

Energy Efficiency Investigation for the MB-OFDM UWB Cross-Layer Design

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Abstract Green communication has become the main concern of many researchers according to the quick evolution of wireless communication applications. For this, in this correspondence we develop a cross-layer framework based on the joint association between Modulation and Coding Scheme together with truncated Selective Repeat Hybrid Automatic Repeat Request type I to examine the global energy consumption per bit of Multiband Orthogonal Frequency Division Multiplexing Ultra Wideband (MB-OFDM UWB) systems. Indeed, we examine a theoretical analysis based on throughput performance investigation when mode selection is performed which is dynamically selected following the Channel State Information. Next, we prove that cross-layer design outperforms the mode selection behavior in terms of outage probability. Then, based on the features of cross-layer MB-OFDM UWB (MB-UWB) design a theoretical framework is derived in terms of Packet Error Rate and overall energy expenditure per bit. Specifically, the closed form relation of energy per bit is determined by exploiting the proprieties of the two link adaptation tools. Correspondingly, since the purpose behind cross-layer design adoption into MB-UWB system is EE improvement, we have compared the impact of different M-QAM modulations into energy consumption per useful bit at various range of distances. The obtained results reveal that cross-layer design is a powerful solution in terms of EE enhancement.

Keywords Energy efficiency · Cross-layer design · Mode selection · Energy consumption per bit

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1 Introduction

Recently, EE requires much attention due to huge explosion of wireless devices which consumes more power. Specifically, energy saving has received significant interest since several efforts are seeking for a new ways to diminish the carbon dioxide generation (CO₂). Therefore, the quick rise of device applications provides 2% of CO₂ generation [1] involving environmental challenges. In particular, energy expenditure minimization is the most important metric that needs great attention in green radio.

In this regard, UWB system appears as a potential candidate offering considerable high data rate under low energy consumption but further investigation is required. Nevertheless, UWB systems provides a spectrum varying from 3.1 GHz to 10.6 GHz with a Power Spectral Density (PSD) of -41,3 dBm/MHz due to the Federal Communications Commission (FCC) in 2002 [2] to overcome the interference with other technologies. Additionally, to satisfy the high data rates for Wireless Personnel Applications (WPAN) [3], the Institute of Electrical and Electronics Engineers (IEEE) introduces the 802.15.3a model [4] which is adapted with MB-OFDM solution. Besides, MB-OFDM proposal was standardized by ECMA-368 [5] as the multiple access technique proposed for IEEE 802.15.3a UWB channel model. Additionally, the MB-OFDM approach was chosen due to its flexibility and ability to ensure high data rates.

Besides, previous contributions haven't given great interest to EE investigation into MB-UWB systems since power is distributed similarly across sub-bands. In addition, most contributions have focused on physical layer applications of MB-UWB systems. Moreover, most of the papers were interested in exploiting the cross-layer structure based on the conjunction between physical layer through MCS scheme and data link layer via HARQ mechanism for spectral efficiency improvement. Specifically the ECMA-368 standardizes MB-UWB system following a given set of data rates without explaining how the rates should be selected.

However, few contributions were devoted in green technology investigation in other scenarios for instance cross-layer design application. In [6] the authors have proposed the Context Aware Scheduling (CAS) algorithm for 5G scenario allowing energy saving. Whereas, in [7] it has been shown a cross-layer design investigation for EE optimization into a sensor network topology. *Cui and Goldsmith* in [8] proposed an energy consumption model where M-QAM and M-FSK modulations optimization were considered under the constraint of transmission time.

The work conducted in [9] has studied the EE by considering the metric of energy consumption per bit of information minimization when HARQ was applied taking into account the quality of service (QoS). The author in [10] has analyzed power minimization under the constraint of outage probability when HARQ scheme was established. The idea was about optimal power allocation towards Rayleigh fading channel under the respect of outage probability related to HARQ scheme. Our work in [11] has addressed the tradeoff between EE and spectral efficiency investigation towards the physical layer of MB-UWB systems. The authors in [12] have applied MCS scheme only for EE improvement into MB-UWB systems. The work of Liu et al. in [13] has shown the efficiency of the joint coupling between MCS and Automatic Repeat Request (ARQ) protocol to maximize the spectral efficiency without analyzing the EE.

A tradeoff analysis between spectral efficiency and EE was identified in [14] wherein the purpose was to investigate three schemes based on EE maximization, energy per bit minimization and EE maximization under the respect of spectral efficiency minimization.

In [15] the purpose was to apply a power allocation algorithm when HARQ with incremental redundancy (IR) was employed in downlink cellular network scenario assuming Channel State Information (CSI) availability. The work in [16] has examined the EE through power allocation in Multiple Input Multiple Output (MIMO) scenario when HARQ with Chase Combining (CC) and with IR were incorporated. Moreover, the challenge of EE into HARQ with CC over Rayleigh channel subject to outage probability was discussed in [17]. The research conducted in [18] has outlined energy adaptation into UWB sensing scenario where the purpose was to enhance both the detection time together with range coverage.

This correspondence addresses the combination between MCS scheme and HARQ retransmission protocol into MB-UWB system. In that context, the joint coupling between physical layer and data link layer are established to ameliorate the EE by reducing the global energy consumed per bit. In fact, we selected SR truncated HARQ type I to examine the EE of the MB-UWB cross-layer system according to its ability into power diminishing in communication devices. Furthermore, to overcome the issue of failed received packets, we exploit the retransmission mechanism provided by ARQ/HARQ protocols which improves the performance of MB-UWB systems. Indeed, we focus mainly on diminishing the total energy expenditure per bit which enables EE enhancement. Hence, we are concerned on exploiting the features of Adaptive Modulation and Coding (AMC) mechanism to adapt the transmitted power depending on the channel condition. Additionally, we exploit the benefit of HARQ protocol as a link adaptation technique achieving transmission reliability.

It should be noticed that our work differs from [8] since we consider HARQ mechanism in our cross-layer design. On the other hand, the theoretical analysis is evaluated in terms of throughput, PER and outage probability. Therein, we derive a theoretical framework examining the overall consumed energy per useful bit based on the energy consumption model of *Cui and Goldsmith* [8] which doesn't consider the retransmission request. Thus, the main idea is to compare the EE of various MCS levels at different distances regarding a fixed retransmission number.

The remainder of this contribution is structured following. Section 1 presents a brief description of the MB-OFDM solution over UWB channel. Next, Sect. 2 highlights the preliminaries related to the MB-UWB system incorporating MCS scheme and HARQ retransmission protocol. Section 3 examines the theoretical analysis of the cross-layer MB-UWB system related to throughput evaluation, PER and outage probability. Energy efficiency analysis is presented in Sect. 4 which depends on energy consumption model. Numerical results are drawn in Sect. 5. Finally, we conclude the paper in Sect. 6.

2 Overview of MB-UWB System

2.1 MB-OFDM Proposal Description

In this section, we present a brief overview about the MB-OFDM systems standardized by ECMA-368 [5]. Specifically, the MB-OFDM scheme exploits the UWB spectrum by dividing it following 14 sub-bands having a 528 MHz. Each sub-band exploits OFDM symbols which consists of 128 subcarriers. We find 122 subcarriers to carry power. In addition, 100 subcarriers are dedicated to carrying the information data. Other 12 subcarriers are dedicated for pilot symbols and the remainder is exploited for guard tones. The

supported data rates vary between 53.3 and 480 Mb/s [5] wherein QPSK modulation is applied. Furthermore, for the data rates ranging from 53.3 to 200 Mb/s a Time Domain Spreading (TDS) component is applied which consists of transmitting the same information over two consecutive OFDM symbols. On the other side, Frequency Domain Spreading (FDS) is employed by the data rates of 53.3 and 80 Mb/s based on transmitting the information and its conjugate into the same OFDM symbol providing frequency diversity. The generated data, as depicted in Fig. 1, are encoded by a convolutional encoder with $[133_g, 165_g, 171_g]$ of polynomials generators and $R = 1/3$ of coding rate [5]. This last, allows obtaining other coding rates through puncturing.

After interleaving task the data are modulated with QPSK constellation. Then, we have framing management consisting on guard symbols insertion with pilot sub-carriers. Moreover, a zero padding component with 37 of length and 60.61 ns of duration [5] is added to overcome problems of Inter-Symbol Interferences (ISI). Otherwise, the hopping process over sub-bands is performed by the Time Frequency Code (TFC) pattern achieving temporal and frequency diversity where various types are introduced in [5].

2.2 UWB Channel Model

The IEEE 802.15.3a UWB channel model dedicated for short range indoor applications is based on the Saleh-Valenzuela model defined in [19]. The IEEE 802.15.3a channel is described following four models (CM1, CM2, CM3, and CM4). In fact, CM1 model corresponding to a Line Of Sight (LOS) scenario is defined following a distance lower than 4 m. Then, CM2 relied to Non Line Of Sight (NLOS) situation. In addition, CM3 modeling is based on a distance varying from 4 to 10 m corresponding to NLOS condition. At the end, CM4 model corresponding to NLOS context. Hence, the overall characteristics of the IEEE 802.15.3a UWB channel model are depicted in Table 1 [4].

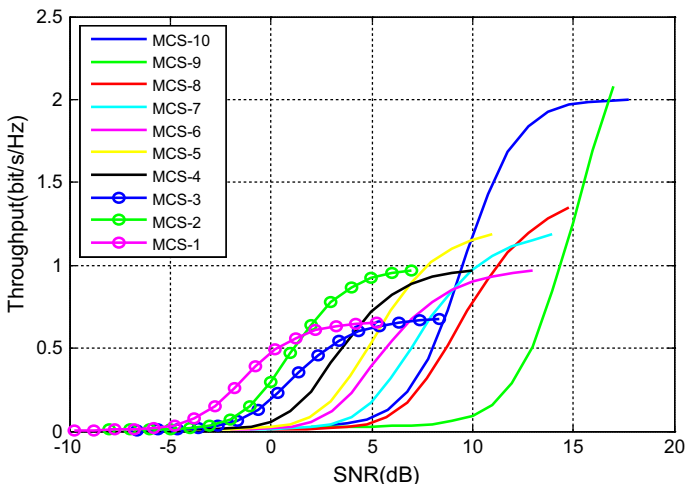


Fig. 1 Throughput performance results over CM 1

Table 1 UWB channel models parameters [4]

	CM1	CM2	CM3	CM4
Mean excess delay (ns)	5.05	10.38	14.18	
RMS delay spread	5.28	8.03	14.28	25
Distance (m)	<4	<4	4–10	10
LOS/NLOS	LOS	NLOS	NLOS	NLOS

3 Preliminaries

We consider a cross-layer design for MB-UWB system based on two link adaptation tools based on MCS scheme joint with SR HARQ type I retransmission protocol applied to examine the EE. We describe each scheme separately afterwards.

3.1 System Model

We consider a single input single output (SISO) point to point wireless communication system where the received signal Y_n is expressed as:

$$Y_n = H_n S_n + N_e \quad (1)$$

Note that H_n is the channel gain at the n th subcarrier. S_n is the transmitted signal in subcarrier n . N_e denotes the noise.

3.2 Mode Selection Scenario

Herein we introduce the MB-UWB system when mode selection is integrated. In fact, MCS approach has been recognized in several contributions as a powerful solution in order to provide significant spectral efficiency enhancement [20]. Therefore, the constellation level selection decision depends on the instantaneous CSI which is conducted through a feedback channel. Besides, the MCS scheme is chosen by partitioning the SNR values denoted by γ into narrow intervals $[\gamma_n, \gamma_{n+1}]$ where n stands for the AMC rank varying between 0 to N in where N relies to the number of the considered MCS scheme. Besides, active selection mode n is due to the SNR's interval falling in $[\gamma_n, \gamma_{n+1}]$. However, once the SNR corresponds to $[\gamma_0, \gamma_1]$ outage is detected. In addition, given the assumption of CSI at both transmitter and receiver, mode selection could be easily performed. Besides, MCS switching is allowed by the returned CSI which adapts the transmitted power following the channel behavior. Our analysis is based on the assumption of absence of both delay and estimation error.

Mode switching depends on the returned instantaneous SNR which is related to the features of UWB channel varying slowly through time and frequency selective. By this way, the transmitted power could be better adapted. In this regard, whenever the channel situation is weak, the transmitted energy is minimized. However, whenever the channel situation is good we obtain much transmitted power. Nevertheless, whenever the transmission is possible SNR should verify:

$$\gamma_n > \gamma_0 \quad (2)$$

Above γ_0 accounts the SNR threshold. The transmitter adapts the transmitted power together with the constellation size according to the channel situation assumed know at

both the transmitter and the receiver which reminds the water-filling principle applied in time over frequency selective channels [20]. Specifically, the considered MCS features are tabulated in Table 2.

3.3 Mode Selection Throughput Analysis

In this section we define the achievable throughput of MB-UWB systems using mode selection as [21]:

$$\tau(\gamma) = r \log_2(M) (1 - P(\gamma)) \tag{3}$$

Being:

- $\tau(\gamma)$ accounts the throughput measured in bit/s/Hz at each instantaneous received SNR (γ).
- r is the coding rate.
- M stands for the constellation size.
- $P(\gamma)$ denotes the PER which could be expresses as [13]:

$$P(\gamma) = \begin{cases} 1 & \text{if } \gamma < \gamma_n \\ a_n \exp(-b_n \gamma) & \gamma \geq \gamma_n \end{cases} \tag{4}$$

Above a_n and b_n are related to the selected mode which are defined following Table 3.

Each selected mode presents its own throughput which depends on the instantaneous reversed SNR γ . Nevertheless, we display in Figs. 1 and 2 the throughput results of MB-UWB applying MCS scheme performed respectively over CM1 and CM4 channel models using (2) taking into account the hopping process performed by TFC pattern following a PER target $P_0 = 10^{-5}$ where the set of MCS values depicted in Table 3 whereby the other features of MB-UWB system are defined following ECMA-368 [5]:

The obtained results highlight that the throughput performance were degraded when CM4 channel model is exploited as the distance separating the transmitter and the receiver is important compared to CM1 model. Besides, if the distance between the transmitter and the receiver is high we could obtain a significant latency. Particularly, the throughput diminishes when we employ high data rates, in particular, MCS-7 corresponding to 400 Mb/s following the importance of PER. In other side, regarding the results of MCS-9 we

Table 2 Mode selection characteristics

MCS index	Data rate	Coding rate (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	800	3/4	16
10	960	1/2	16

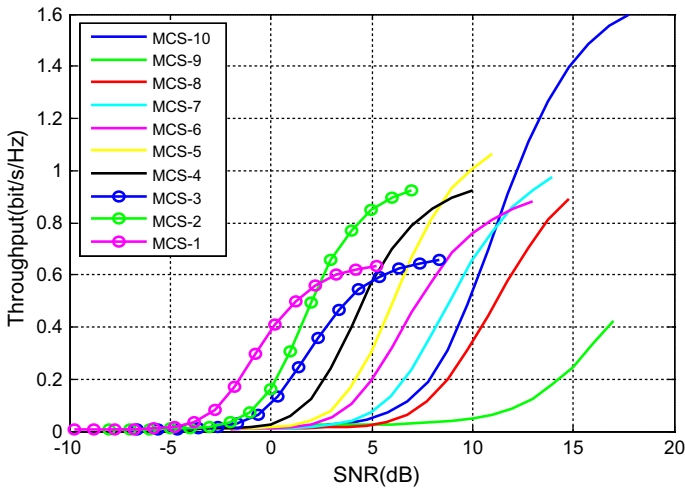


Fig. 2 Throughput performance results over CM 4

Table 3 Simulation parameters are obtained by simulation with curve fitting

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

remark that 16-QAM constellation is not adapted with CM4. Therefore, we obtain similar results when we employ low data rates as 53.3 and 80 Mb/s at CM1 and CM4 channel models. In this context, as a consequence we choose CM1 UWB channel model for the next results of performance evaluation.

In Fig. 3 we illustrate the MB-UWB system performance results when MCS approach is considered following CM1 model showing Bit Error Rate (BER) versus SNR with a target $BER = 10^{-5}$.

We remark from the obtained results that at low ranges of SNR, the low data rates of {53.3, 80 and 200 Mb/s} show their efficiency due to the TDS spreading component application allowing temporal diversity. Otherwise, for high values of SNR the other data rates of {320, 400, 480, 800 and 960 Mb/s} are more powerful.

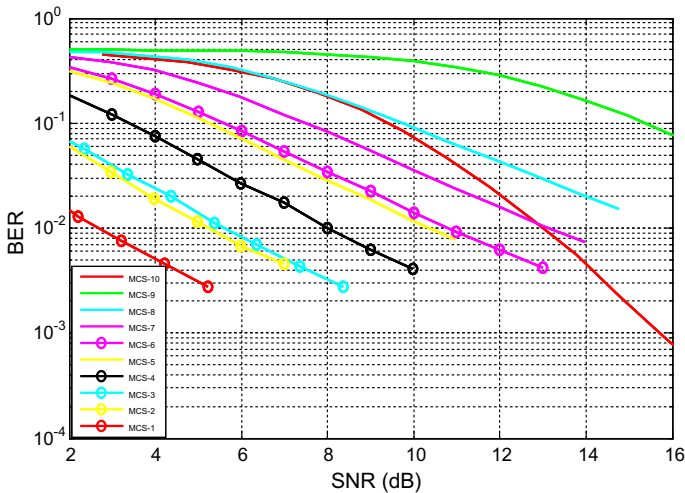


Fig. 3 BER versus SNR performance results

3.4 HARQ Type I

Facing to fading problems, HARQ protocols was adopted to ensure reliability. Therefore, since wireless channel is susceptible to fading problems HARQ scheme is the best way to ensure reliability of transmission. In addition, the transmission over wireless channel could be better improved when the joint coupling between MCS approach and HARQ scheme is established. HARQ proposal is the result of a combination between ARQ mechanism and FEC component. Note that a SR HARQ type I retransmission protocol is employed such that whenever a packet is erroneously received a retransmission request at the data link layer is activated.

It should be noticed that HARQ type I was chosen relied to its simplicity and low requirement of energy consumption. In particular, the feedback relied to HARQ scheme differs from the one conveying CSI required for MCS mechanism.

3.5 Joint Combination Between MCS and HARQ Type I

MB-UWB systems employing MCS mechanism is influenced by multipath problems even the features of modulation and coding. In this context, HARQ type I protocol is employed to overcome multipath problems. We pursue our analysis assuming CSI available at both transmitter and receiver.

Nevertheless, among the characteristics of HARQ type I mechanism is that the retransmitted packet is similar to the transmitted one. Therefore, the unsuccessfully received packet will be discarded without buffering. Besides, the cross-layer MB-UWB system depicted in Fig. 4 combines the benefits of MCS mechanism in terms of power accommodation together with the reliability of HARQ protocol since the wireless channel is subject to noise issues and interferences. Furthermore, the cross-layer MB-UWB system modeling is based on two other scenarios. Firstly, mode selection is responsible for adjusting the transmitted power following the instantaneous CSI variation. Then, data link layer via HARQ protocol ensures reliability of the transmitted data with the help of the

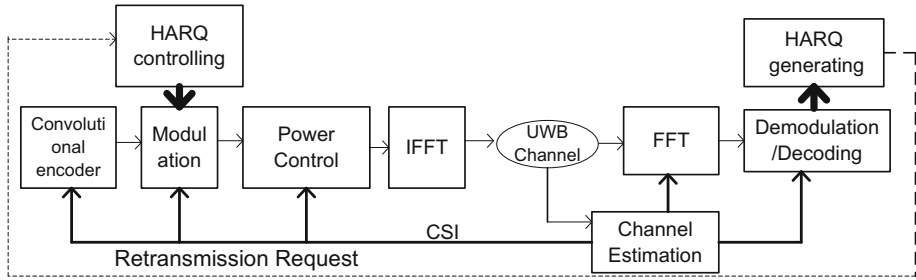


Fig. 4 System model

returned request when the decoding operation fails. Otherwise, we follow the combinatorial association defined in [13]. HARQ mechanism is based on a coupling between FEC component and ARQ scheme to enhance the transmission reliability. Nevertheless, the cross-layer design is operating as follows. The delivered packet from the data link layer will be divided towards frames which are adapted to the physical layer components. The frame form of the physical layer is composed of different packet which include payload and Cyclic Redundancy Check (CRC) error detection pattern. Consequently, the cross-layer design is established assuming:

- Availability of CSI at both transmitter and receiver.
- At each retransmission round, the transmitted symbol shows similar amount of power.
- We neglect the delay and the estimation’s errors.
- The channel varies from frame to other but it is assumed in invariant status at a retransmission attempt.
- The CRC processing is perfectly done.
- We employ the same MCS at each retransmission round.

In reception, after decoding process accomplishment, error detection is established through a CRC component. Further, the bits obtained from the Viterbi decoder will be converted into a packet that will be sent further to the data link layer.

Otherwise, the retransmission call is returned to the transmitter through a separate feedback channel. Besides, whenever the packet is successfully decoded a positive acknowledgment (ACK) will be send to the transmitter following a short time in comparison to the delivered one. However, if the MB-UWB packet is faulty received a negative acknowledgment (NACK) will be fed back and a retransmission request is declared. Therefore, if the maximum number of retransmission is reached the packet will be dismissed and the other packet will be delivered. Besides, the receiver returns continuously the wrong packet until the achievement of maximum number of retransmission or the decoding process is performed successfully. Once the packet keeps erroneous status after the maximum number of retransmission $K = 2$, we obtain a packet loss. Hence, outage probability is obtained when the decoding process fails particularly if the channel situation is bad. We note the target PER by P_0 , once the packet is erroneously received after a maximum number of retransmission K the packet loss probability of the MB-UWB cross-layer design denoted by P_1 should follow this condition:

$$P_1 \leq P_0^{K+1} \tag{5}$$

4 Analytical Analysis of the Cross-Layer MB-UWB System

4.1 Throughput Evaluation

In this subsection we derive the achievable throughput expression of the developed cross-layer MB-UWB system. To determine the throughput of the proposed cross-layer MB-UWB design we define the average number of retransmission \bar{N} as [22]:

$$\bar{N} = \frac{1}{1 - P} \tag{6}$$

Above P accounts the PER. Next, if we consider the throughput of mode selection defined in (2) and according to HARQ mechanism association, each packet will be delivered following the average retransmission \bar{N} . This implies that the throughput Th of the cross-layer MB-UWB design could be quantified according to the author in [22] as:

$$Th(\gamma) = \frac{\tau(\gamma)}{\bar{N}} \tag{7}$$

The throughput of the MB-UWB cross-layer design could be represented in Fig. 5 using (6) over channel model CM1 following a target PER $P_0 = 10^{-5}$ where the maximum number of retransmission is $K = 2$ and exploiting the MCS features reported in Table 3 with WiMedia parameters given in [5].

The obtained results display the impact of the retransmission number in the throughput performance of the cross-layer MB-UWB system. We remark that the throughput decreases compared to the illustrated results in Fig. 1 as once retransmission occurs, the throughput will be minimized. Note that the diminishing in throughput simulations results relied to spent time in retransmission. In the case of bad channel status, SNR shows lower values which increases the retransmission of information.

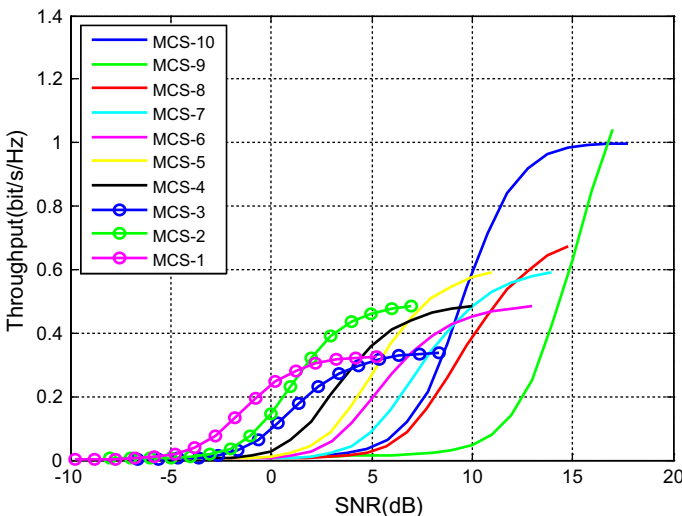


Fig. 5 Throughput performance results versus SNR of the cross-layer MB-UWB system

4.2 Packet Error Rate Investigation

In this section, we examine the theoretical framework of the MB-UWB cross-layer approach in terms of packet error rate (PER). Hence, as we are employing Viterbi decoder with hard decision property, errors can't be independent. Following the contribution in [23] the PER P of the cross-layer structure is upper bounded by:

$$P \leq 1 - (1 - P_e)^L \tag{8}$$

Above L corresponds to the packet size and P_e stands for the probability of error expressed by [21]:

$$P_e < \sum_{d=d_f}^{\infty} a_d f(d) P_e(d) \tag{9}$$

where:

- a_d represents the global number of occurring errors having d of weight.
- d_f related to the free distance of the convolutional encoder.
- $f(d)$ corresponds to the amount of bits errors caused by incorrect choice of the path.
- $P_e(d)$ quantifies the probability of wrong path selection following a distance d from the correct one.

Then, in Fig. 6 we illustrate the performance results of $PER = f(SNR)$ for the MB-UWB cross-layer system through CM1 UWB channel model. Therefore, we examine the MB-UWB cross-layer design performance results in terms of PER wherein we consider 100 channel realizations for simulation computing. We consider 500 as a number of packets following a target $PER < 8\%$.

The obtained results show that MCS-1 employing QPSK modulation and 1/3 coding rate presents the lower PER according to TDS and FDS incorporating components allowing frequency and temporal diversity providing environmental problems mitigating. Moreover MCS-9 and MCS-10 corresponding respectively to the data rates of 800 Mb/s

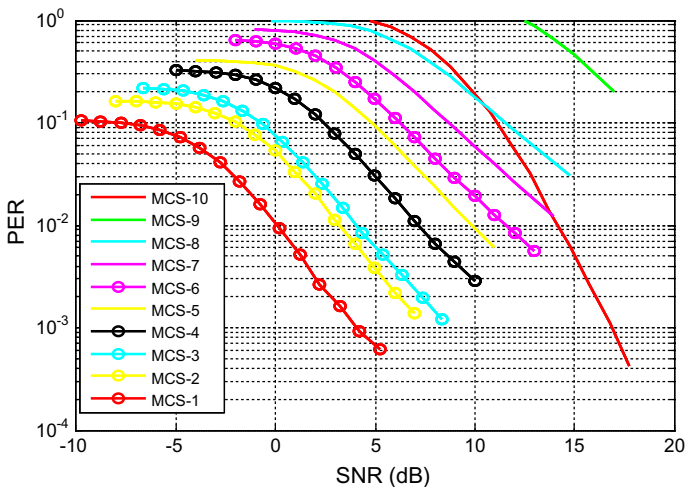


Fig. 6 PER performance results of the MB-UWB cross-layer design

and 960 Mb/s increase the PER of the overall system despite the throughput enhancement illustrated previously. Thus, the PER performance results depend on the constellation size. We disclose that whenever the SNR is increasing, PER decreases which is due to the massive number of packet received.

4.3 Outage Probability

Herein we examine the outage probability features of the cross-layer MB-UWB design. Indeed, outage probability can be obtained whenever the Viterbi decoder couldn't achieve the decoding process after the number K of retransmissions where $K = 2$ particularly when the channel status are weak. Otherwise, outage probability corresponds to the probability of unsuccessful decoding process at the reception. Nevertheless, the outage probability P_{out} corresponds to the probability with no transmission which is achieved when the system couldn't be active at a given transmission rate denoted by R expressed in bit/s/Hz which is derived as follows [16]:

$$P_{out} = \Pr\{I_k < R\} = \Pr\left\{\sum_{k=1}^K \log_2\left(1 + P_r * \frac{|h_k|^2}{N_0}\right) < R\right\} \tag{10}$$

Above P_r stands for the received power and I_k accounts the mutual information. h_k denotes the channel impulse response according to the k th HARQ round. N_0 represents the PSD. Moreover, we illustrate in Fig. 7 the outage probability of the MB-UWB system considering mode selection only and when cross-layer design is done.

We remark from the plotted results that HARQ scheme minimizes outage probability at the expense of the throughput following the retransmission rounds. However MCS selection proposal suffers more from drop events. In addition, the illustrated results show the efficiency of the retransmission protocols since outage probability decreases once HARQ-I is applied. Correspondingly, the MB-UWB cross-layer design outperforms the MB-UWB with mode selection incorporation only since the outage probability was

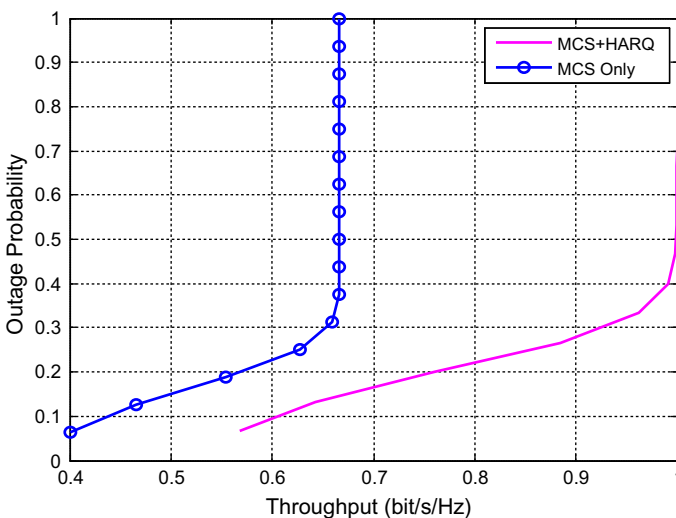


Fig. 7 Outage probability comparison results

reduced. Consequently, we conclude that even mode switching scheme offers spectral efficiency improvement which is an interesting advantage, it shows a penalty plotted in Fig. 7 illustrating more occurrence of outage probability. In addition, the MCS feedback needs more energy than the HARQ mechanism.

Consequently, the reliability offered by HARQ protocol into MB-UWB systems toward transmission drop reduction is accompanied with a penalty related to throughput diminishing.

5 Energy Efficiency Analysis and Problem Formulation

The developed cross-layer MB-UWB system is examined in terms of total energy consumption per bit of information. In other words, we evaluate the energy consumption per bit reduction allowing a powerful Quality of Service (QoS) across wireless channels. Since we focus in EE improvement related to total energy expenditure reduction, we require an accurate energy consumption model.

Energy expenditure per bit reduction into MB-UWB cross-layer system should take into account all power consumed by the electronic components. In particular, we are interested in the power consumed by the radio frequency (RF) components. Specifically, the energy consumption model includes both the energy consumed at the transmission and by the circuit components. Consequently, the data at the output of IFFT are converted to analog behavior by the Digital to Analog Converter (DAC). Next, the converted signal after meeting the channel conditions is filtered to be amplified through the Low Noise Amplifier (LNA). Intuitively, in the receiver side, the signal after Analog to Digital Converter (ADC) will be treated by the FFT block.

It should be noticed that the idle operation mode of energy expenditure is not considered in our examination since it doesn't need much power consumption. We consider in our examination the energy consumption model shown in Fig. 8.

5.1 Energy Consumption Model

The problem modelling could be explained in considering that the MB-UWB transmitter provides a given packet composed of L bits to a destination according to a distance d . Energy expenditure model identification is based on MB-UWB packet retransmission and transmission with circuit energy at both the transmitter and the receiver. Furthermore, the

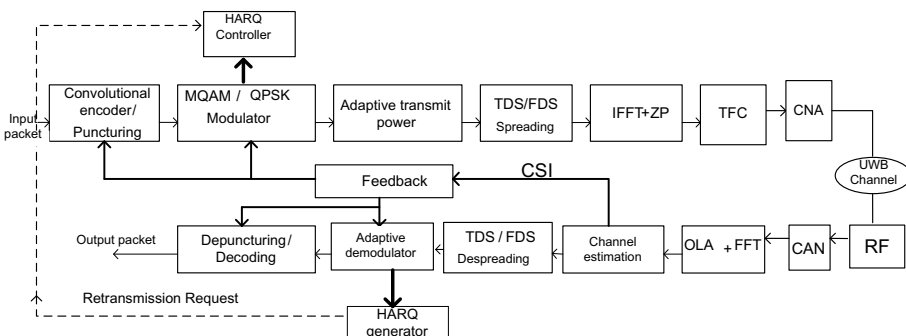


Fig. 8 Cross-layer MB-UWB structure with RF components

MB-UWB channel hardware modelling is depicted in Fig. 8 where the data in the IFFT block output are converted with the help of the digital to analog converter (DAC) to obtain analog signal that after crossing the channel status is filtered, and then amplified with the help of the Low Noise Amplifier (LNA). After that, at the reception the amplified signal will be further transformed towards a digital one with the Analog to Digital Converter (ADC) block representing the FFT block input.

Since our goal is to minimize the consumed energy into the transmission link, we need an accurate energy consumption model. Motivated by the energy consumption model presented in [8] we have three operational modes defined following:

- E_t accounts for the operational transmission mode providing transmitting or receiving data information.
- E_s relies to the transient status presenting a transition from active process to idle mode.
- E_{tr} stands for the relaxing mode which allows power saving as it corresponds to a lack of transmission.

Consequently, the overall consumed energy E could be derived as:

$$\begin{aligned}
 E &= E_t + E_s + E_{tr} \\
 &= P_e T_t + P_s T_s + P_{tr} T_{tr}
 \end{aligned}
 \tag{11}$$

Being P_e includes the transmitted power requiring a transmission time T_t accompanied with the circuit power at both the transmission P_{tc} and the reception P_{tr} . P_s the consumed power at the transient mode according to a duration T_s . P_{tr} stands for the required power in relaxation status spending a duration T_{tr} . Obviously, the circuit power incorporates:

- P_{ADC} : the power consumed by the ADC.
- P_{DAC} : the power consumed by the DAC.
- P_{LNA} : the power consumed by the LNA.
- P_m : the power consumed by the mixer.
- P_f : the power consumption of the filter.
- P_{SY} : the power consumption of the frequency synthesizer.

Correspondingly, in transmission side the energy consumed by the circuit components E_{ct} is expressed as:

$$E_{ct} = (P_m + P_f + P_{DAC} + P_{SY}) T_t
 \tag{12}$$

Otherwise, the energy consumed through the circuit devices at the reception denoted by E_{cr} is derived by:

$$E_{cr} = (P_m + P_{LNA} + P_f + P_{ADC} + P_{SY}) T_t
 \tag{13}$$

Consequently, the overall energy consumed through the circuit components E_c including all the digital and electronic components at both the transmitter and receiver side could be expressed by:

$$E_c = E_{ct} + E_{cr}
 \tag{14}$$

Note that we don't take into account the sleeping scenario in our investigation as it doesn't need much power expenditure. Thus, the energy consumed at the transmission scenario E_t is expressed as:

$$E_t = ((1 + \alpha)P_t + P_{ct} + P_{cr})T_t \tag{15}$$

Above α relied to the quotient between the amplifier power expenditure and the delivered power at the transmission. It is represented by $\alpha = \frac{\beta}{\epsilon} - 1$ where β corresponds to the Peak to Average Power Ratio (PAPR) and ϵ accounts to the drain efficiency. Otherwise, the author in [22] defines the transmitted power under the assumption of μ th-power fading process across a distance d which leads to obtain:

$$P_t = P_r G d^\mu M_l \tag{16}$$

being:

- G is the gain factor following a distance $d = 1$ m.
- P_r (Watts) corresponds to the power at the reception which is derived by:

$$P_r = \frac{L E_b}{T_t} \tag{17}$$

Being E_b the considered energy per bit at the reception. Note that, to simplifying the investigation we follow the same parameters in [8] such that $\mu = 3.5$ and $G = 30$ dB. Additionally, M_l is exploited to compensate the variation challenging the hardware operability. Consequently, the energy consumed at the transmission mode could be expressed by:

$$E_t = (1 + \alpha)LE_b G d^\mu M_l + E_c \tag{18}$$

If we denote by L the corresponding size related to the MB-UWB packet and by considering the assumption of sleeping status relaxation with switching mode, the overall energy expenditure per bit E_p delivered following a transmission time T_t will be expressed as follows:

$$E_p = \frac{E_t}{L} = ((1 + \alpha)L E_b G d^\mu M_l + E_c)/L \tag{19}$$

Consequently, if we consider by E_a the global energy consumption per bit taking into account the average of retransmission \bar{N} we have:

$$\begin{aligned} E_a &= E_p * \bar{N} = ((1 + \alpha)LE_b G d^\mu M_l + E_c) * \bar{N}/L \\ &= \left((1 + \alpha)E_b G d^\mu M_l + \frac{E_c}{L} \right) * \left(\frac{1}{1 - P} \right) \end{aligned} \tag{20}$$

Note that the total energy consumption per bit of information expressed by (20) represents the EE of the MB-UWB cross-layer design that we need to minimize. Correspondingly, our problem formulation consists on minimizing E_a constrained by the maximum transmission power denoted by P^{max_t} as the consumed power in transmission shouldn't exceed P^{max_t} . By this way we obtain:

$$\begin{aligned} &\min E_a \\ &\text{subject to } ((1 + \alpha) P_t + P_{ct} + P_{cr}) \leq P^{max_t} \end{aligned} \tag{21}$$

6 Numerical Analysis

In this sub-section we illustrate computer results of the developed cross-layer MB-UWB structure over the UWB channel model by considering the three first sub-bands corresponding respectively to the associated three central frequencies varying from 3.1 to 4.7 GHz [4]. Numerical results are done through UWB CM1 channel model being $N_o = -114$ dBm/MHz [4] the density of noise. Nevertheless, herein we investigate the heuristic MCS providing energy consumption per bit minimization which allows EE enhancement. The considered MCS approach are previously tabulated in Table 3 exploiting 16-QAM and QPSK modulations exploiting data rates varying from 53.3 Mb/s to 960 Mb/s. The exploited FEC are obtained from a convolutional encoder characterized by a coding rate of 1/3 with [133₈, 165₈, 171₈] generator polynomials. Additionally, we use CRC-32 for error detection.

Nevertheless, the MB-UWB packet lasts following [4] a period $T_p = 312.5$ ns with a sub-band's bandwidth $B = 528$ MHz. In addition, the maximum number of retransmission is $K = 2$ following a target PER = 10^{-5} . The MB-UWB features are mentioned in [3] in which the frame having a payload of 1024 bytes. Note that the required hardware features of the MB-UWB system are varying from a sub-band group to another. As we consider the group 1 in mandatory process the Noise Figure (NF) is $N_f = 6.6$ dB [3]. It is worth mentioned that the other parameters of M_l , P_f , P_m , μ and G , defined previously, are taken from the energy consumption model identified in [8] to simplify the MB-UWB cross-layer architecture which are reported in Table 4. The transmission distances are ranging from 0 to 15 m.

After defining the energy consumption model, we illustrate in Fig. 9 the simulation results of $E_a = f(d)$ developed in (20) for each MCS level. It should be noticed that the energy consumption per bit is computed in (dBmJ).

We remark from the observed results in Fig. 9 that for small values of d , 16-QAM modulation are more suitable in terms of EE since circuit power expenditure is more active in this situation. Hence, CRC pattern is more adapted for 16-QAM constellation since retransmission rounds are minimized in this situation which saves power. For the distances between 5 to 10 m MCS-8 related to 480 Mb/s and MCS-9 related to 800 Mb/s are the most suitable candidates for energy expenditure minimization. The other MCS schemes related to 53.3, 80 and 110 Mb/s using TDS with QPSK modulation require more consumed power due to the diversity offered which need more retransmission request

Table 4 Simulation parameters

N_f	6.6 dB
T_p	312.5 nsec
P_{SY}	65 mA
B	528 MHz
P_{LNA}	12.5 mW
P_m	30.3 mW
G	30 dB
μ	0.35
N_o	-114 dBm/MHz
M_l	40 dB
P_f	2.5 mW

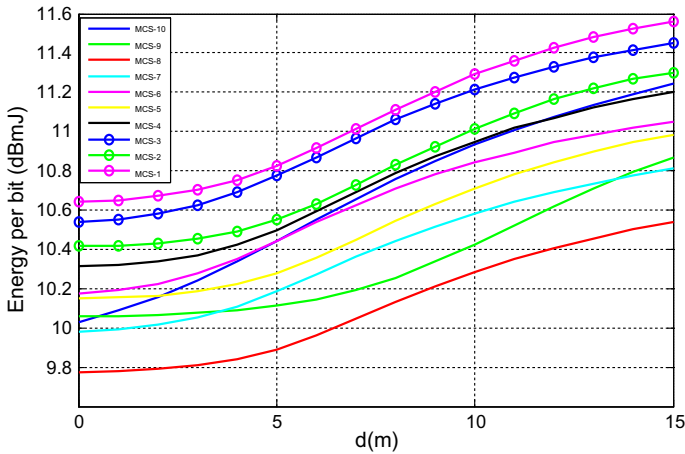


Fig. 9 Total energy consumption per bit comparison results

involving EE diminishing. We conclude that total energy consumption decays whenever the constellation size increases.

However, the MCS schemes related to 53.3, 80 and 110 Mb/s need more power consumption due to the diversity offered which needs more retransmission request involving EE diminishing. In addition, the EE depends on the coding rate. Thus, the coding rate of 3/4 related to MCS-8 enhances the EE according to the observed minimization towards global energy expenditure per bit even for increasing values of the distance d . MCS-1 is not prominent following the restricted strength of the coding rate 1/3 which needs much energy consumption.

Besides, we remark that for higher values of d the power at the transmission is the most operational scenario for this the MCS-4 associated to the data rate 160 Mb/s following the QPSK mapping and MCS-6 corresponding to the data rate of 960 Mb/s using 16-QAM constellation show identical results. Consequently, we conclude that distance optimization ensures energy saving. Otherwise, energy consumption diminishing depends on the coding rate. Nevertheless, the coding rate of 3/4 corresponding to the data rate of 480 Mb/s allowing returned request of retransmission minimization which provides EE enhancement according to the observed minimization of overall energy expenditure per bit even for the considered higher values of d . However, MCS-1 is not efficient due to the limited strength of 1/3 coding rate consuming more power.

7 Conclusion

The considerable growth of wireless applications highlights their need to a significant attention into the energy consumed since by exploiting the features of link adaptation tools performed through the flexibility exploitation of MCS mechanism joint with transmission reliability of HARQ retransmission protocol.

Due to the great requirement of the tradeoff establishment between throughput improvement and power consumption, EE requires much attention. In this context, in this paper we examined the cross-layer MB-UWB design characteristics to enhance the EE as energy expenditure diminishing is the goal of many operators. In particular, the

developed approach exploits the advantage of MCS scheme combined with HARQ type I protocol characteristics in terms of reliability improvement. Performance evaluations are based on PER, throughput and outage probability. In addition, we examined the idea of energy consumption per bit diminishing toward the cross-layer MB-UWB systems by considering HARQ type I mechanism reliability. Besides, total energy consumption per bit minimization ensures that the MB-UWB model be a prominent solution for indoor communication systems. Nevertheless, we displayed the energy consumption per bit at different distances taking into account the constellation size switching. Computer results highlight the dependence between total energy consumption minimization per bit and the transmission distances when different M-QAM modulations are applied. By this way, we have shown the efficiency of the developed cross-layer scheme to enhance the EE by applying the link adaptation characteristics in one hand and the MCS scheme flexibility in other hand.

Further investigation should take into account the delay and estimation errors impacts into the cross-layer MB-UWB system. In addition, we could include other type of retransmission protocols. We could investigate resource allocation of the cross-layer MB-UWB scheme.

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