Performance Improvement of CDMA Wireless Sensor Networks in Low SNR Channels Based on Raptor Codes

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Abstract: Some kinds of communication systems work in very low signal to noise power ratio (SNR) environments. For these systems to function reliably, certain techniques and methodologies have to be used to mitigate the degrading effects of the channel.The channel coding method is the key element in most low SNR communication systems with emphasis on the Code Division Multiple Access (CDMA) as a recommended transmission technique in these channels. To enhance the system capacity of the CDMA scheme and reach to unprecedented ranges of low SNR values in systems like the Wireless Sensor Network (WSN), this paper suggests a technique for combining CDMA with certain types of channel coding algorithms such as the Raptor codes. The Raptor channel encoding technique has shown an improved performance for the CDMA system when using BPSK digital modulation in AWGNchannels. It has achieved a low bit error rate in the range of 10^{-6} at E_b/N_o value of -2 dB and 10^{-7} at E_b/N_o value of -3 dB for code rates 1/2 and 1/3 resprctively. The Raptor-coded CDMA scheme showing an improvement of about 6 dB when compared with some other channel coding methods used with the CDMA system for the same BER.

Keywords: LSNR, CDMA, Rateless code, Raptor code, LDPC code, LT code

1 Introduction

WSNs have become an attractive research topic in recent years. It is considered one of the most promising technologies due to its distinctive properties like low cost, flexibility, and ease of development. WSNs are used in various applications, including medical monitoring, military operations, security, environmental monitoring, and industrial surveillance [1]. It consists of massive, small, cheap, and intelligent sensor nodes that are able to sense, process, and send the gathered information to the base station [2].

The massive increase in demand for a wide range of wireless services, each with its own set of needs in terms of service quality, has led to the search for new technologies to enhance the capacity of digital communication systems. For achieving that vision to the future, wireless technology's current state is essential for significant improvement [3] One of the most significant issues in developing communication systems is related to the degree of bandwidth occupancy. In fact, the bandwidth requirement has resulted in a search for the protocol that may be utilized to increase bandwidth utilization. Code Division Multiple Access (CDMA) is a method for accommodating multiple users with various rate and Quality of Service (QoS) requirements in the same bandwidth and at the same time in the third and fourth generations of mobile communication systems [4]. Users can share the channel with the CDMA system through the use of signal properties or codes. This scheme has established itself as a powerful rival for multiple access communication systems.Direct sequence code division multiple access (DS-CDMA) has gained popularity in recent decades due to its many advantages when compared to other multiple access techniques [5]. Also, DS-CDMA can provide high resistance to jamming and interference and reduce the effects of multipath distortion. DS-CDMA is also extremely adaptable in cellular systems due to its lowest frequency reuse factors. Furthermore, it performs efficiently in these systems due to its low interference with other communication systems. Because of these properties of the DS-CDMA, it was first deployed in military applications. The system's main characteristics were reliability, security, robustness, and flexibility. This technique is also influenced by other aspects like transmission power, bandwidth, and overall system efficiency [5][6]. In DS-CDMA technology, each user is assigned a unique code, and the code assigned to the user is essential for modulating the signal since the overall system performance depends on it. Depending on the type of CDMA technique, different codes can be used. In a synchronous system, the orthogonal codes like (OVSF codes, Hadamard codes) have been used, while in an asynchronous system, pseudo-random codes or Gold codes have been used[6] [7] .Channel coding can minimize multi-access interference (MAI) by decreasing the transmitted power at the expense of increasing the transmitted signal bandwidth through the redundant codes. Specific techniques can be used to improve the DS-CDMA system effectiveness and performance. Besides, channel coding is one of the most common techniques for identifying and correcting errors caused by noise in a communication system. It allows for near-capacity operation due to its ability to detect and correct errors. Also, by employing efficient coding algorithms with error-correcting capabilities and high coding gain, system performance can be improved by minimizing the bit error rate [7] [8]. There are two types of channel codes: block codes and convolutional codes. In practical communication systems, convolutional codes are one of the most commonly utilized channel codes. These codes are mainly used for real-time error correction and are developed with a separate mathematical framework. Also, the entire data sequence is converted into a single codeword, and the encoded bits are determined by the previous k input bits and the underlying k input bits. The Viterbi algorithm is the most popular decoding technique for convolutional codes. The convolutional error-correcting codes have been used extensively to provide reliable communication over channels with low signal-to-noise ratio (LSNR)[9] .Turbo code[10] is an error correction algorithm that sends data over a channel with very low bit error rate. This code is made up of two-block convolutional codes that are concatenated in parallel and separated by a random interleaver [11]. In both the additive white Gaussian noise (AWGN) and fading channels, turbo codes have been confirmed to be highly effective [12].Fountain code [13], also referred to as rateless code, is a new member of the channel coding family that can produce an infinite number of encoding symbols from a set of source symbols k. It is designed specifically for reliable communication across an erasure channel with an unknown erasure probability. MacKay in [13] demonstrates the essential advantages of Fountain codes related to efficiency, durability, and reliability over the AWGN channel as well as over fading channels[14] [15]. A practical class of Fountain codes is known as Luby-Transform (LT) codes [16]. LT codes have been used to improve the probability of the weight distribution for the rateless code [16]. These codes can recover the source information from any set of the output symbols whose size is near the ideal value[17]. LT codes with direct time encoding and decoding outperform Low-Density Parity-Check (LDPC) codes in bursty channels [18]. Raptor codes, introduced by A. Shokrollahi, represent a first-class of Fountain codes with linear encoded and decoded time. They are extensions of the LT codes, with relatively high error floors in extremely noisy channels. These issues are solved by using a linear block pre-code that encodes a specific source block of data before the LT encoder [16] [17] . The pre-code is typically a mixture of several codes, such as the LDPC code and another linear code like the Hamming code. Fountain codes, due to their rateless nature, may adapt to changes in channel conditions where the block codes may fail in the adaptation process. Rateless codes were rapidly applied to other channels, such as binary-input additive white Gaussian noise (BIAWGN) and erasure channels [15] . Moreover, Raptor codes combine block and Fountain codes' advantages to create a new type of Fountain code with linear encoding and decoding costs and adjust to changing channel conditions using rateless systems. On the other hand, Raptor codes can completely recover the source block of data with minimal overhead, making them suitable for many high-data-rate applications [17] [19].

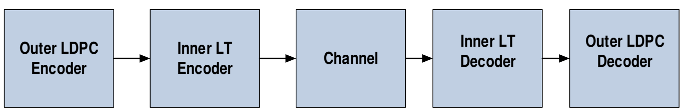
Because of its property of rateless LT codes and Raptor codes, feedback overload can be avoided in broadcast situations. The rateless codes may also be used in massive MIMO systems and relay channels. Due to their high performance, the LT and Raptor codes have made their way into standards and applications, such as the 3GPP of Multimedia Broadcast Multicast Services (MBMS) and Digital Video Broadcasting (DVB) [20]. However, many communication systems, like ad-hoc wireless networks, sensor networks, and ultra-wideband networks, operate with low SNR per node despite the large degrees of freedom available [9]. Therefore, a performance enhancement technique for the DS-CDMA multi-user system through the use of Raptor coding is proposed in this work. This paper is organized as follows. In Section 2, related work is introduced. The concepts of Raptor code are revisited in Section 3. In Section 4, the proposed system model construction is discussed. The Performance Analysis of Proposed System Based on Hybrid Raptor Code with DS-CDMA are presented in Section 5. Performance Metrics of the Proposed system are presented in Section6,and last Section describes the main concluding remarks.

2 Related Works

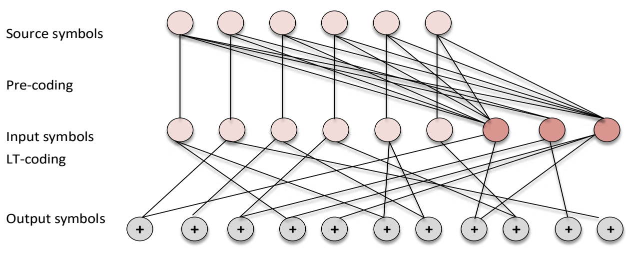
Since the last few decades, many researchers have developed algorithms for simplifying improve Gaussian estimation method to evaluate the efficiency of the CDMA technique in wireless communication systems. In addition, many works in the literature have analyzed the error performance of the multi-user DS-CDMA scheme in a Rayleigh fading channel. Many researchers employed various techniques to evaluate the error performance of such a system[5] A study has been performed on channel-coded direct-sequence CDMA systems using maximum free distance for convolutional code [21]. This study presented low-rate convolutional codes with distinct constrained lengths and varying code rates for the CDMA scheme. In [22], quadratic residue theory based on pseudo-noise (PN) sequences is proposed to design low density parity check (LDPC) codes using the DS-CDMA technique. In that approach, an effective decoding algorithm known as Sum-Product Algorithm (SPA) is used to improve the performance of LDPC codes over a range of Eb/No ratio from 0 dB to 6 dB. Similarly, in[23] the authors proposed an LDPC coded CDMA receiver system. This approach uses the LDPC technique and the scrambling code in the CDMA system to improve security and ensure its usability. The performance of system was verified by measuring the BER for different values of SNR with limits between 1 dB and 13 dB.In[24] , a design for a Polar-Coded CDMA system is proposed. This approach has proved that the performance of the BER of the polar channel-coded with DS-CDMA system outperforms the convolutional DS-CDMA system by a wide margin (approximately 4 dB gain at Eb/No of 4 dB) based on the obtained simulation results. According to[25], the design of CDMA systems using MIMO-LDPC can achieve good error rate performance with short LDPC codes and fewer decoding iterations. It was shown that the MIMO-CDMA system outperforms the traditional CDMA system that use only one transmission antenna with an improvement in the signal to interference noise ratio (SINR) of about 2.5 dB[25] .I. Marcu and S. V. Halunga presented an analysis of a multi-user CDMA system behavior using minimum mean square error (MMSE) detector[4]. In the presence of LDPC/Turbo coding and decoding techniques, the LDPC-Code DS-CDMA system performance is investigated when an optimal multi-user detector is used in the recovery of the information data, and the performance is improved with a BER = 10^{-3} for SNR = 4 dB in an AWGN channel. In [10], over a Rayleigh fading channel, a convolutional code for the IS-95 standard CDMA system and a turbo-code for the CDMA 2000 system were proposed. Because of their recursive design, turbo codes provide better performance due to their constructional capabilities. The simulation was run in a Rayleigh fading environment, showing that the turbo code outperforms convolutional codes at low SNRs for both IS-95 and CDMA 2000 systems. Khoueiry and Soleymani proposed a system that evaluated a combination of the LDPC technique and Raptor codes in a Rayleigh fading channel[26]. In [14], a Raptor-coded OFDM system with Binary Phase Shift Keying (BPSK) was implemented for improving the BER of the codeless OFDM system, which was verified to offer enhanced error performance for OFDM over AWGN channels. M. Kadochb and D. Benzida suggested a new scheme for a massive MIMO communication system. In this scheme, the receiver uses the Raptor decoding symbols jointly with the MMSE technique, and this approach estimates the channel without using pilot symbols at the receiver [27].

3 Raptor code

Raptor code is considered as a more advanced variant of the LT code with low computational cost and the potential for minimizing channel effects [14]. It incorporates the advantages of block and Fountain codes to construct modern Fountain codes with linear encoding and decoding techniques. As shown in Fig. 1, the Raptor code consists of a serial concatenation of the high rate LDPC encoder as an outer code and the LT encoder as the inner code, resulting in better performance than the single LT codes[15][17]. Raptor codes are both theoretically and practically superior to LT codes. The generation of an encoding symbol in Raptor codes takes O(1) time. Furthermore, the Raptor coding concept eliminates the need for all input symbols to be reconstructed as it is required in LT codes [27].



(a)



(b)

Fig. 1 Raptor codes: (a) Structure, (b) Tanner graph[28].

First, a set of k input symbols are encoded into (n, k) blocks by error-correction block codes to create the intermediate symbol n. Then, these intermediate symbols are further coded with the LT codes. Every encoded symbol is created by selecting the degree d randomly through the degree distribution $\Omega(x)$, by choosing the distinct d input symbols randomly and xoring them. Thus, the (k, C, Ω(x)) parameters can be used to specify a Raptor code, where C represents the (n, k) of the error-correction block codes, also known as the pre-code, and Ω(x) represents the generated polynomial for the degree distribution of the LT code [28] . Raptor codes differ from LT codes due to the degree distribution and high-rate pre-code process performance. There are two types of raptor codes: systematic and non-systematic. We are mostly interested in the systematic case in which the source packets are included within the set of created encoded packets. Gaussian elimination can be used to find the inverse of the generating matrix in a systematic Raptor decoding process, following the established relations between the intermediate packets and the data packets. This process is due to the decoding of the k source packet symbols. The source packets are protected by the pre-code, which corrects erasure packets that the LT code cannot recover. The LT code complexity is reduced to the order of O(log k), which is superior to the typical LT code complexity of O(k log k). As a result, this serial concatenated block code might have a low level of complexity while still providing a high level of protection [28] . However, the Raptor technique can achieve any coding rate (k/n), depending on the lengths of the produced codewords. Assuming that BPSK modulation with 0 to +1 and 1 to -1 mapping is employed, the received signal for an AWGN channel with input data symbols $x_i = \pm 1$ is $y_i = x_i + n_i$, where $x_i = 1\text{-}2c_i$ represents the BPSK modulating signal, c_i is the encoded symbol, and n_i represents the Gaussian noise with zero mean and variance of σ^2. For each received symbol y_i, the Log-Likelihood Ratio (LLR) of the decoder can be calculated as follows [28][29] :

$$L(c_i) = ln\frac{P(c_i = 0 / y_i)}{P(c_i = 1 / y_i)} = \frac{2y_i}{\sigma^2} \tag{1}$$

where $n_i \sim N(0, \sigma^2)$ is a Gaussian random variable with zero mean and variance of σ^2. The two-step sequential decoding method introduced in [30] decodes the inner system first, then followed by the outer code. The sum-product algorithm (SPA) is used to decode a Tanner graph that uses intermediate variable nodes (VNs), and the output symbol represents the check nodes (CNs) to an inner decoder. The LLR updates the link j^{th} CN to i^{th} VN, which is referred to as L_{cjVi}, as well as the i^{th} variable node to j^{th} check node, indicating that L_{Vicj} is determined as follows [30] :

$$L_{C_jV_i} = 2\tanh^{-1}((\tanh\frac{L(C_j)}{2})\prod_{i'\in N_c(j)-\{i\}}\tanh(\frac{L_{i'}C_j}{2})) \tag{2}$$

$$L_{V_iC_j} = L(V_i) + \sum_{j'\in N_v(j)-\{j\}} L_{C_{j'}V_i} \tag{3}$$

$N_c(j)$ represent the set of the variable nodes connected to the j^{th} check node. Moreover, $N_v(i)$ displays the check node collection associated with the i^{th} variable node. After the decoded process is completed, the final value of LLR is connected using equation (3), which represents the decision rule for each variable node

(VN), and is used as the outer decoder's channel estimate. Since both the encoding and decoding processes of the Raptor code are performed using the SPA algorithm, then the code rate of the inner (R_i) and outer (R_o) codes are related by the overall code rate (R) [30] :

$$R = R_o R_1, \quad R_o = k/k', \quad R_o = k'/n \tag{4}$$

Where k in the number of the bits per packet entered into the encoder, k' is the number of bits per block at the output of the inner stage of the coder, and n is the number of the bits per block at the output of the channel encoder. It is assumed that for transmitting one codeword, the channel signal to noise ratio is E_b/N_o and the noise variance is $\sigma^2 = N_o/2$ [31].

4 Proposed Model of Hybrid channel Coding with CDMA System

The combination between CDMA transmission technique and Raptor channel coding will create a reliable communication system for sending data in low SNR channels. Implementing and testing the proposed scheme needs to build a general model for the communication system under fair environment to assess the effect of adding Raptor coding into the CDMA transmission system. This approach requires specifying the parameters of the system before starting the testing process through Matlab simulation. This section will describe the properties of the proposed system as illustrated in the following two sub-sections.

4.1 Raptor Coded DS-CDMA System

The block diagram of the proposed system, including the channel coding technique, is shown Fig. 2. In this work, we have investigated the system based on Raptor codes. The performance of this code depends partly on the structure of the pre-code parity-check matrix, H, for the LDPC codes that represent the first layer of the Raptor structure. It has been assumed that the structure of the parity-check matrix H has no girth of 4. Also, we have used a regular LDPC with dimensions of (4, 204) in H so that the number of ones per column is 4, and the number of ones per row is 204. These codes are characterized with a high code rate of 50/51 [32][29]. LDPC codes are usually represented by their parity-check matrices H of size M xK, where, M = N -K and H is the null space of the K xN generator matrix G. The second layer is the LT codes with weight distribution Ω(x) that is optimized for Raptor code and is set as[33]

$$\Omega(x) = 0.007969x + 0.493570x^2 + 0.166220x^3 + 0.072646x^4 + 0.082558x^5 + 0.056058x^8 + 0.037229x^9 + 0.055590x^{19} + 0.025023x^{65} + 0.0003135x^{66} \tag{5}$$

At the transmitter side, each user source of information bits is encoded through a raptor encoder to produce the FEC-encoded codeword symbol sequence with rate of R, and bit interval of $1/R$. Then, these encoded bits are modulated by BPSK. Afterwards, the modulated data streams are multiplexed by Walsh–Hadamard codes using a sequence of length M. The receiver can retrieve the desired signal by multiplying the received signal with the same Walsh code used during transmission. The de-mapped signal is then passed to the LT decoder, employing the belief propagation (BP) or SPA algorithm for decoding. After that, the log-likelihood ratio (LLR) output values from the LT decoder are entered to the LDPC stage which represents fixed-rate outer decoder. The Raptor code uses the LLR information to produce an estimation of the original data. Furthermore, the BER is then used to evaluate the coding scheme reliability for the desired E_b/N_o ratio.

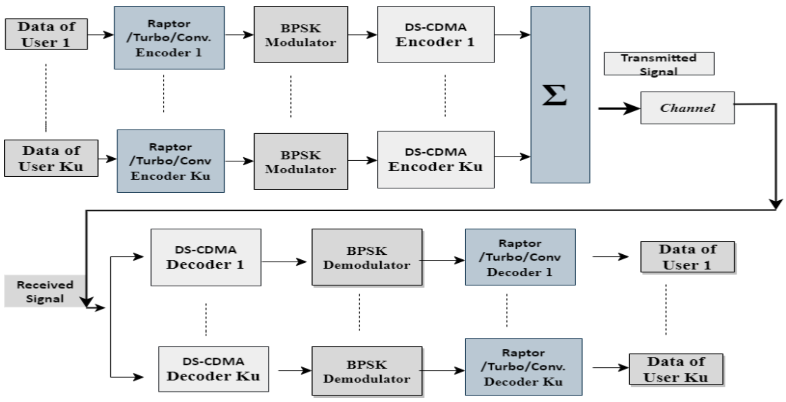


Fig. 2 Block Diagram for the System Model

4.2 Turbo/ convolutional -coded DS-CDMA System

We have also considerd the same communication system with the use of turbo and convolutional codes rather than Raptor encoder, as shown in Figure 2. At the transmitter side, the information bits are encoded and block-interleaved. For the turbo code, the encoding stage comprises two recursive systematic convolutional (RSC) encoders concatenated in parallel at a rate of 1/2, as specified in [12]. The traditional 1/3 rate in turbo code is converted to a rate of 1/2 by puncturing the parity bits alternately. On the other hand, for designing a convolutional encoder, the encoding level consists of RSC encoders with rate of 1/2. The encoded bits from Turbo/convolutional encoder for each user are modulated by BPSK. Then, the modulated data are multiplied with Walsh code sequence. The Turbo/convolutional coded DS-CDMA system uses the following two encoders. One of encoders has the constraint length of 7, the code rate of 1/2 and generators 133, 171, expressed in octal notation [34]. The other encoder has the same constraint length, the code rate of 1/3 and generators 133, 145, 171. Each system uses soft decision Viterbi decoding algorithm for the decoding process .

5 Performance Analysis of Proposed System Based on Hybrid Raptor Code with DS-CDMA

In this work, the performance characteristics of the proposed scheme consisting of a Raptor channel code in conjunction with DS-CDMA multiple access technique is examined and compared with other channel coding algorithms used with the same DS-CDMA system. Specifically, the BER versus SNR ratio is evaluated for four kinds of systems. In the first scheme, the DS-CDMA technique is used solely without channel coding. In the second system, a convolutional channel code is used prior to the modulation and multiple access stages, while in the third scheme a turbo channel code is utilized together with the DS-CDMA technique. Finally, in the last scheme, Raptor coding is used with the DS-CDMA system to illustrate its unique advantages in reducing the BER for very LSNR in which the noise level is comparable to the signal power. In the simulation process, data are modulated with BPSK then transmitted in the form of packets with a block length of k =1000 and the four schemes are analyzed under the same SNR and channel conditions.To simplify the system simulation, we set the number of users in each Raptor-CDMA cell to be 4, and used Walsh-Hadamard code with length of 4 for different users. Also, to investigate the performance of the Raptor coded DS-CDMA system; we have used a DS-CDMA system with a spreading code of length equal to 8 and evaluated its performance before inserting the channel coding stages for comparison purposes. Table (1) summarize the parameters used in the simulation process .Where these parameters represent the most practical and used values in previous work. Raptor codes include several steps or stages, as shown in Algorithm (1),(2)

Table 1 Basic parameters of the Raptor code

Parameters	**Specifications**
LT code parameters	$\Omega(x)$
Number of bits per Raptor packet	1000
Number of source packets K	1000,10000
Raptor code rate	1/2,1/3,5/7
LDPC component code	dv=4, dc =204
Code rate of LDPC	R=50/51
LDPC&LT decoding algorithm	SPA
Modulation	BPSK
Channel	AWGN

Algorithm (1): Proposed Algorithm of Raptor Encoding combined with Walsh code

Input: Let source block s [1xk], k denotes the number of source symbols
Determine realized code rate R, k, d, Walsh Hadamard (WH) codes
Length of chip sequences = WH = 4
Wm is a unique, orthogonal code word (Walsh Hadamard) of length m
Output: Raptor encoded symbols multiplied with Walsh code (**total encoded traffic on the channel**) (coded transmission for each J senders.

Procedure :

- Calculate n = k/R
- Generate G matrix of size [kxn],
- Generate Encoded codeword t_{LDPC} = s G
- Sample the degree distribution used for a degree d.
- Select d source symbol uniformly at random
- XOR the selected source symbols
- Repeat the previous last three steps n times -> Raptor codeword = T_R
- Generate coded four Walsh codewords of length 4. (Walsh codes are simply built from Hadamard matrices)
- Generate coded transmission for each J sender $Z_{i,m}^{J} = T\_R * W_m^J$
- total encoded traffic on the channel= $Z_{i,m}^{T} = \sum_{m=1}^{4} Z_{i,m}^{J}$

Algorithm (2): Decoding of Proposed Algorithm

Input: Received code word $y[1x\,\boldsymbol{WH} \ * n]$ where n denotes number of collected encoded symbols

Let y[$1x\,\boldsymbol{WH} \ * n$] = $Z_{i,m}^{T}$ +e, where e is the errors or noise added by the channel.

Output: decoded word with approximate of source symbols

- Procedure:
- Multiply Received code word y[1x $\boldsymbol{WH}$ *n] with $\boldsymbol{WH}$
- Use the same distribution used by the encoder and the same random generator to reconstruct the generator matrix G_{LT} of LT decoder.
- Use G_{LT} to build the dynamic decoding graph
- Check nodes represent the n symbols in y
- Variable nodes represent the m encoded symbols by the precode.
- Decode on the dynamic graph for certain number of iterations.
- Pass the final $LLRs$ for each of the m symbols to the static (LDPC) part of the decoding graph
- Run for certain number of iterations.
- Reach a decision about the value of each bit

In Fig. 3, BER performances of three Raptor codes of block lengths 500, 1000, and 2000 bits are shown using BPSK modulation scheme and sum-product decoding algorithm with 50 iterations . The curves in this figure show that the BER performance improves with the increased code block length. Fig. 4 shows the results of simulated BER performance of a single-user Raptor coded DS-CDMA system together with a Turbo/Convolutional coded DS-CDMA system with a common source block length of k =1000, code rate of R = 1/3, and a spreading code with length equal to 4. Compared to the Turbo and convolutional coded CDMA systems, the Raptor coded DS-CDMA system has achieved an improvement in the SNR of about 6 dB for a BER = 10^{-6}.

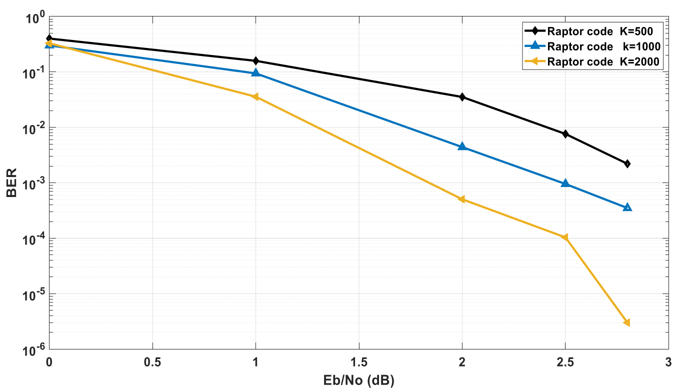


Fig. 3 BER performance of Raptor code of rate ½ as a function of code length

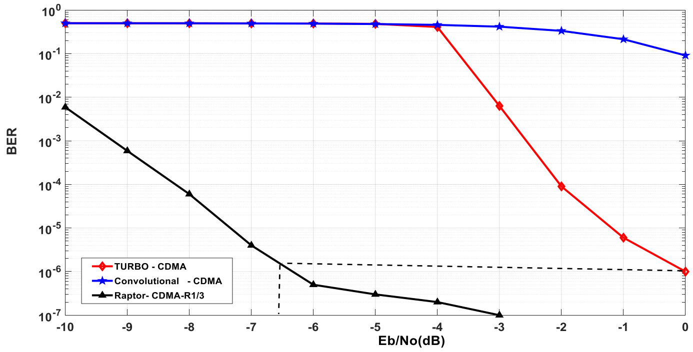


Fig. 4 BER comparison of Raptor coded DS-CDMA system with turbo- and convolutional-CDMA schemes with k =1000 and code rate =1/3.

According to the results of simulation presented in Fig. 5. The receiver in the Raptor-coded CDMA scheme using a spreading factor of length of 4 outperforms the conventional DS-CDMA receiver that uses a higher spreading factor with length of 8. Besides, the Raptor-coded system achieves an improvement in the Eb/No ratio of about 7 dB when compared with the Turbo/Convolutional coded DS-CDMA schemes for a BER = 0.008, message block length of k=1000, and a code rate R = 1/2 for each system.

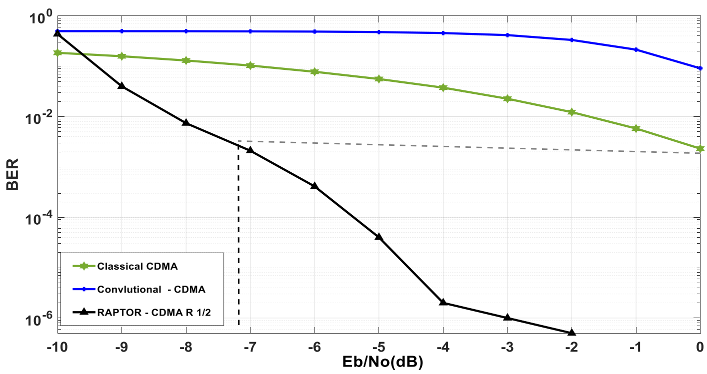


Fig. 5 BER comparison of Raptor coded DS-CDMA system with turbo, convolutional and conventional CDMA systems with k =1000 and code rate =1/2.

From these test results (Table 1, Fig. 4, and Fig. 5), we can observe the consistency of the theoretical prediction after comparing it with the practical results, indicating that Raptor codes greatly improve the performance of the conventional CDMA transmission scheme under the same conditions. On the other hand, our simulation result shows that convolutional-encoders present the weakest performance in comparison with both the turbo and Raptor codes. It is obvious that the Raptor-coded DS-CDMA scheme provides superior performance under low Eb/No conditions, and therefore it is highly recommended to be used in such channels. Fig. 6 presents the BER performance comparison of a single-user Raptor coded DS-CDMA system for k = 1000 for different code rates of 1/3, 1/2, and 5/7, respectively using a spreading factor with a length of 4. The results show that the performance of the Raptor-coded DS-CDMA systems is superior at a code rate of 1/3 when compared to other code rate values. As a result, we conclude that using Raptor code with DS-CDMA is very effective in LSNR conditions and can provide reliable communication. In contrast, the traditional DS-CDMA receiver useless in this ranges due to its relatively high BER.

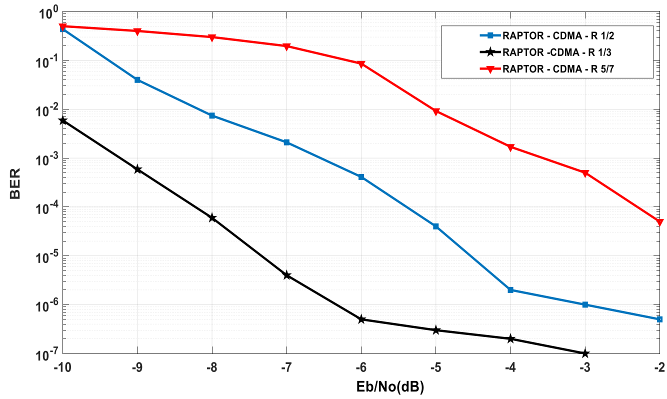


Fig. 6 BER comparison of Raptor code DS-CDMA system of block size k=1000 as a function of coding rate.

6 Performance Metrics of the Proposed Raptor code DS-CDMA system

To objectively compare different multiple access techniques when coupled with channel codes some quantitative performance metrics must be established. This section will introduce and discuss the primary metrics of performance used in this work to evaluate the proposed system (Raptor code DS-CDMA) for WSN. These parameters when considered collectively, give a summary of the overall performance of tested codes.

A- Number of Lost Packet (NLP)

This metric is used to examine the error performance of the scenarios offered; it determines the quantity of data loss by calculating the percentage of lost packets (NLPP). It's also used to assess how well the technologies on display can withstand a data loss attack. The following equations are used in the simulation program to calculate this scale.

$$NLP = N_{all} - N_c \tag{6}$$

$$NLPP = (\frac{NLP}{N_{all}})x100 \quad (7)$$

The N_{all} represents the total number of packets transferred. The N_c represents received repaired packets. Every packet that has at least one erroneous bit after decoding is referred to as a lost packet. The number of lost packet percentages is used as a metric in the results section to compare the error performance of the traditional and proposed LSNR transmission scenarios. This metric NLP is shown in Fig. 7.

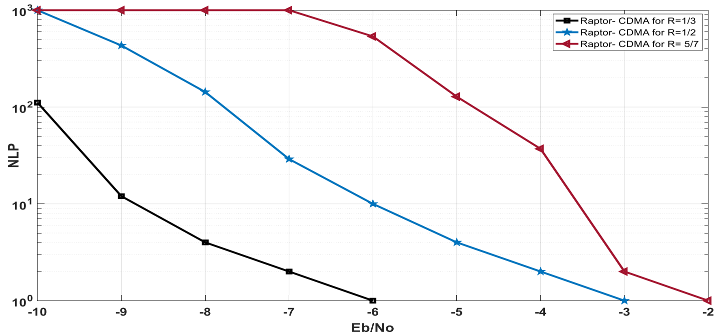


Fig. 7 NLP of Raptor code DS-CDMA system vs. Eb/No over BI-AWGN channel with different code rate

B- Throughput Performance

The throughput assessment is one of the most important assessments for wireless networks. It refers to the ability of a wireless network to provide high data rates and achieve resource efficiency. Throughput or capacity is the number of bits that can be processed by a decoder, or the amount of data that the decoder can process in a given time [35]. The throughput can be considered one of the vital metrics for measuring the performance of communications systems. In this work, throughput η (bit per second) was defined as:

Throughput= η=k(1-BER)/(4*n) (8)

Where *k* is the source is a symbol (encoded message) and n is the code word message.

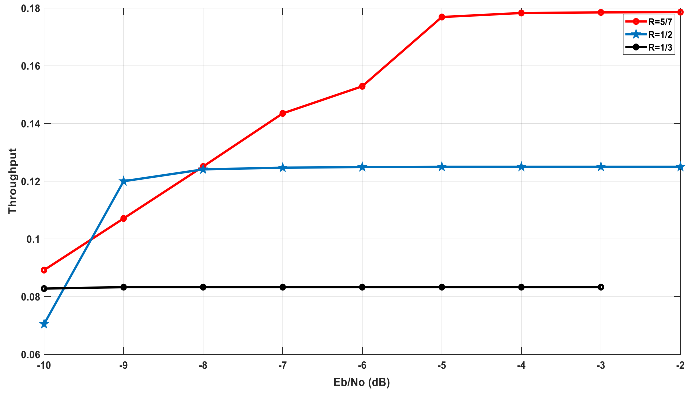


Fig. 8 Throughput performance of Raptor code DS-CDMA as a function of code rate

C-Computational complexity

Computational complexity represents the number of computations performed by an algorithm, e.g. encoder or decoder, to process a data array. This parameter has a unimpact on the latency of the decoder so low computational complexity is one of the most important requirements for WSN. In general, the required operations for the encoding or decoding processes are referred to as the computational complexity of coding scheme. The computational complexity of a system/process is described as the total amount of arithmetic, logic, and memory access operations necessary for this process. The combination between the DS-CDMA transmission technique and Raptor channel coding will create a reliable communication system for sending data in LSNR channels. Implementing and testing the proposed scheme needs to build a general model for the communication system under a fair environment to assess the effect of adding Raptor coding into the DS-CDMA transmission system. This approach requires specifying the computational complexity before starting the testing process through hardware implementation. The computations performed by Raptor code need an average number of operations per generated encoded symbol for a given source block of k symbols, and overhead $\epsilon > 0$ is $O[\log(1/\epsilon)]$. On the other side, the number of operations required to decode the received data is $O[k\log(1/\epsilon)]$ per symbol. However, the implementation of the DS-CDMA with Walsh–Hadamard Code of order $n=2^m$ adds a computational complexity of $O(n^2)$, where m is the number of bits and n is the code length [36],[37]. Therefore, the total computational complexity of the proposed system of Raptor code DS-CDMA combines the computational complexity of Raptor code with the Computational complexity of DS-CDMA and is calculated as:

Table 2 Computational complexity of raptor code, turbo code, and some of the Previously channel code methods in the literature

Channel coding Type	Computational complexity	parameters

Turbo[38]	I_{max} x16xkx2^{m} +I_{max} x8xkx2^{m}	m=memory length. I_{max}=itt max
Convolution code (CC) [39]	O[(2^{L} k+ 2^{L} m)]	m is the memory length of the encoder or the number of shift registers used in the encoder. the constraint length L would be $\mathrm{L} = \mathrm{m} + 1$
Raptor [17]	O[klog(1/ϵ)],	ϵ is epsilon= 0.038
DS-CDMA with Walsh code	O(n^{2}), where $n = 2^{m}$	m is the number of bits and n is the code length

Table 3 comparison of the computational complexity of Raptor code and turbo code

Code Scheme	Parameters						Complexity No of math and logic operation	Complexity Ratio w.r.t. Turbo Decoder(%)
	k	L	m	N = K/R	R	I_{itt_max}		
Turbo		-	3	-		10	960000	100
CC	500	7	6	1000	1/2	-	64768	6.7466
Raptor		-	-	1000		-	18687	1.9466
DS-CDMA	-	-	2	-			16	0.00167
Raptor + DS-CDMA	500	-		1000			18703	1.948229
Turbo		-	3	-		10	1920000	100
CC	1000	7	6	2000			128768	6.7067
Raptor		-	-	2000	1/2		37374	1.9465625
DS-CDMA		-	2	-			16	0.00083
Raptor + DS-CDMA				2000			37390	1.94739
Turbo		-	3	-		10	3840000	100
CC	2000	7	6	4000			256768	6.6867
Raptor			-	4000	1/2		74748	1.9466
DS-CDMA		-	2	-			16	0.00041
Raptor + DS-CDMA		-		4000			74764	1.94698

7 Conclusions

This paper has studied and compared the performance of turbo-coded and convolutional-coded with DS-CDMA schemes with a Raptor-coded with DS-CDMA scheme for multi-user communication systems over AWGN channels. A high code rate and girth test selection are developed to design a regular LDPC parity check matrix H for the outer encoder of Raptor code. This work showed that the Raptor code BER performance with the DS-CDMA system, including

BPSK over AWGN channels, is superior to other schemes. The simulation results concluded that the Raptor code DS-CDMA with a short length of raptor codes and Walsh code length of 4 and a lower number of decoding iterations could achieve better performance than conventional DS-CDMA with Walsh code length of 8. The performance analysis of Raptor CDMA and Turbo/convolutional coded multiuser DS-CDMA systems having code rates of 1/3, 1/2, and 5/7 is analyzed. Simulation results showed that the Raptor-coded CDMA system is better than the conventional CDMA transmission system under the same channel conditions. When used with the CDMA system, it also outperforms other channel coding schemes like the Turbo and convolutional codes. Thus, the Raptor-coded CDMA system is a promising candidate to work reliably under severe noise and low power conditions.

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Data Availability The corresponding author may provide the data and material used in the manuscript subjected to reasonable request.

Code Availability The code of the algorithm has been run in MATLAB software.

Declarations

Confict of interest The authors have no conficts of interest.

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