Exact BER Performance Analysis of an Elementary Coding Techniques for NOMA System on AWGN Channel

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Abstract. *Ultra-Reliable Low Latency Communication (URLLC) requirements of modern wireless communication systems have heightened the need for complexity reduction in data processing along with error detection and correction techniques. Motivated by this fact, we introduce a low-complexity coding scheme for Non-Orthogonal Multiple Access (NOMA). Furthermore, this work presents a comprehensive mathematical analysis of the proposed coded NOMA communication system and evaluates its Bit Error Rate (BER) performance in various scenarios. Our study showcases a precise match between practical and theoretical results, underlining the presented mathematical analysis precision. Moreover, we conduct a comparison between the proposed NOMA system and other coded and uncoded NOMA systems. This comparison highlights the superior performance of the proposed system, providing evidence of its potential to achieve the desired complexity reduction without compromising performance. Finally, in the same work environment, it is worth noting that the proposed system demonstrated superior performance compared to typical uncoded NOMA systems. It achieved a minimum improvement of 21 dB for the 1st user and a 17 dB improvement for the 2nd and 3rd users.*

Keywords

NOMA, constructive interference, BER, repetitive code, channel coding

1. Introduction

Non-Orthogonal Multiple Access (NOMA) is an emerging technology that has garnered considerable attention in recent years as a promising solution to meet the growing demand for high-speed and reliable wireless communications. NOMA offers numerous enhancements to modern communication systems, including the capability to accommodate more users within the same network compared to conventional Orthogonal Multiple Access (OMA) systems [1]. Furthermore, NOMA improves both coverage and spectral efficiency by enabling users near and far to use the same frequency simultaneously [2], [3]. This reduces delays and enhances the overall efficiency of data transmission within the network. Moreover, NOMA enhances security as eavesdroppers face challenges in decoding the transmitted data.

Even though NOMA offers various benefits, NOMA systems have faced several challenges. These challenges include complex signal processing techniques and algorithms, interference, and the complexity of determining optimal power allocation coefficients [4–7]. Hence, the aforementioned challenges need to be considered in the research to optimize the overall performance of NOMA systems. Many researchers have already started addressing these challenges and exploring solutions to enhance NOMA system performance.

The fundamental concept of NOMA decoding operations involves Successive Interference Cancellation (SIC), which is a sequential process that includes decoding, regeneration, and subtraction. The decoding and encoding system begins by decoding the strongest user signal (usually the farthest user) while treating the remaining signals as interference. After successful decoding, the data are re-encoded to subtract it from the received signal and reshape the data of the remaining users and so forth [8–11]. Inaccurate reconstruction of the data from the first user will result in erroneous data propagation into subsequent users' received signals. Furthermore, the sharing of transmitting energy among users exposes the data to noise and increases the risk of potential data loss. While the proposed system does not require SIC for data reconstruction of the three users, each user's data reconstruction solely depends on the data received for that specific user.

Meanwhile, in certain scenarios, NOMA reduces spectral efficiency due to interference between users' signals and the sub-optimal allocation of power [12]. To address this issue, the researchers in [13–15], utilize frameworks based on the NOMA energy domain, which enhances the usage of resources. However, these frameworks face a set of limita-

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tions, including the additional complexity of the frequency blocks required for each group of users or devices connected to the network and the presence of a sub-optimal power gap between users. It is important to note that our proposed system differs from these frameworks, as the three users in our system transmit their data using the same frequency band. Furthermore, the process of selecting the ideal power factor is much simpler compared to these existing systems.

In [16], the authors focused on improving the power allocation approach for down-link NOMA systems and introduced the Artificial Bee Colony (ABC) algorithm as a more efficient solution. In [17], researchers addressed optimal power allocation in a multi-user down-link Hybrid-NOMA system. They proposed fast algorithms for users' Sum-Rate (SR) and system Energy Efficiency (EE) maximization while analyzing algorithm complexity and discussing potential extensions. Another study proposed optimal power allocation for weighted sum-rate maximization in a down-link NOMA network. The study validated the approach through extensive simulations for a two-user system [18]. Utilizing these complex algorithms for estimating optimal power allocation factors for NOMA users introduces system complexity that may not be suitable for all scenarios considering factors such as channel type, noise, and terminal device limitations. Additionally, some of these methods are unrealistic and impractical.

In [19], we proposed a low-complexity coding technique dedicated to NOMA, supporting two users using a repetitive coding scheme for user one and encoding every "0" as "01" and "1" as "10" for user 2. This coding method achieved good BER performance and reduced NOMA system complexity by eliminating the need for SIC. While this scheme provides a solid foundation for such a coding technique, it is not sufficient for accommodating more than two users. In contrast, this paper supports a 3-user NOMA system with constructed encoding methods detailed in Sec. 2. This new scheme significantly improves the system's performance and reduces the complexity, especially in scenarios involving three users.

After reviewing the foregoing literature, the main contributions of this manuscript can be succinctly outlined as follows:

1. Proposing a coded NOMA communication system for three users that exploits the interference between their signals and transforms it into constructive interference to enhance the BER performance.
2. Deriving mathematical expressions for the BER performance of the proposed system in the cases of two and/or three users and demonstrating the accuracy and consistency of both practical and theoretical results.
3. Measuring the complexity levels of the proposed system and the conventional uncoded NOMA reveals that the former presents less complexity. This advantage translates into reduced time and computational demands when utilizing the proposed system.
4. The most significant achievement of the proposed system is the elimination of the need for SIC operations in decoding the received data for all three users in the system.
5. The ultimate achievement of the proposed system is the elimination of the need for complex algorithms to calculate optimal power allocation coefficients for each user. This is possible because the system completely eliminates interference between the signals of the three users. Therefore, there is no requirement for complex algorithms to determine the ideal power allocation coefficients. Additionally, the only condition for selecting the power allocation coefficients is when one of the users experiences a harsh channel.

The remaining sections of the paper are organized as follows: Section 2 introduces the system model of the proposed coded-NOMA system. Section 3 presents the theoretical analysis of the BER performance for the proposed 3-user coded NOMA system. Section 4 illustrates the obtained findings and discusses their significance. Lastly, Section 5 provides the conclusions of the work.

2. System Model

Figure 1 depicts the structured coded NOMA system for three users on an AWGN channel. The input messages for users 1, 2, and 3 are represented by m_1, m_2 and m_3, respectively. The input message stream is first decoded using elementary encoding processing, and the resulting codewords are:

$$\mathbf{C}_1 = \{c_1^1, c_1^2, c_1^3, c_1^4\} = \{m_1, m_1, m_1, m_1\}, \tag{1}$$

$$\mathbf{C}_2 = \{c_2^1, c_2^2, c_3^3, c_3^4\} = \{m_2, \bar{m}_2, m_3, \bar{m}_3\}, \tag{2}$$

$$\mathbf{C}_3 = \{c_2^1, c_2^2, c_3^3, c_3^4\} = \{m_2, \bar{m}_2, m_3, \bar{m}_3\} \tag{3}$$

where $\mathbf{C}_1$, $\mathbf{C}_2$, and $\mathbf{C}_3$ are the 4-bit codewords for users 1, 2, and 3, respectively. It can be observed from (2) and (3) that the output of the second encoder is used as input to the third encoder for the first two bits, while the output of the third encoder is used as input to the second encoder for the last two bits. Next, the obtained codewords are fed into a binary phase shift keying (BPSK) modulator, which maps each "0" bit to a "-1" and each "1" bit to a "+1". The output of that modulator will be denoted as $\mathbf{X}_1$, $\mathbf{X}_2$, and $\mathbf{X}_3$, respectively.

Then, the superposition encoding technique is applied to assign the dedicated power allocation coefficients for each user. Typically, the highest power allocation is assigned to the far user, and so on, to reduce the interference between users' signals. It is worth noting that in our proposed system this will not be the case, since the structured coding will benefit from this interference as a constructive interference. The superposition encoding can be expressed mathematically as:

$$\mathbf{X} = \sqrt{a_1 E_c}\mathbf{X}_1 + \sqrt{a_2 E_c}\mathbf{X}_2 + \sqrt{a_3 E_c}\mathbf{X}_3 \tag{4}$$

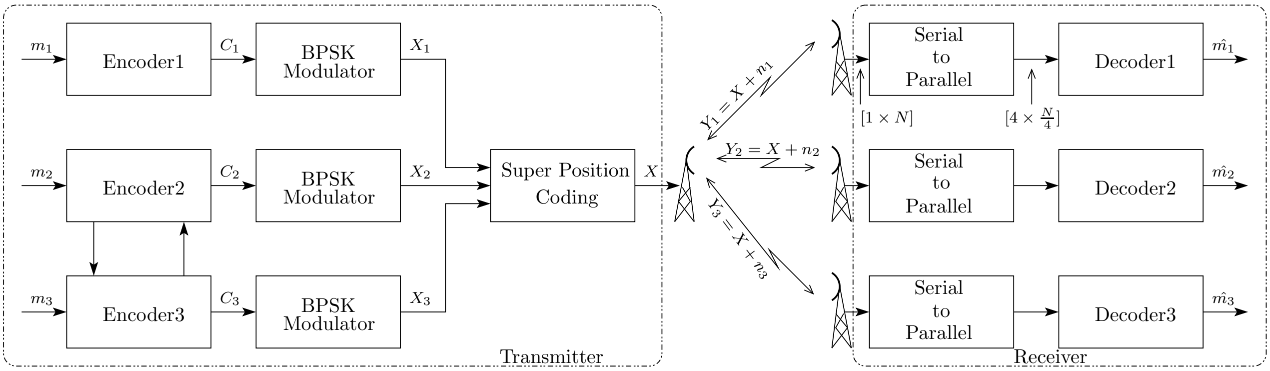

Fig. 1. Structured low-complexity coded NOMA system diagram for 3 users.

where E_c represents the energy per encoded bit and it is equivalent to $E_b R$, where E_b represents the energy of uncoded bit and R is the code rate. Furthermore, a_1, a_2, and a_3 denote the power allocation coefficients for the 1st, 2nd, and 3rd users, respectively, and $a_1 + a_2 + a_3 = 1$.

Equation (4) represents the general formula, whereas in the proposed system, the superposition codewords are processed bit by bit. Therefore, the mathematical expression for the superposed signal of each bit can be represented as:

$$\mathbf{x} = \sqrt{E_c}\left[\sqrt{a_1} \quad \sqrt{a_2} \quad \sqrt{a_3}\right] \times \begin{bmatrix} x_1^1 & x_1^2 & x_1^3 & x_1^4 \\ x_2^1 & x_2^2 & x_3^1 & x_3^2 \\ x_2^1 & x_2^2 & x_3^1 & x_3^2 \end{bmatrix}. \quad (5)$$

If we apply our understanding of (5), we can derive the superposed signal for each bit of the 4-bit codewords per user as follows:

$$x^1 = \sqrt{E_c a_1} x_1^1 + \sqrt{E_c a_2} x_2^1 + \sqrt{E_c a_3} x_2^1, \quad (6)$$

$$x^2 = \sqrt{E_c a_1} x_1^2 + \sqrt{E_c a_2} x_2^2 + \sqrt{E_c a_3} x_2^2, \quad (7)$$

$$x^3 = \sqrt{E_c a_1} x_1^3 + \sqrt{E_c a_2} x_3^1 + \sqrt{E_c a_3} x_3^1, \quad (8)$$

$$x^4 = \sqrt{E_c a_1} x_1^4 + \sqrt{E_c a_2} x_3^2 + \sqrt{E_c a_3} x_3^2 \quad (9)$$

where the subscript x_i denotes the i-th user, and the superscript x^i denotes the i-th bit in the codeword.

The output of the superposition encoder, $\mathbf{X}$, will be broadcasted to all the users in the network. Our scenario involves three users and the received signal at each node can be given as:

$$\mathbf{Y}_1 = \sqrt{E_c a_1}\mathbf{X} + \sqrt{E_c a_2}\mathbf{X} + \sqrt{E_c a_3}\mathbf{X} + N_1, \quad (10)$$

$$\mathbf{Y}_2 = \sqrt{E_c a_1}\mathbf{X} + \sqrt{E_c a_2}\mathbf{X} + \sqrt{E_c a_3}\mathbf{X} + N_2, \quad (11)$$

$$\mathbf{Y}_3 = \sqrt{E_c a_1}\mathbf{X} + \sqrt{E_c a_2}\mathbf{X} + \sqrt{E_c a_3}\mathbf{X} + N_3 \quad (12)$$

where $\mathbf{Y}_i$ denote the i-th user's received signal and N_1, N_2, and N_3 are the additive white Gaussian noise signal for 1st, 2nd and 3rd user, respectively.

The decoding process begins with transforming the received stream into a parallel signal, given by:

$$\mathbf{Y}_{[1 \times N]} = \mathbf{Y}_{\left[4 \times \frac{N}{4}\right]}. \quad (13)$$

After undergoing elementary encoding, the input message streams are processed by the first decoder, which adds each group of four bits together before making a decision. Eventually, the decision-making process for the first decoder is based on the equation shown below:

$$\hat{m}_1(i) = \begin{cases} 1, & \text{if } Y_1^1(i) + Y_1^2(i) + Y_1^3(i) + Y_1^4(i) > 0 \\ 0, & \text{else} \end{cases} \quad (14)$$

where $\hat{m}_1(i)$ is the estimated bit value for the ith bit of the 1st user.

While the decision for the 2nd user will be based on the following conditions:

$$\hat{m}_2(i) = \begin{cases} 1, & \text{if } Y_2^1(i) - Y_2^2(i) > 0 \\ 0, & \text{else.} \end{cases} \quad (15)$$

Finally, the following simple conditions are used to evaluate the original messages of the 3rd user after the decoding process:

$$\hat{m}_3(i) = \begin{cases} 1, & \text{if } Y_3^3(i) - Y_3^4(i) > 0 \\ 0, & \text{else.} \end{cases} \quad (16)$$

In essence, the proposed system shown in Fig. 1 can be extended to include more than three users by adding another elementary encoder for each additional user on the transmitting side. The energy allocation for each user is determined by dividing a portion of the total energy available in the system by the number of users. While on the receiving side, an additional decoder should be added, along with one more serial to parallel block for converting the signal to the suitable form for making a decision.

Alternatively, if the system is designed to serve only two users, it is possible to eliminate the need for *Encoder*$_3$ and *Decoder*$_3$, and the superposed signal for 1st and 2nd user can be expressed, respectively as:

$$\mathbf{X} = \sqrt{a_1 E_c}\mathbf{X}_1 + \sqrt{a_2 E_c}\mathbf{X}_2. \quad (17)$$

m_1	m_2	m_3	x_1				x_2				x_3				D_1	D_2	D_3	$\hat{m}_1$	$\hat{m}_2$	$\hat{m}_3$
0	0	0	–1	–1	–1	–1	–1	1	–1	1	–1	1	–1	1	–3.34	–1.52	–1.52	0	0	0
1	0	0	1	1	1	1	–1	1	–1	1	–1	1	–1	1	3.34	–1.52	–1.52	1	0	0
0	1	0	–1	–1	–1	–1	1	–1	–1	1	1	–1	–1	1	–3.34	1.52	–1.52	0	1	0
1	1	0	1	1	1	1	1	–1	–1	1	1	–1	–1	1	3.34	1.52	–1.52	1	1	0
0	0	1	–1	–1	–1	–1	–1	1	1	–1	–1	1	1	–1	–3.34	–1.52	1.52	0	0	1
1	0	1	1	1	1	1	–1	1	1	–1	–1	1	1	–1	3.34	–1.52	1.52	1	0	1
0	1	1	–1	–1	–1	–1	1	–1	1	–1	1	–1	1	–1	–3.34	1.52	1.52	0	1	1
1	1	1	1	1	1	1	1	–1	1	–1	1	–1	1	–1	3.34	1.52	1.52	1	1	1

Tab. 1. CodeBook of all valid codewords of the proposed coded NOMA System, when the power allocation coefficients for the 1st, 2nd and 3rd users are; $a_1 = 0.7$, $a_2 = 0.2$ and $a_3 = 0.1$, respectively.

To numerically clarify these processes of encoding, modulating, superposing, transmitting, and receiving, as well as to provide a clear representation of the results at each step, Tab. 1 was created for this purpose. Table 1 shows all possibilities for messages sent by three users, M_1, M_2, and M_3, as well as the entire path that this data go through in terms of encoding, superposing, transmitting, and receiving. The data are encoded and modulated, and the output of these operations is represented by x_1, x_2, and x_3 in the table. The decision-making process will be based on the product of the conditions in (14), (15), and (16), which is represented by the columns D_1, D_2, and D_3 in the table. The power allocation for a_1, a_2, and a_3 is set to 0.7, 0.2, and 0.1, respectively. Finally, the decoded messages are represented in the table as $\hat{m}_1$, $\hat{m}_2$, and $\hat{m}_3$, corresponding to the transmitted data of the 1st, 2nd, and 3rd users, respectively, assuming a noise-free environment for simplicity.

3. BER Performance Analysis

This section presents the theoretical BER performance analysis of the proposed 3-user coded NOMA system. In essence, we derive and introduce the exact mathematical expression for the BER performance of the proposed system.

First, the performance of the 1st user in the proposed 3-user coded NOMA system will be derived. The received signal for the 1st user is characterized by (10), where, the BPSK modulation and an AWGN channel model with zero mean and σ^2 variance (i.e. $\mathcal{N}(0, \sigma^2)$) are considered. The additive noise is represented by the random variable τ_i, which follows a Gaussian probability density function (PDF), such that

$$f(\tau) = \frac{1}{\sqrt{2\pi\sigma^2}} \mathrm{e}^{-\frac{\tau^2}{2\sigma^2}} \tag{18}$$

where τ_i is a Gaussian random variable that represents the i-th sample of the additive noise with zero mean and σ^2 variance.

Since the modulation scheme used is BPSK, only the real part of the N_1 in (10) will have an impact on the decision-making process, so we can rewrite (18) as [20]:

$$f(\tau) = \frac{1}{2\sqrt{\pi\sigma^2/2}} \mathrm{e}^{-\frac{\tau^2}{2\sigma^2/2}}. \tag{19}$$

So the error will occur only if the summation in (14) is less than the level of the real part of N_1 and the probability of error can be expressed as:

$$P_{\mathrm{u}_1} = P\left(N_1(i) \geq Y_1^1(i) + Y_1^2(i) + Y_1^3(i) + Y_1^4(i)\right) \tag{20}$$

where Y_1^1, Y_1^2, Y_1^3 and Y_1^4, if the transmitted bit is 1, respectively, are:

$$Y_1^1 = \sqrt{E_\mathrm{c} a_1} \pm \sqrt{E_\mathrm{c} a_2} \pm \sqrt{E_\mathrm{c} a_3}, \tag{21}$$

$$Y_1^2 = \sqrt{E_\mathrm{c} a_1} \mp \sqrt{E_\mathrm{c} a_2} \mp \sqrt{E_\mathrm{c} a_3}, \tag{22}$$

$$Y_1^3 = \sqrt{E_\mathrm{c} a_1} \pm \sqrt{E_\mathrm{c} a_2} \mp \sqrt{E_\mathrm{c} a_3}, \tag{23}$$

$$Y_1^4 = \sqrt{E_\mathrm{c} a_1} \mp \sqrt{E_\mathrm{c} a_2} \pm \sqrt{E_\mathrm{c} a_3}. \tag{24}$$

As it is clear, the combination of these four equations will always lead to $4\sqrt{E_\mathrm{c} a_1}$ and (20) can be rewritten as

$$P_{\mathrm{u}_1} = P\left(N_1 \geq 4\sqrt{E_\mathrm{c} a_1}\right). \tag{25}$$

Eventually, the probability of error can be calculated by integrating (19) for the period from $4\sqrt{E_\mathrm{c} a_1}$ to infinity, as shown

$$P\left(N_1 \geq 4\sqrt{E_\mathrm{c} a_1}\right) = \frac{1}{\sqrt{2\pi\sigma^2/2}} \int_{4\sqrt{E_\mathrm{c} a_1}}^{\infty} \mathrm{e}^{-\frac{\tau^2}{2\sigma^2/2}} \mathrm{d}\tau. \tag{26}$$

Substituting $\frac{\tau}{\sigma}$ with μ, then $\mathrm{d}\tau = \mu \mathrm{d}\mu$ and the above equation can be updated as [21]:

$$P\left(N_1 \geq 4\sqrt{E_\mathrm{c} a_1}\right) = \frac{1}{\sqrt{2\pi}} \int_{4\sqrt{\frac{E_\mathrm{c} a_1}{\sigma/2}}}^{\infty} \mathrm{e}^{-\frac{\mu^2}{2}} \mathrm{d}\mu. \tag{27}$$

Equation (27) can be simplified by using the Q-function and the probability of error of the received data by the far user (P_{e_1}) can be expressed as follows

$$P_{\mathrm{e}_1} = Q\left(\sqrt{\frac{4E_\mathrm{c} a_1}{\sigma^2}}\right) = Q\left(\sqrt{8Ra_1 SNR}\right). \tag{28}$$

While the decoding process for the 2nd user as can be seen in (15) is based on subtracting the first bit of received signal from the second one (i.e., $Y_2^1 - Y_2^2$) and compares the result to a threshold value to estimate the transmitted symbol $\hat{m}_2$.

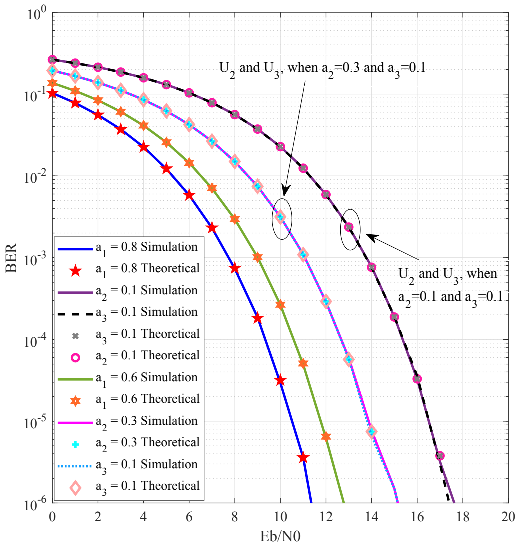

Fig. 2. Simulation and theoretical BER versus SNR for the proposed coded NOMA system with 3 users and various power allocation coefficients.

These received signals can be mathematically expressed as:

$$Y_3^1 = \sqrt{E_c a_1} \pm \sqrt{E_c a_2} \pm \sqrt{E_c a_3}, \tag{29}$$

$$Y_3^2 = \sqrt{E_c a_1} \mp \sqrt{E_c a_2} \mp \sqrt{E_c a_3}, \tag{30}$$

afterwards, subtracting these signals if the transmitted bit of the 2nd user is 1, will necessarily produce, $2\sqrt{E_c a_2}+2\sqrt{E_c a_3}$. By following the same previous steps to calculate P_{e_1}, the probability of error for the 2nd user (P_{e_2}) can be formulated as follows:

$$P_{e_2} = Q\left(\sqrt{4R\left(\sqrt{a2}+\sqrt{a3}\right)^2 SNR}\right). \tag{31}$$

In addition, the probability of the 3rd user receiving the data in error can be computed by taking into account the condition described in (16)

$$Y_3^3 = \sqrt{E_c a_1} \pm \sqrt{E_c a_2} \mp \sqrt{E_c a_3}, \tag{32}$$

$$Y_3^4 = \sqrt{E_c a_1} \mp \sqrt{E_c a_2} \pm \sqrt{E_c a_3}, \tag{33}$$

and the subtraction of these equations will inevitably result; $(2\sqrt{E_c a_2} + 2\sqrt{E_c a_3})$, so the probability of error for the 3rd user (P_{e_3}) will be:

$$P_{e_3} = Q\left(\sqrt{4R\left(\sqrt{a2}+\sqrt{a3}\right)^2 SNR}\right). \tag{34}$$

It is worth mentioning and noting that the performance of the proposed system will be identical for the 2nd and 3rd users and this is shown by (31) and (34) and Fig. 2.

Figure 2 presents the performance analysis of the proposed system using both simulation and theoretical results, for different power allocation parameters. The figure highlights the consistency between the practical and theoretical findings, which serves as evidence of the validity and accuracy of the mathematical derivation of the proposed system's efficiency.

4. Results and Discussion

To showcase the benefits of the proposed coded NOMA system and enable comparisons with other coded and uncoded NOMA systems, various performance metrics such as BER and complexity level are evaluated and compared in this section. In this research, the results were obtained using the MATLAB-R2022b program on a Macintosh computer running the Sonoma 14.0 system with 16 GB of RAM, and powered by an Apple M2 Pro chip, where the code length is set to 1×10^6 for all scenarios.

Figure 3 presents the BER performance comparison between the proposed coded NOMA system and the uncoded NOMA system using BPSK modulation on an AWGN channel, where the power allocation coefficients for the 1st, 2nd, and 3rd users are set to $U_1 = 0.7$, $U_2 = 0.2$, and $U_3 = 0.1$, respectively. It is worth noting that, under the same working conditions, the proposed coded NOMA system demonstrates superior efficiency compared to the uncoded one. Precisely, for the 1st user, the proposed system shows a 21 dB improvement, while for the 2nd and 3rd users, it shows a 17 dB improvement, highlighting the significant benefits of the proposed system.

Figure 4 presents a comparison between the proposed coded NOMA system and the $(1, 7/5)_8$ convolutional coded NOMA system with a code rate of $\frac{1}{2}$. This comparison is essential to evaluate the effectiveness of the proposed coding technique and identify potential areas for improvement. However, it is important to first evaluate the performance of the two coding techniques for a conventional communication system (i.e., single user) before proceeding with a coded NOMA comparison. As shown in this figure, the convolution code performs better for a single user and can reach a BER of 1×10^{-6} at an SNR value of 6.9 dB, while the proposed coding scheme for a single user can attain the same BER level at 10.5 dB SNR. This highlights the advantage of convolutional codes for single-user systems. However, it is important to note that the performance of the convolutional coded NOMA system can degrade when used in conjunction with NOMA due to interference among the users.

In Fig. 5, a comparison is presented between the BER performance of the proposed system and recent research [19] in the field of coded NOMA. The results clearly demonstrate that the proposed system surpasses the performance of the referenced research by 2 dB, 1 dB, and 6 dB for the 1st, 2nd, and 3rd users, respectively. These findings indicate that the proposed system exhibits significantly improved BER performance compared to the recent research conducted in the coded NOMA field.

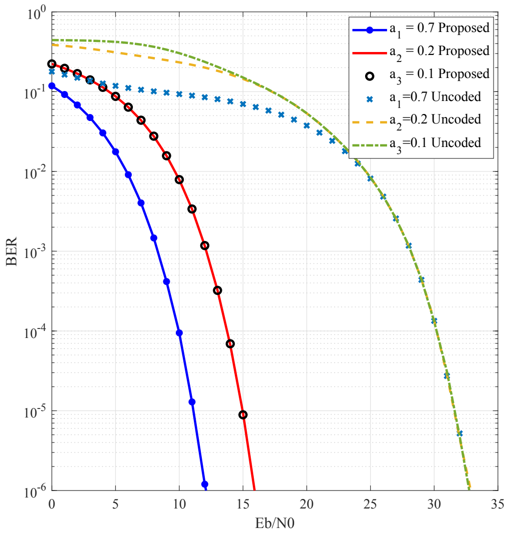

Fig. 3. Comparison of proposed and uncoded NOMA BER versus SNR for a system with 3 users.

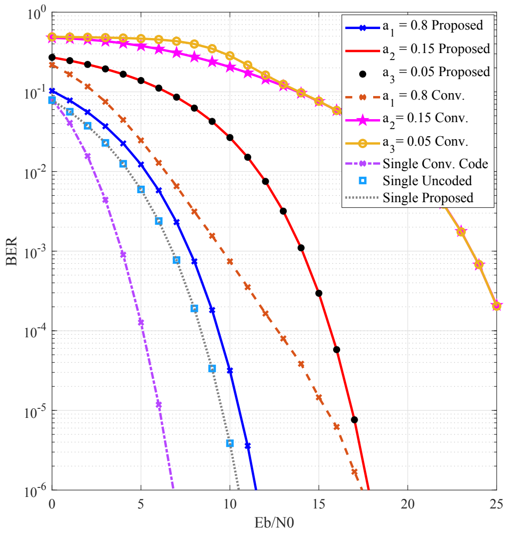

Fig. 4. Comparison of proposed and convolutional coded NOMA BER versus SNR for a system with 3 users.

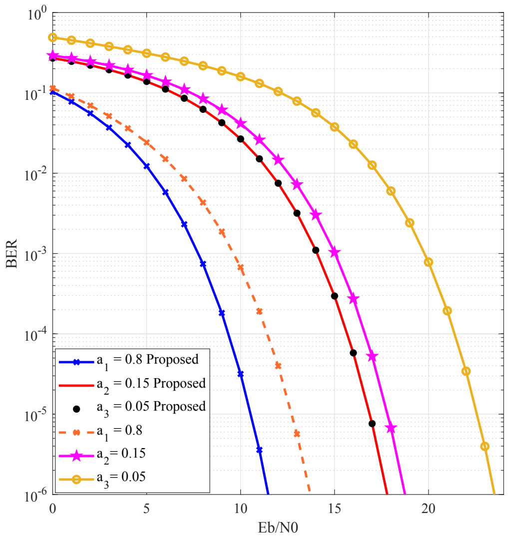

Fig. 5. Comparison of proposed and coded NOMA in [19] BER versus SNR for a system with 3 users.

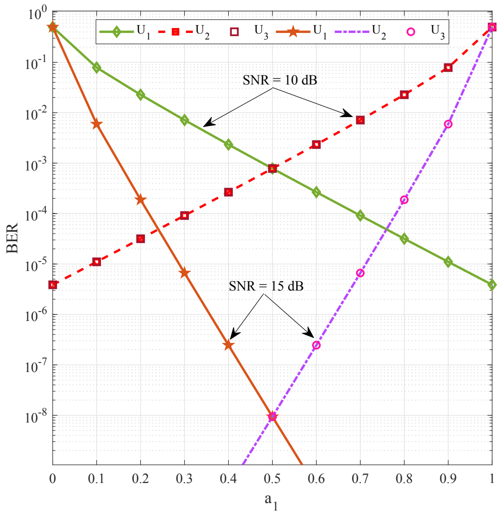

Fig. 6. BER vs. power allocation for the proposed coded NOMA system with 3 users at SNR of 10 and 15 dB.

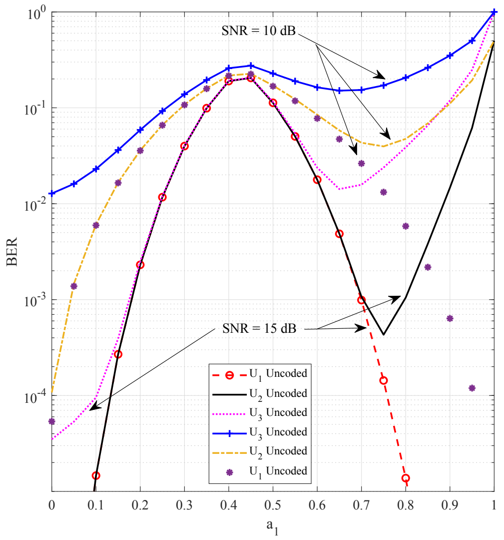

Fig. 7. BER vs. power allocation for the conventional NOMA system with 3 users at SNR of 10 and 15 dB.

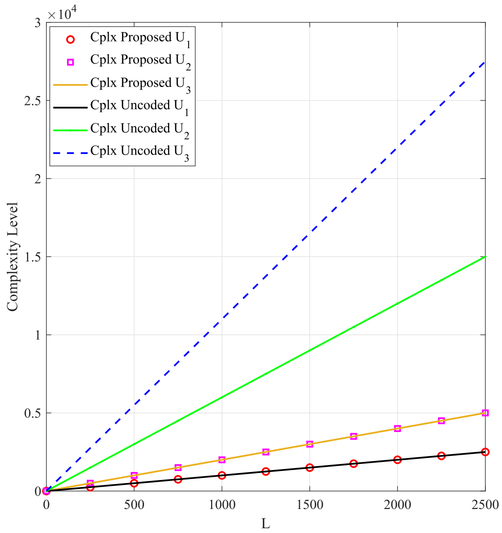

Fig. 8. Comparison of complexity levels between the proposed system and conventional NOMA system with frame length L.

Moreover, to determine the optimal performance, the BER performance of the proposed systems was comprehensively evaluated under various power allocation coefficients. Additionally, that performance was compared with the that of uncoded-NOMA system. Figures 6 and 7 were provided to illustrate the aforementioned aspects, specifically when the SNR was set to 10 dB and 15 dB, respectively. These figures illustrate the BER performance of the proposed system, revealing the impact of different power allocation coefficients and highlighting the improvements achieved compared to the uncoded-NOMA system.

Figure 6 shows that when the SNR is 10 dB, the power allocation coefficient of the 1^{st} user is 0.5 and the sum of the power allocation coefficients of the 2^{nd} and 3^{rd} user is 0.5, the lowest BER can be attained by the proposed coded NOMA system for all users is 1×10^{-3}. While the lowest BER can be reached is 1×10^{-8} at the same power allocation values when the SNR is 15 dB. Comparing the results presented in Fig. 6 with those in Fig. 7, a significant difference can be observed.

Conversely, setting the power allocation coefficient of the 1^{st} user to 0.75, while the sum of the power allocation coefficients for the remaining users is set to 0.25, the lowest BER at SNR of 15 dB is 1×10^{-3}. This comparison underscores the impact of varying SNR levels on the system's BER performance and highlights the effectiveness of different power allocation coefficients in achieving improved error rates for the proposed coded NOMA system.

Lastly, a significant claim of this research is the reduced complexity of the proposed system compared to other NOMA systems. This claim is supported by Fig. 8, which clearly illustrates that the complexity of the proposed system is considerably lower than that of the uncoded NOMA system, despite having the same number of users and transmitting the same length of bits (L). In essence, Figure 8 provides evidence that the proposed system significantly reduces complexity for users 2 and 3. A closer inspection of Fig. 8 shows that the complexity levels for user 2 and user 3 in the proposed system are $2 \times L$, while those of the uncoded system are $6 \times L$ and $11 \times L$, respectively. The detailed methodology for estimating the degree of complexity can be found in [19], [22]. Furthermore, the source code for the simulation will be accessible on the GitHub repository at: https://github.com/Dr-Wael-AbdAlaziz.

5. Conclusion

NOMA is a promising technology for 5G wireless communication systems due to its ability to support multiple users with different channel conditions on the same radio resource. However, NOMA also presents challenges such as increased complexity and inter-user interference (IUI). In this paper, we proposed a low-complexity coding scheme for a 3-user NOMA system that aims to address these challenges. The proposed scheme combines repetitive code and parity check codes with Multiple Access (MA) techniques to serve multiple users and mitigate inter-user interference.

Moreover, the obtained results have shown that the proposed scheme has low encoding and decoding complexity compared to existing NOMA schemes. We evaluated the performance of the proposed scheme through simulations in various channel conditions, and the results showed that it achieves comparable performance to existing NOMA schemes with significantly reduced complexity. Therefore, the proposed low-complexity coding scheme can be considered as a promising solution for the practical implementation of NOMA in future wireless communication systems.

In summary, although the conventional coding techniques are well-established error correction methods, their performance in NOMA systems can be negatively affected by IUI. To overcome this challenge, the proposed dedicated coding schemes are specifically designed for NOMA-based multiple access systems. These proposed coding schemes take into account the interference characteristics of NOMA and aim to optimize the performance in the presence of IUI. The evaluation of incorporating the proposed coding scheme with NOMA has shown that it can effectively mitigate the effects of interference, improve the overall system performance, reduce the complexity of coding-decoding processes, and enhance the reliability of communication among multiple users sharing the same resources.

Finally, as future work, we plan to apply the proposed system to realistic channels, such as Rayleigh fading. Additionally, testing this system in a Power Line Communication (PLC) context would be very interesting to observe its behaviour in such a challenging context.

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