Performance Analysis of LDPC-IDMA-UWB Signals in Non-Gaussian Noisy Channel

Doaa E.El-Matary, Esam A.A. Hagras, Hala Mansour Abdel-Kader

Abstract—In this paper, Low-Density Parity Check (LDPC) codes is applied to IDMA-UWB System, called as, LDPC-IDMA-UWB System, in which multi-user communication scenario under the effect of Non-Gaussian noisy channel has been considered. Two different non-Gaussian noise models, Laplacian and Gaussian Mixture Model (GMM), have been proposed which are more realistic models for UWB systems. Simulations are performed using UWB channel model proposed by IEEE 802.15.3a working group. The performance comparison between LDPC and Un-coded IDMA-UWB systems is made over Non-Gaussian and AWGN models. The results show that the LDPC-IDMA-UWB scheme at least gives a significant improvement by about 4.5 dB compared with Un-coded- IDMA-UWB scheme under the proposed noise models, also achieves near single user performance in situations with large numbers of users while maintaining low cost and low receiver complexity.

Index Terms— LDPC-IDMA-UWB, Chip By Chip Iterative Receiver (CBC-IR), Laplacian noise, Gaussian Mixture Model (GMM).

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1 INTRODUCTION

DUE to inherent advantages of high speed transmission, immunity towards multipath, low power and low cost, Ultra Wide Band (UWB) has become the key technology for the next generation of wireless communication systems [1]. In multiuser environments, multi access interference (MAI) is occurred in UWB System. To overcome this problem, Multiuser Detection (MUD) Schemes, and Channel coding techniques are used in wireless UWB System to reduce that (MAI) [2].

Current UWB systems utilize low-density parity-check codes (LDPC) due to their superior error correction capability and low complexity when iterative decoding is used. LDPC Codes are designed by constructing a sparse parity check matrix first and then determining a generator matrix for the code. Such Codes are characterized by the sparseness of ones in the parity-check matrix. This low numbers of ones allow for a large minimum distance of the code, resulting in improved performance [3].

LDPC code is considered as a powerful FEC, which achieves performances near Shannon limit. Note that adopting LDPC code in an IDMA-based system is efficient since both MUD in IDMA layer and LDPC require computing logarithm likelihood ratio (LLR) values. A turbo-type iterative receiver structure is investigated to mitigate MUI [4]. In the field of code division multiple access (CDMA) systems, MUD techniques have been extensively studied to mitigate Multi User Interference (MUI) and Inter-Symbol Interference (ISI) [5].

Recently, a novel technique for multi-user spread-spectrum systems, called Interleave Division Multiple Access (IDMA) scheme, was proposed by Li Ping etc. [6], [7], [8], [9]. In opposition to CDMA scheme, which utilizes different spreading sequences for user separation, IDMA scheme relies on different chip level interleaving to distinguish the signals from different users. One advantage of IDMA is that it inherits many special features from CDMA, such as alleviation of intra-cell interference.

Moreover, it's capable of employing a very simple chip-by-chip iterative multi-user detection strategy. Due to this strategy, IDMA has a receiver complexity being linearly dependent of multi-user number [10]. Although the multiple access techniques for UWB channel have been extensively investigated, the nature of the noise phenomenon and its impact on UWB systems has thus far been ignored. The traditional approach of considering just the thermal noise, modeled as a stationary and memory less Gaussian random process, does not agree with relevant field measurements.

As introduced in [11] that indoor environments are subject to impulsive (non-Gaussian) noise because of electronic equipment widely deployed in every office as well as home environment. A set of measurements have been performed to determine the sources of impulsive noise. It has been found that photocopiers, printers, elevators and microwave ovens are sources of significant noise with amplitudes of 50dB above thermal noise. So the Gaussian noise model is not appropriate due to infrequent and high level noise spikes. Hence, the noise distribution for UWB systems should be discussed as non-Gaussian. Commonly used impulsive (non-Gaussian) noise models are Laplacian, and GMM [12].

In this paper, the BER performance of multi-user communication based LDPC Coded-IDMA-UWB system over non-Gaussian noisy channel has been proposed. The rest of paper is organized as follow. The system model of LDPC-IDMA-UWB is described in Section II. Next, Section III introduces the UWB channel models. Section IV describes Non-Gaussian UWB noise models. Section V evaluates the performance of the proposed system by conducting the simulation experiments. Finally, Section VI concludes this paper.

2 LDPC-IDMA-UWB SYSTEM

Fig. 1 decpites the block diagram of the transmitter and receiver structures for LDPC-IDMA-UWB system with K simultaneous users.

- *Doaa E. El-Matary is currently pursuing PhD degree program in Electronics and Communications Department, Faculty of Engineering at Shoubra, Benha University. E-mail: doaa_elmatary@yahoo.com*
- *Esam A. A. Hagras, Electronics and Communications Departmen, Technical Research Center, E-mail: esamhagras_2006@yahoo.com*
- *Hala Mansour Abd-Elkader, Prof. Electronics Electronics and Communications Department, Faculty of Engineering at Shoubra, Benha University. E-mail: hala.abdelkader@gmail.com*

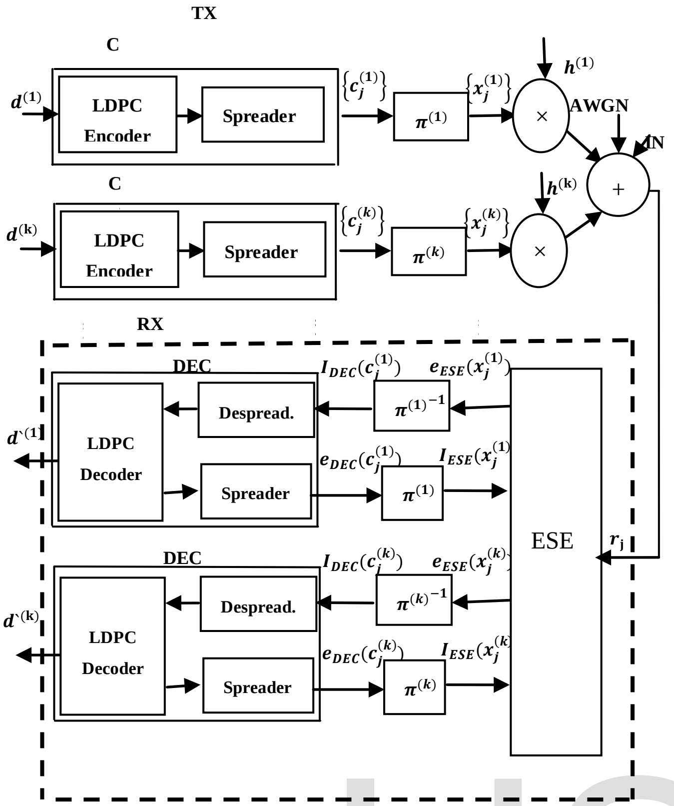

Fig. 1 LDPC coded-IDMA-UWB Transmitter and Receiver structures

2.1 LDPC-IDMA-UWB Transmitter

The upper part of Fig. 1 shows the transmitter structure of LDPC-Coded spreading IDMA system with k simultaneous users [13]. We only consider BPSK modulation for simplicity. The nth bit data sequence $d_n^{(k)}$, in the input data stream $d^{(k)}$ from user-k is encoded by an LDPC encoder, generating $c_n^{(k)}, n = 1,2,\ldots,N$, where N is the frame length. The nth coded bit from user-k, $c_n^{(k)}$ is spread using a length-S spreading sequence $s^{(K)}$in the form $c_n^{(k)} \rightarrow c_n^{(k)} s^{(k)}$. We write the chip sequence obtained after spreading as $\{c_j^{(k)} \in \{+1,-1\}, j = 1,2,\ldots,J\}$, where $J = N \times S$ is the frame length. A chip-level interleaver $\pi^{(k)}$ is then applied to produce the transmitted signals $\{x_j^{(k)}, j = 1,2,\ldots,J\}$.

2.2 LDPC-IDMA-UWB CBC-Iterative Receiver

The receiver structure is roughly the same as that of [1]. The difference is that the addition of DEC with de-spreading and spreading in the turbo process. The receiver consists of an elementary signal estimator (ESE) and K a posteriori probability (APP) decoders (DECs). From Figure 1 we can see that the received signal first processed by ESE, which executes signal detection. Then for every user de-interleaving is performed, followed by de-spreading, and then decoding is performed. After decoding the message is processed by spreading and interleaving, and then ESE is carried out.

We use a standard form of Sum Product Algorithms (SPA) of LDPC decoder due to its capacity to achieve desirable performance and complexity trade-offs. We call the iterative decoding of LDPC inner iteration, and the whole iterative operation of ESE, de-interleaving, dispreading, LDPC decoder, spreading, interleaving is outer iteration. The iteration number can be adjusted depending on system requirement and computational power.

In Fig. 1, $\{I_{ESE}(x_k(j))\}$ and $\{I_{DEC}(c_k(j))\}$ are used in the ESE and DECs separately as the a priori logarithm likelihood ratios (LLRs) about $x_k(j)$ and $c_k(j)$. And the outputs of the ESE and DECs, $\{e_{ESE}(x_k(j))\}$ and $\{e_{DEC}(c_k(j))\}$, are extrinsic LLRs about $\{x_k(j)\}$ and $\{c_k(j)\}$. The ESE generates extrinsic information, which is used as the a priori information for DECs after de-interleaving, and vice versa. The receiver completes the turbo-type iterative process by incessant updating the extrinsic information generated by ESE and DECs. The DECs produce hard decisions d_k on information bits d_k after the final iteration. In the following, we will focus on the ESE and the DECs function in detail.

2.3 The ESE Function

ESE is a chip-by-chip multi-user detection maintaining very low complexity (independent of the number of users) [14]. Only one channel observation value r_j is processed at a time.

The received signal at time instant j can be written as

$$r_j = \sum_{k=1}^{K} h^{(k)} x_j^{(k)} + N_j, \quad j = 1,2,\ldots\ldots,J \tag{1}$$

Where $x_j^{(k)} \in \{+1,-1\}$ denotes the transmitted chip from user-k at time instant j, $h^{(k)}$ the channel coefficient for user-k, and $N_j = n_j + In_j$. $n_j$is zero-mean additive white Gaussian noise (AWGN) with variance $\sigma^2 = N0/2$, and In_j is zero-mean Impulsive noise with different variances . We will assume perfect knowledge of the channel coefficients at the receiver. To simplify discussion, we also assume that the channel coefficients $\{h^{(k)}\}$ are real, but the principle can be extended to situations with complex channel coefficients [15].

The ESE performs chip-by chip estimation. We concentrate on $x_j^{(k)}$ and re-write (1) as

$$r_j = h^{(k)} x_j^{(k)} + \xi_j^{(k)} \tag{2}$$

Where $\xi_j^{(k)} = r_j - h^{(k)} x_j^{(k)}$ represents a distortion (including interference plus noise) with respect to user- K . The objective of the chip by chip estimation technique in the ESE is to calculate the extrinsic information about $x_j^{(k)}$ by using r_j and $I_{ESE}(x_k(j))$ as its inputs. So we focus on the mean and variance of $\xi_j^{(k)}$, the distortion contained in r_j and also the extrinsic information in r_j. We treat each $x_j^{(k)}$ as a random variable with mean $E(x_j^{(k)})$ and variance $Var(x_j^{(k)})$ (initialized to 0 and 1 respectively). Then from (1), we have

$$E(r_j) = \sum_{k=1}^{K} h^{(k)} E(x_j^{(k)}) \tag{3a}$$

$$Var(r_j) = \sum_{k=1}^{K} \left|h^{(k)}\right|^2 Var(x_j^{(k)}) + \sigma^2 \tag{3b}$$

Using the central limit theorem, $\xi_j^{(k)}$ in (2) can be approximated by a Gaussian random variable with

$$E(\xi_j^{(k)}) = E(r_j) - E(h^{(k)} x_j^{(k)}) \tag{4a}$$

$$Var(\xi_j^{(k)}) = Var(r_j) - \left|h^{(k)}\right|^2 Var(x_j^{(k)}) \tag{4b}$$

The ESE outputs are the logarithm likelihood ratios (LLRs) about $\{x_j^{(k)}\}$ computed based on (3) (using (4)) as

$$\mathrm{e_{ESE}}\left(\mathrm{x_j^{(k)}}\right) \equiv \log\left(\frac{\Pr(\mathrm{x_j^{(k)}} = +1|\mathrm{r_j})}{\Pr(\mathrm{x_j^{(k)}} = -1|\mathrm{r_j})}\right)$$

$$= \log\left(\frac{\exp\left(-\frac{\left(\mathrm{r_j} - \mathrm{E}\left(\xi_j^{(k)}\right) - \mathrm{h}^{(k)}\right)^2}{2\mathrm{Var}\left(\xi_j^{(k)}\right)}\right)}{\exp\left(-\frac{\left(\mathrm{r_j} - \mathrm{E}\left(\xi_j^{(k)}\right) + \mathrm{h}^{(k)}\right)^2}{2\mathrm{Var}\left(\xi_j^{(k)}\right)}\right)}\right)$$

$$= \left(\frac{2\mathrm{h}^{(k)}\left(\mathrm{r_j} - \mathrm{E}\left(\xi_j^{(k)}\right)\right)}{\mathrm{Var}\left(\xi_j^{(k)}\right)}\right) \quad \forall \mathrm{k,j} \tag{5}$$

2.4 The DEC Function

Corresponding to the C part in the transmitter, the DEC part includes de-spreading/spreading and LDPC decoding operations showed in Fig.1. The DECs carry out decoding using the output of the ESE as the input and generate $e_{DEC}\ (c_k\ (j))$ as their output, which are used to calculate the statistics in (3a) and (3b) after interleaving [1].

$$\mathrm{E}\left(\mathrm{x_j^{(k)}}\right) = \tanh\left(\frac{\mathrm{I_{ESE}}\left(\mathrm{x_j^{(k)}}\right)}{2}\right) \tag{6a}$$

$$\mathrm{Var}\left(\mathrm{x_j^{(k)}}\right) = 1 - \mathrm{E}\left(\mathrm{x_j^{(k)}}\right)^2 \tag{6b}$$

As discussed above, $\mathrm{E}\left(\mathrm{x_j^{(k)}}\right)$ and $\mathrm{Var}\left(\mathrm{x_j^{(k)}}\right)$ will be used in the ESE to update the interference mean and variance in the next iteration.

3 UWB CHANNEL MODELS

The accurate design of channel model is a very important issue for ultra wideband WPAN (Wireless Personal Area Network) communication system. The standardized channel model for indoor UWB environments proposed by the channel modeling subcommittee of the IEEE 802.15.3a Task Group is a modified version of the Saleh–Valenzuela (S–V) model [16], where the Rayleigh distribution of the channel coefficient amplitude in the S–V channel model is replaced by the log-normal distribution.

The measurements of S–V channel shows that the multipath components arrive from transmitter to receiver in the form of clusters. Indoor channel environments are classified as CM1, CM2, CM3, and CM4. CM1 describes a line-of-sight (LOS) scenario with T-R separation less than 4m. CM2 describes the same range for T-R separation but it is in NLOS (non line of sight). CM3 describes a NLOS medium for separation between transmitter and receiver of range 4-10m. CM4 describes an environment of more than 10m with strong delay dispersion.

According to [16], the channel impulse response is defined as

$$h(t) = X\sum_{l=0}^{L-1}\sum_{k=0}^{K-1}\alpha_{k,l}\ \delta(t - T_l\ | - \tau_{k,l}\ ) \tag{7}$$

where $\{\alpha_{k,l}\ \}$ are the multipath gain coefficient of kth ray related to lth cluster, $\{T_l\}$ is the delay or arrival time of first path of the lth cluster, $\{\tau_{k,l}\ \}$ is the delay of the kth multipath component within the lth cluster relative to arrival time $\{T_l\}$,$\{X\}$ denotes the lognormal shadowing term.

4 NON-GAUSSIAN UWB NOISE MODEL

Recently, there has been considerable interest in the detection of signals in non-Gaussian noise. One form of frequently encountered non-Gaussian noise is that known as impulsive noise. Impulsive noise is typically characterized as noise whose distribution has an associated "heavy tail" behavior. That is, the probability density function (pdf) approaches zero more slowly than a Gaussian pdf. Commonly used non-Gaussian (Impulsive) noise models are Laplacian, and GMM which will be introduced below.

4.1 Laplacian Noise Model

Laplacian noise model has been used in ultra-wideband receiver design and in modeling impulsive noise. Notice that Laplace noise has the heavy tail behavior associated with implusive noise. The pdf of Laplacian noise is given by

$$\mathrm{f_n(x)} = \frac{1}{\sqrt{2\sigma^2}}\exp\left(-\sqrt{\frac{2}{\sigma^2}}|\mathrm{x}|\right) \qquad ,-\infty < x < \infty \tag{9}$$

Where $\sigma^2$is the noise variance

4.2 Gaussian Mixture Model

The mixture Gaussian model has been found to provide a good fit to empirical noise data. The mixture Gaussian model is the more realistic model for UWB systems whose main application will be in indoor environments. As shown in [11], the indoor noise is typically impulsive in nature due to the interference emanating from other man-made devices.

The pdf of Gaussian Mixture Model is

$$f_{n_{j,l}}(x)\ =\ (1-\epsilon)g(x)\ +\epsilon h(x) \tag{10}$$

where $g(.)$ is the nominal Gaussian pdf with variance N_0 and $h(.)$ is the heavier tailed Gaussian with variance ηN_0,where η is the impulsive part's relative variance with respect to nominal Gaussian noise variance ($\eta \geq 1$). The parameter $\epsilon \in [0,1]$ controls the contribution of impulsive component to the whole pdf.The main assumption about the channel noise is that the samples are independent and identically distributed so that an impulsive noise source can be studied by modeling its first-order probability density function (pdf) [17]. The pdf model is constructed as the mixture of two Gaussian random process with zero mean and different variances, where one is a multiple of the other for the representation of the heavy tail of the distribution producing large amplitudes.

Therefore, the noise samples $n_{j,l}$, have the variance $(1-\epsilon)N_0\ +\ \epsilon k N_0$. When $\eta =\ 1$, the usual AWGN case is obtained. The ϵ-mixture model is an approximation to Middleton's class-A noise model pdf [17], which consists of an infinite expansion of Gaussian density functions with different variances and identical means. In [18], it is shown that the first two terms of the expansion sufficiently describe the class-A noise pdf. In addition, the ϵ-mixture model is much more tractable than the class-A noise pdf.

5 SIMULATION RESULTS

In this section, BER performance of LDPC-IDMA-UWB scheme is shown. Regular (128,256) LDPC codes are applied to

128 data length in system simulation whose parity-check matrix has 128 rows and 256 columns. Obviously, the corresponding coding rate is 1/2. The maximum iteration number of SPA decoding is 7, the length of spreading sequence is 32, and the Iteration number of IDMA receiver is 3.

The discrete time channel model proposed by the IEEE 802.15.3a working group [16] is utilized, which is based on the modified S–V model. We focus on the line-of-sight (LOS) channel model 1 (CM1) which corresponds to a short-range (0–4 m) indoor wireless environment.

The simulation results are averaged over a large number of channel realizations. Not only AWGN is considered here but also non-Gaussian noise models like Laplacian noise, and Gaussian mixture noise.

Fig. (2-9) show the BER performance of LDPC coded-IDMA-UWB scheme for varying users in LOS (Line of Sight) scenario under different conditions.

The system performance have been studied using 3 different noise models, AWGN, Laplacian noise, GMM respectively, and then the results have been compared together as shown in fig. from (2-6).

Fig. 2 shows the comparison between BER performance of the proposed LDPC-IDMA-UWB system, and the Un-Coded system introduced in [1] under the effect of AWGN model. The results indicate that the proposed system can achieve a significant improvement over the Un-coded system in [1] by about 4.5dB for different numbers of users and considered near single user performance until 16 users.

Fig. 3 shows the same comparison between the two systems mentioned above but under Laplacian noise model. The results indicate that the proposed system improves the system performance by about 5.5dB until 16-users compared with Un-coded case and this improvement increases to 8dB at 32 users.

Fig. 4 shows the same BER comparison but under GMM noise model. The results indicate that the proposed system improves the system performance by about 4.5dB for different users compared with Un-coded case.

Fig. 5 shows the effect of three noise models mentioned above on the BER performance at fixed number of users=32. It can be noticed that the performance degrades by about 0.5dB in case of Laplacian noise model, and this degradation increases to 2.5dB under GMM model compared with AWGN model for the same system parameters.

Fig. 6 shows the BER performance comparison between the same proposed noise models but in terms of different numbers of users, and fixed Eb/No=4dB. It can be observed that the system outperforms well with multi-users under AWGN model and the performance have a little degradation compared with AWGN model in case of Laplacian noise model, and this degradation increases under GMM model for the same system parameters.

Fig. 7 shows the performance of the proposed scheme under different numbers of LDPC-decoding iterations. It is observed that the performance is improved by increasing the iteration numbers to 7 while, it gives a fixed response after 7 iterations.

Finally, fig. 8, 9 show the effect of control parameter ϵ and impulsive parameter η on the system performance. It is clear that the BER performance is degraded by increasing the value of those parameters.

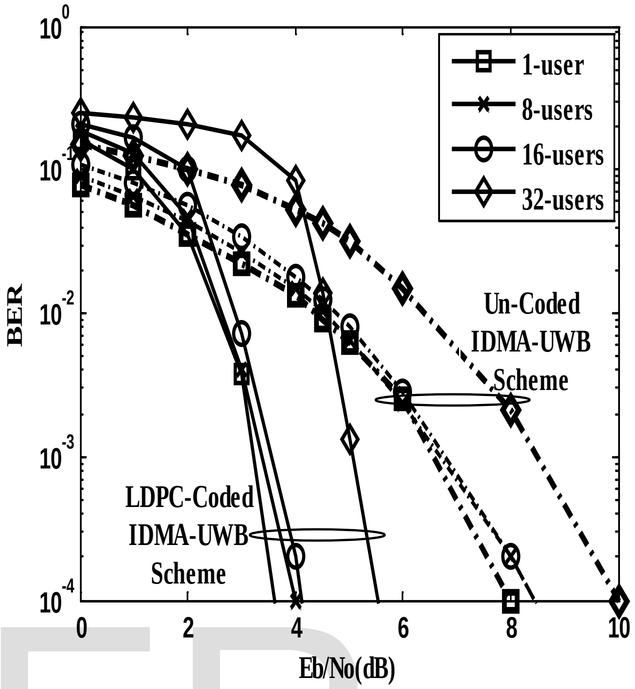

Fig. 2. BER performance of IDMA-UWB scheme for various users under AWGN in CM1 with data length N=128, LDPC code with rate=1/2, SPA decoding iteration=7, spreading length Sp=32, IDMA iteration =3.

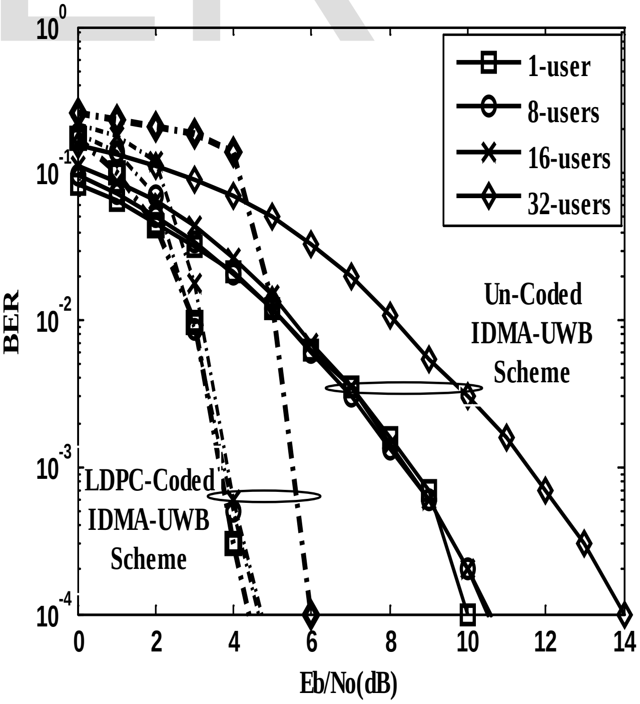

Fig. 3. BER performance of IDMA-UWB scheme for various users under Laplacian noise in CM1 with data length N=128, LDPC code with rate=1/2, SPA decoding iteration=7, spreading length Sp=32, IDMA It=3.

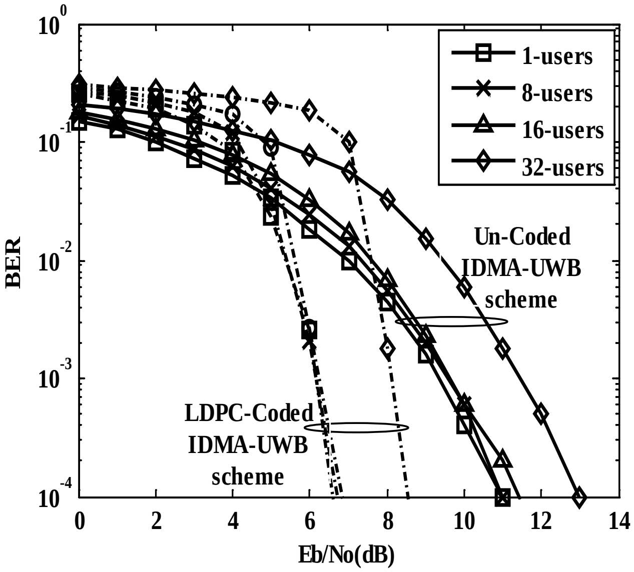

Fig. 4. BER performance of IDMA-UWB scheme under GMM for various users in CM1 with N=128, LDPC code with rate=1/2, SPA decoding iteration=7, Sp=32, IDMA It=3,control parameter $\epsilon = 0.1$, impulsive parameter $\eta = 10$.

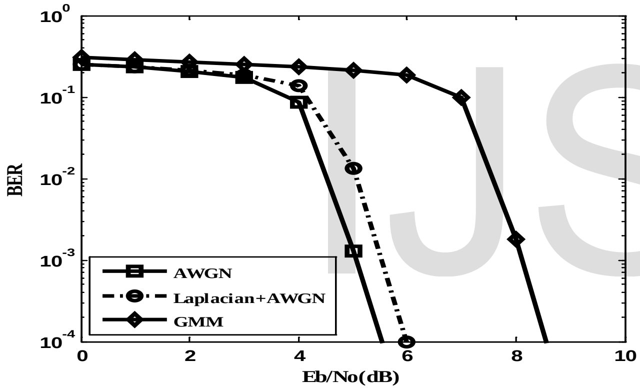

Fig. 5. Comparison between BER performance of LDPC coded-IDMA-UWB scheme for previous 3 models of noise in CM1 with nusers=32, N=128,C=256, iter=7, Sp=32, It=3, $\epsilon = 0.1$, $\eta = 10$.

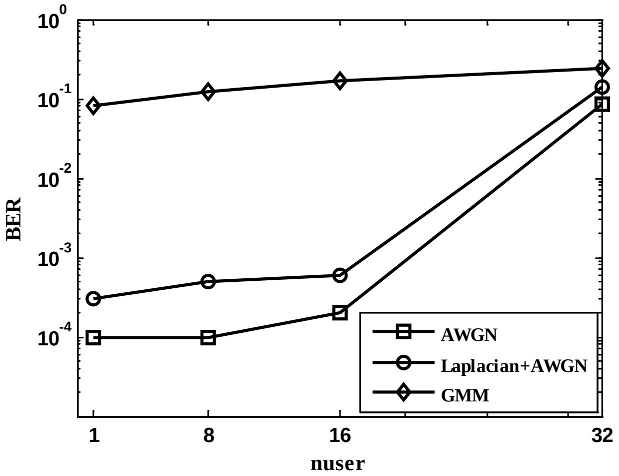

Fig. 6. Comparison between BER performance of LDPC coded-IDMA-UWB scheme for previous 3 models of noise in CM1 with $Eb/No = 4$dB, N=128,C=256, iter=7, Sp=32, It=3, $\epsilon = 0.1$, $\eta = 10$.

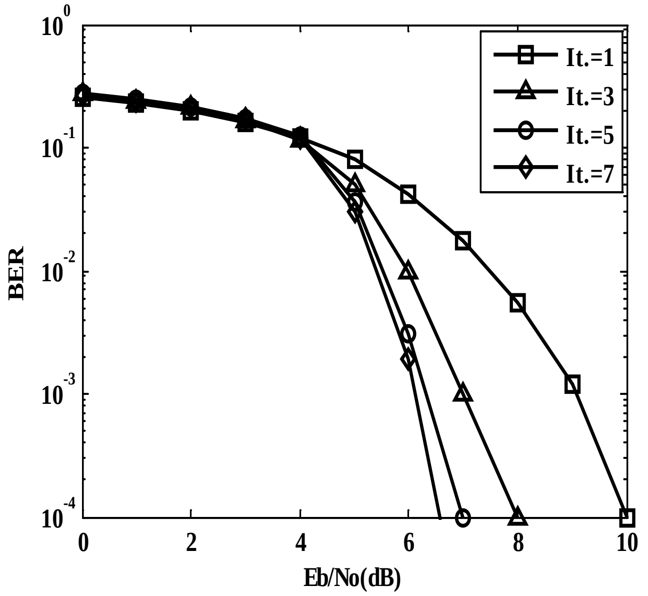

Fig.(7) : BER performance of LDPC coded-IDMA-UWB scheme with different iterations of encoder at 8-users, and N=128, C=256, Sp=32, $\epsilon = 0.1$, $\eta = 10$ in GMM.

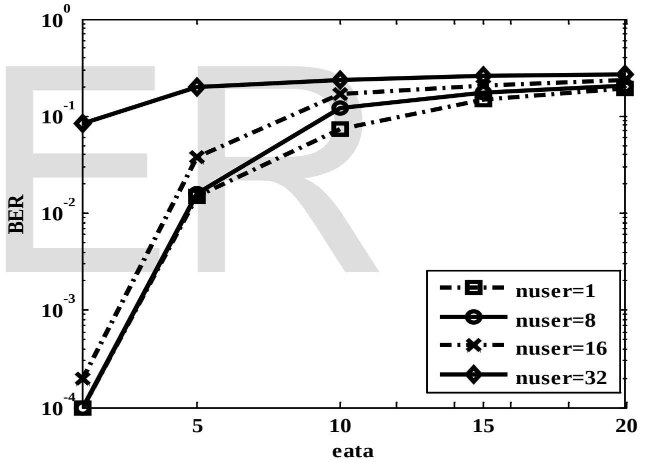

Fig.(8) : Effect of impulsive parameter η on BER performance of LDPC coded-IDMA-UWB scheme with $\mathrm{Eb/No} = 4$dB and $\epsilon = 0.1$.

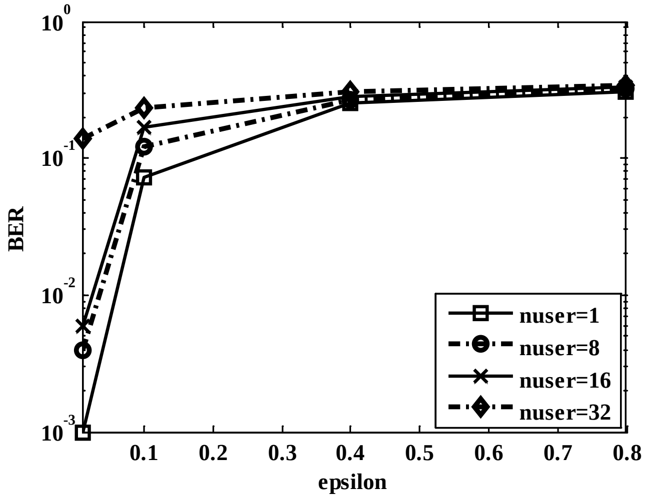

Fig. 9. Effect of control parameter ϵ on BER performance of LDPC coded-IDMA-UWB scheme with $\mathrm{Eb/No} = 4$dB and $\eta = 10$.

6 CONCLUSION

This paper addresses the performance of LDPC-IDMA, for UWB signals over non-Gaussian noisy channels. The simulation results show that, the LDPC-IDMA system offers a significant performance gain by exploiting the power of LDPC codes. Furthermore, simulation results point out that LDPC-IDMA is robust against MUI in UWB indoor environment and provides an effective solution to high-rate multiuser communications over multipath channels.

Because of the Gaussian noise model is not appropriate for UWB indoor environments due to infrequent and high level noise spikes, non-Gaussian noise models include Laplacian noise, and mixture noise have been proposed which is more realistic models for UWB systems. Simulations are performed using UWB channel model considered proposed by IEEE 802.15.3a working group. A performance comparison shows that the BER performance under AWGN, laplacian, and GMM has been improved by about 4.5dB, 5.5dB, and 4.5 dB respectively compared with Un-coded case, also achieves near single user performance in situations with large numbers of users while maintaining low cost and low receiver complexity.

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