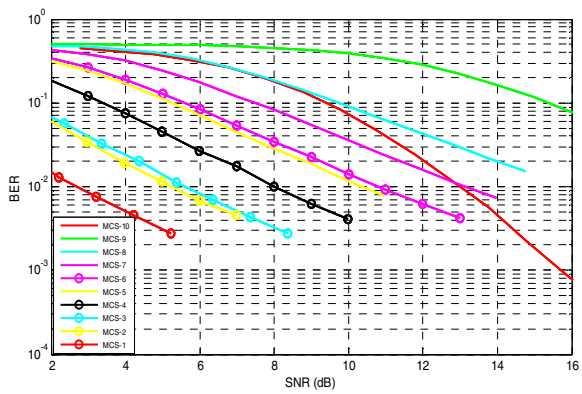

Fig. 3. BER versus SNR performance curves of MB-UWB MCS systems.

Fig. 3 displays the variation of BER versus SNR for the MB-UWB MCS systems. At low SNR values QPSK modulation with 1/3 coding rate is the dominant MCS scheme corresponding to the suitable selection mode. Otherwise, at high SNR values 8QAM and 16QAM are the dominant selection mode.

Therefore, the performance in terms of BER is clearly degraded for high data rates at a given BER target of 10^{-4}.

Next, Fig. 4 depicts the performance of MB-UWB MCS systems through BER = f (E_b/N_o):

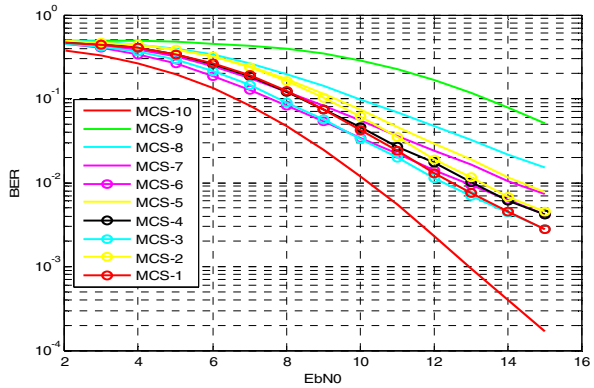

Fig. 4. MB-UWB MCS systems performance behavior in terms of BER versus E_b/N_o.

Fig. 4 depicts the BER performance behavior versus E_b/N_o when different MCS orders are carried out in MB-UWB systems. It is shown that although MCS-10 hasn't applied TDS and FDS components the performance are good. On the other side the MCS corresponding to 53.3 Mbps with QPSK modulation applying FDS and TDS components highlights bad performance results.

V. Conclusion

In conclusion, we note that MCS approach appears as the optimum solution to overcome problems of fading and to adjust the transmitted power respecting the features of MB-UWB systems according to the instantaneous received feedback assuming the knowledge of the channel at both the transmitter and the receiver in the way to satisfy user requirement in terms of data rate. Next, the performance of MCS mechanism is investigated through throughput simulation. Additionally, the performance of the modulation and coding approach is shown through BER versus SNR simulation in one hand and BER versus E_b/N_o investigation in other hand. The obtained results reveal that AMC proposal is a powerful tool providing efficient transmission of information and enhancing the energy efficiency at a given BER target according to the instantaneous received SNR.

Further work should consider the latency in performance analysis as well as the estimation's errors.

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