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Energy Expenditure Per Bit Minimization Into MB-OFDM UWB Systems

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ABSTRACT

The growing demand of high data rates requires much energy consumption. For this, in this paper we examine energy efficiency (EE) through total energy expenditure per bit characterization when the joint coupling between Modulation and Coding Scheme (MCS) related to the physical layer and Selective Repeat (SR) truncated Hybrid Automatic Repeat reQuest (HARQ) type I protocol of data link layer is performed into Multiband Orthogonal Frequency Division Multiplexing (MB-OFDM) Ultra-Wideband (UWB) system. The optimization is based on total energy expenditure per bit diminishing constrained by MCS rate and Packet Error Rate (PER). We propose an algorithm to identify the optimal MCS rate basing on dichotomy policy. Thus, analytical analysis highlights a closed-form expression of the optimal MCS rate allowing energy per bit minimization. In addition, in measuring the energy consumption per useful information the hardware components of MB-OFDM UWB (MB-UWB) cross-layer structure are considered. Further, the analytical framework is validated through computer results which reveal the effectiveness of our method in terms of energy saving.

KEYWORDS

Energy per bit minimization; MCS rate; HARQ; MB-OFDM; UWB.

1 INTRODUCTION

The explosive evolution of wireless technologies yields energy consumption improvement which implies environmental challenges due to carbon dioxide (CO2) generation. In that context, EE appeared as a key metric that needs more investigation. Indeed, power consumption plays an interesting role for EE improvement. In this regard, since UWB systems are recognized by the important data rates that they provide, EE should be examined.

In 2002, the Federal Communications Commission (FCC) [1] allowed a spectrum range between 3.1 GHz and 10.6 GHz for UWB system with a Power Spectrum Density (DSP) about -41.3 dBm/MHz. It was shown that MB-OFDM solution, standardized by ECMA-368 [2], is an emerging approach enabling high data rates. For this reason it was chosen as an efficient candidate for IEEE 802.15.3a channel [3]. In other side, EE wasn't well investigated toward MB-UWB systems as power is distributed identically through sub-bands. Specifically, the majority of contributions are interested in physical layer performance evaluation of the MB-UWB systems. Otherwise, herein we investigate the combination between two link adaptation approaches based on MCS of the physical layer joint with HARQ type I of the data link layer into the MB-UWB systems. It should be mentioned that few contributions discuss link adaptation into MB-UWB systems [4]. ECMA-368 proposes various data rates for MB-UWB systems without explaining the interaction between them. In other side, it should be mentioned that the combination between Automatic Repeat reQuest (ARQ) and MCS was at first the subject of the contribution in [5]. Several contributions have investigated the EE for instance in [6] where the author examined the EE in Multi-Input Multi-Output (MIMO) scenario when ARQ is applied with antenna selection. In [7] the purpose was about giving insights according to the EE of both HARQ with Chase Combining (CC) and Incremental Redundancy (IR) for Long Term Evolution (LTE) system following two cases of relaying applications namely Decode and Forward (DF) and Amplify and Forward (AF). The authors analyzed the trade-off between EE and Spectral Efficiency (SE). In [8] the goal was to characterize the EE for HARQ mechanism constrained by statistical buffering. Therefore, the authors took into consideration the effects of buffering, deadline and outage probability. The analysis proposed in [9] compared the EE between two link adaptation schemes including AMC and HARQ by using the principle of Energy Delay Trade-off (EDT) in which Channel State Information (CSI) was restricted. The contribution conducted in [10] evaluated power allocation for HARQ-IR in downlink scenario under the respect of Quality of Service (QoS). In addition EE was described in [11] through power adaptation in various Incremental Multiple Input Multiple Output (IMIMO) scenarios based on ARQ, HARQ-CC, and HARQ-IR where the purpose is to reduce the outage probability. In [12] it has been reported three optimization approaches namely energy per bit reduction, minimizing the normalization between energy per bit and SE, the trade-off between EE and SE. The proposed optimization in [13] was about energy relay determination allowing throughput maximization through dichotomy approach. Moreover, the main concern in our previous work [14] was about EE improvement by considering MCS scheme only. In [15], our purpose consisted on minimizing the energy per throughput into a cross-layer MB-UWB design. The focus pursued in this contribution is to determine the efficient MCS rate allowing energy per bit expenditure diminishing. Note that the optimization approach is based on energy per bit minimization constrained by MCS rate together with PER. A theoretical analysis was proposed for the optimal MCS rate determination basing on dichotomy policy. The analysis is performed over a cross-layer MB-UWB design based on the joint association between MCS of the physical layer and SR HARQ type I retransmission scheme relying to the data link layer. Besides, MCS approach is recognized by its effectiveness in spectral efficiency improvement. However, herein MCS rate is optimized to minimize the energy per bit. The remainder of this contribution is organized as follows. Section I presents a brief survey about MB-UWB systems. The MB-UWB cross-layer design is described in section II. Section III introduces the energy consumption model needful for energy per bit optimization. Computer results are shown in section IV where we compare our proposed approach with other solutions. At the end, we draw the conclusion in section V.

2 MB-OFDM SYSTEM DESCRIPTION

In this section, we provide an overview about the MB-OFDM proposal following the ECMA-368 standard. Thus, MB-OFDM solution consists on dividing the UWB overall spectrum through 14 sub-bands supporting data rates of [53.3 Mb/s, 80 Mb/s, 110 Mb/s, 160 Mb/s, 200 Mb/s, 320 Mb/s and 480 Mb/s]. Each sub-band includes 128 Inverse Fast Fourier Transform (IFFT) of OFDM system following 528 MHz of bandwidth. The coding process is performed with a convolutional encoder allowing other Forward Error Correction (FEC) components through puncturing. The interaction between sub-bands is ensured by a Time Frequency Code (TFC) allowing the hopping process where more details are given in [2].The UWB channel model follow IEEE 802.15.3a standard [3] where we distinguish four channel models namely CM1, CM2, CM3 and CM4 which differs by various features. CM1 model is defined following a range inferior than 4 m corresponding to Line Of Sight (LOS) model. CM2 relies to Non Line Of Sight (NLOS) model. CM3 defined into a range between 4 m and 10 m following NLOS situation. Lastly, CM4 associated to NLOS condition as well.

3 MB-UWB CROSS-LAYER DESIGN MODELING

The considered joint association between the truncated SR HARQ type I retransmission protocol and MCS mechanism into the MB-UWB system is performed following a Single Input Single Output (SISO) wireless communication system in which the transmitter and the receiver are separated according to a distance d such that the developed cross-layer design is depicted in Fig.1. The packet delivered from the data link layer accompanied with Cyclic Redundancy Check (CRC) pattern are firstly stored into an unlimited buffer and will be further divided into frames at the physical layer. Besides, each frame incorporates a number of information bit denoted by B together with Bo overhead bits which could be encoded via a convolutional encoding through different coding rates. Then, after meeting various MCS scheme where we have I transmissions modes, the frames will be delivered across the wireless channel.

3.1. MCS scheme principle

Considering the physical layer, the convenient MCS mechanism is chosen according to the channel condition where the impact of estimation's errors is not considered in our analysis. Typically, MCS selection is based on dividing the overall SNR range into I+1 small intervals denoted by [γ_i γ_{i+1}) wherein i = 0,1,…I+1, in which following the convention γ_0= 0 and γ_{i+1} = ∞. It should be noticed that MCS_i presents a rate R_i. Specifically, the MCS scheme is selected according to the instantaneous CSI which is supposed available at both the transmitter and the receiver. In addition, the returned feedback is assumed without latency and without estimation's error. Indeed, the receiver notifies the transmitter about the suitable MCS according to the received SNR which then justifies the suitable transmitted power which improves the EE.

3.2 Joint Coupling between MCS scheme and HARQ mechanism

In this subsection we explain the association between MCS scheme and SR HARQ type I retransmission protocol. Facing to fading problems HARQ retransmission protocol is required due to the reliability that they could ensure. Otherwise, MCS scheme is widely employed for throughput maximization for instance in [16]. Motivated by the reliability requirement we have applied SR HARQ type I retransmission protocol of the data link layer. According to fading problems, we have combined HARQ type I mechanism with the features of MCS scheme to improve the EE. Furthermore, HARQ scheme is based on the association between ARQ together with FEC. In fact, HARQ type I was chosen due to its hardware simplicity which doesn't require much power consumption. Particularly, if the packet is correctly received a positive acknowledgement (ACK) will be conveyed in a returned feedback. Once a packet is erroneously received a negative acknowledgement (NACK) is conveyed across a returned feedback which is assumed without latency with zero estimation's error calling for a new retransmission and presenting the same power. Note that, the retransmitted packet is similar to the discarded one. The retransmission operation is repeated until a successful reception of the erroneous packet. Beyond that thanks to truncated HARQ protocol features if the repeated retransmission of the erroneous packet reached the maximum resending number K, the packet will be rejected and outage event happens. Error detection is assumed perfectly performed by the CRC pattern. In addition, the same power is equally distributed at each retransmission attempt. Following this modeling process, if we assume a fixed length of the transmitted packet and taking into account the retransmission attempts denoted by k, the received signal could be expressed by:

$$y_l^k = x_l^k\, h_l^k + n_l^k \qquad (1)$$

Above x_l^k denotes the transmitted symbol at the l^{th} subcarrier. h_l^k stands for the channel coefficient at the k^{th} retransmission attempt. n_l^k corresponds to the noise.

4 ENERGY EFFICIENCY OPTIMIZATION

4.1 Energy consumption model

Energy expenditure measuring depends on the MB-UWB cross-layer design in which hardware structure should be considered. Especially, the energy consumption model is depicted in Fig.1.

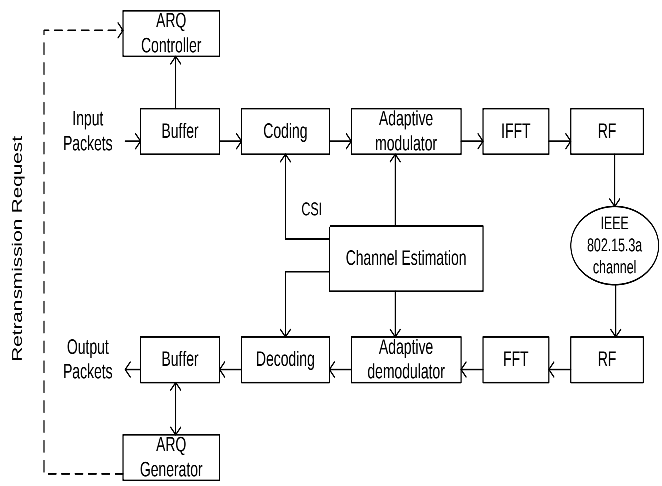

Figure 1. Energy consumption modeling.

4.2 Energy expenditure per bit minimization

EE examination demands several features investigation like PER and MCS rate. For this, the aim of the optimization approach is to investigate MCS rate impacts on energy expenditure per bit minimization under the respect of PER. Interestingly, total energy consumption per bit diminishing provides EE improvement. Thus, the optimization issue of determining the optimal MCS rate enabling energy expenditure diminishing can be represented by:

$$R^* = \underset{R(\varepsilon_0)}{\arg\min}\, E_a \quad (2)$$

Above Ea denotes total energy consumption per bit. R (bit/sym) stands for MCS rate. Henceforth ε_0 refers to PER. Correspondingly, the achievable MCS rate selection is denoted by Ri which fundamentally depends on the CSI. Thus, after the repeated retransmission attempts the overall energy consumed per bit could be quantized by:

$$E_a = \frac{\eta}{(1-\varepsilon_0)} \cdot \left(\frac{L}{L+L_0}\right) \cdot \left(\frac{1+\alpha}{R}\right) \cdot \left(\frac{L+L_0}{L} . f(R,\varepsilon_0)A + B\right) \quad (3)$$

being:

$$A = \frac{\zeta_M N_0 G_d}{\mu}, B = \frac{\beta}{R_b}, R = r.\log_2 M \quad (4)$$

$$\eta = \frac{1}{(1-\varepsilon_0)} \quad (5)$$

Above r is the coding rate and M corresponds to MCS level. η is the retransmission average defined in [17] since the optimization is based on SR HARQ type I retransmission protocol. $G_d = G_l\, d^{\mu}\, M_l$ [18] quantifies the power gain in which G_l stands for the gain factor at d = 1m. M_l compensates the variability due to hardware process. N_0 stands for the noise density. β corresponds to the effects of baseband processing. L accounts the number of uncoded bit. L_0 denotes the overhead bits. α stands to the filter roll-off factor. μ is the drain efficiency of the amplifier. $R_b = \tau . R$ denotes the information rate in net shape in which τ accounts the bit information per packet length. ζ_M accounts the Peak to Average Power Ratio (PAPR). Moreover, for sake of simplicity we adopt the PER formula derived in [5] as:

$$\varepsilon_0(\gamma) = \begin{cases} 1, & 0 < \gamma < \gamma_i \\ a_i . \exp(-b_i * \gamma), & \gamma \geq \gamma_i \end{cases} \quad (6)$$

Note that a_i and b_i could be identified through curve-fitting method where γ_i relies to SNR threshold level such that $\{\gamma_i\}_{i=0}^{I+1}$ tabulated in Table I. In other side, $f(R,\varepsilon_0)$ corresponds to the smallest Signal to Noise Ratio (SNR) value identifying the PER corresponding to a specific MCS rate.

Due to E_a convexity ($\frac{d^2E_a}{dR^2} \leq 0$), the optimization challenge could be solved by setting $\frac{dE_a}{dR} = 0$ which implies

$$\frac{d}{dR}\left(\frac{1}{(1-\varepsilon_0)^2} \cdot \left(\frac{L}{L+L_0}\right) \cdot \left(\frac{1+\alpha}{R}\right) \cdot \left(\frac{L+L_0}{L} . f(R,\varepsilon_0)A + B\right)\right) 0 \quad (7)$$

Table 1. MCS FEATURES

MCS level	Data rate (Mb/s)	Coding rate (r)	Mapping (M)	a_i	b_i	γ_i (dB)
1	53.3	1/3	4	0.69	0.212	-2.23
2	80	1/2	4	0.56	0.044	-5.44
3	110	11/32	4	0.63	0.17	-2.72
4	160	1/2	4	0.66	0.31	-1.74
5	200	5/8	4	0.70	0.49	-0.98
6	320	1/2	4	0.65	0.49	-1.09
7	400	5/8	4	0.68	0.78	-0.35
8	480	3/4	4	0.69	1.34	0.42
9	800	3/4	16	0.66	1.29	0.39
10	960	1/2	16	0.67	2.32	1.24

By this way we write:

$$\frac{1}{(1-\varepsilon_0)^2}.\left(\frac{L}{L+L_0}\right)\left(-\left(\frac{1+\alpha}{R^2}\right).\left(\frac{L+L_0}{L}.f(R,\varepsilon_0)A+B\right)+\left(\frac{1+\alpha}{R}\right).\left(\frac{L+L_0}{L}.\frac{df(R,\varepsilon_0)}{dR}A-B\right)\right)=0 \quad (8)$$

After that, if we denote by SNRc a constant value of SNR which could be expressed in function of MCS rate and PER ε_0 as follows:

$$f(R,\varepsilon_0) = SNR_c \quad (9)$$

where f is the function related to PER ε_0 and MCS rate R. Thus (8) could be rewritten as:

$$\left(-\left(\frac{1+\alpha}{R^2}\right).\left(\frac{L+L_0}{L}.SNR_c.A+B\right)+\left(\frac{1+\alpha}{R}\right).\left(\frac{L+L_0}{L}.\frac{df(R,\varepsilon_0)}{dR}A-B\right)\right)= \quad (10)$$

Secondly, we denote respectively by SNR_o and R_o the values of SNR and R related to the previous MCS scheme where we have:

$$K_1 = \frac{L+L_0}{L}.SNR_c.A\ ,\ B=\frac{\beta}{kR}\ ,\ \frac{df(R,\varepsilon_0)}{dR} = \frac{SNR_c-SNR_o}{R-R_o} \quad (11)$$

Which leads that (10) could be expressed as:

$$K_1+\frac{\beta R}{k}+\frac{k}{\beta R} = R\frac{L+L_0}{L}.\frac{SNR_c-SNR_o}{R-R_o}A \quad (12)$$

Yields:

$$G(R)=\left|k_1+\frac{\beta R}{k}+\frac{k}{\beta R}-R\frac{L+L_0}{L}.\frac{SNR_c-SNR_o}{R-R_o}A\right| \quad (13)$$

In other side, we remark that if G(R) =0, the obtained MCS rate R_i mayn't be included into the set of MCS rate $\mathcal{R}$. For this reason we highlight further the proposed algorithm which follows these steps:

Optimal MCS Rate Algorithm

1. We define the set of MCS rate following Table 1 as below

$$\mathcal{R} = r.\log_2 M = \{\tfrac{2}{3},1,\tfrac{22}{32},1,\tfrac{5}{4},1,\tfrac{5}{4},\tfrac{3}{2},3,2\}$$

2. We solve $G(R)=0$ by bisection method to find $R^* = R$.
3. As we seen, maybe the obtained R^* is not available in $\mathcal{R}$, so we need to find R^* which should be located between R_i and R_{i+1} such that $R_i \le R^* \le R_{i+1}$.
4. We compute $G(R_i)$ and $G(R_{i+1})$.
5. If $G(R_i) < G(R_{i+1})$ then $R^* = R_i$ otherwise $R^* = R_{i+1}$.
6. Output of algorithm is R^* that we find it.

5 PERFORMANCE ANALYSIS

Numerical results are performed into the MB-UWB systems following the ECMA-368 standard according to the first three sub-bands. Indeed simulations results are carried out over CM1 IEEE 802.15.3a channel model. In addition for simplicity reasons we adopt the features of the energy consumption model defined in [18] such that M_l = 40 dB, G_l = 30 dB, μ = 3.5, $N_0/2$ = -174 dBm/Hz. In addition, B = 1024 bytes and the other parameters are defined as [12] such that $R_b = 300$ kb/s and B_0= 48. Additionally, we exploit the MCS parameters reported in Table I with a CRC-32 component. The maximum number of retransmission attempts is K = 2 with a target PER = 10^{-5}. Hence, the proposed algorithm for the most energy efficient MCS guaranteeing energy per bit minimization is validated in Fig.2 in which we compare the results of the energy consumption per bit relied to the optimal MCS rate with other MCS schemes when ε_0 varies between 10^{-1} and 10^{-6}. Otherwise, the energy per bit is simulated for various combination of MCS with HARQ type I.

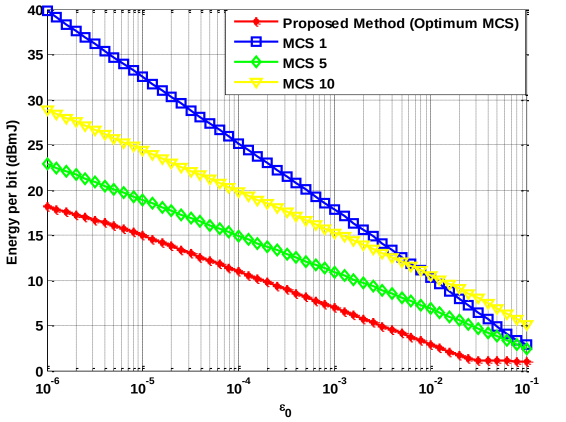

Figure 2. Total energy consumption per bit of the proposed method compared with other MCS scheme at different values of ε_0.

Secondly, we compare the effectiveness of our approach versus other applied methods in Fig.3.

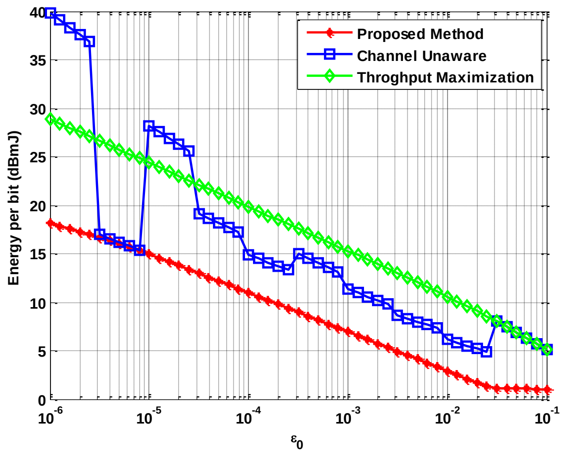

Figure 3. Energy consumption per bit comparison results between our solution and other methods.

We deduce from the obtained results that our proposed approach based on the appropriate choice of MCS rate is a prominent solution for improving the EE through energy per bit diminishing since the solution proposed in [19] determines each MCS's throughput to decide about the optimal one related to channel's parameters. In other hand, the proposed algorithm in [20] is about identifying the best MCS scheme in terms of throughput maximization for each user. However, we remark from the obtained results that this is not the best since it doesn't ensure energy per bit diminishing. By this way, we conclude that our method is a prominent approach following the significant minimization of energy per bit which is the requirement of EE.

6 CONCLUSION

Following the great improvement of wireless applications, energy consumption management has become an important criterion that needs much investigation. In this context, the developed cross-layer MB-UWB design based on the joint combination between MCS scheme of the physical layer and HARQ type I retransmission protocol appears as a solution to evaluate the EE. Therefore, based on energy per bit minimization purpose constrained by PER, we have developed an algorithm allowing optimal MCS rate determination by employing dichotomy proposal. Thereby, MCS approach capabilities exploitation is shown as a powerful approach to fulfill the cross-layer MB-UWB design EE improvement. The optimization is based on energy per bit diminishing under the respect of MCS rate depending on the PER. Theoretical analysis is validated through computer results which reveal the effectiveness of the proposed algorithm in terms of energy expenditure diminishing. Further contributions should consider the delay towards the returned request. In addition, estimation's errors should be included in the optimization issue.

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