INTL JOURNAL OF ELECTRONICS AND TELECOMMUNICATIONS, 2025, VOL. 71, NO. 3, PP. 1–7
Manuscript received December 14, 2024; revised July, 2025. doi: 10.24425-ijet.2025.155453

Uplink and downlink performance analysis of a structured coded NOMA in Cognitive Radio Networks

Wael Abd-Alaziz, Safaa N. Awny, and Bilal A. Jebur

***Abstract*—This study examines the uplink and downlink communication in a structured coded nonorthogonal multiple access (NOMA) in the context of cognitive radio networks (CRNs). Due to the ever-increasing demand for spectrum-efficient communication systems, NOMA has emerged as an effective approach to enhance spectral efficiency by allowing multiple users to share the same frequency resources. Furthermore, CRN also improves spectrum utilization by enabling dynamic spectrum access while primary users are present. This work presents a method that can maximize the spectral efficiency by combining NOMA and CRN mechanisms. The suggested system is evaluated in terms of throughput, spectral efficiency, and bit error rate (BER). The collected results show that the proposed strategy performs better in reducing data mistakes when two users access the spectrum at different signal-to-noise ratios (SNR), with a 7 dB improvement for 1st user and a 2.5 dB improvement for the 2nd user, respectively, in the downlink scenario. Next, the exact BER expressions for both coded and uncoded uplink NOMA systems are introduced. As a result, the proposed system demonstrates superior performance and needs only 11 dB to reach 1×10^{-6} of BER while the uncoded system cannot operate in this harsh environment and the BER is fixed at 0.25 dB.**

***Keywords*—NOMA, Cognitive radio networks (CRNs); uplink and downlink; throughput; spectral efficiency; Performance analysis; Low complexity; Bit Error Rate (BER)**

I. Introduction

EFFICIENCY in using the frequency spectrum has become critical to the modern communications revolution, due to great growth in the number of applications and users seeking to access the radio frequency spectrum, and the need for speed in data transfer with high quality and reliability. Cognitive Radio Spectrum Networks (CRNs) have been one of the key solutions to improve spectral efficiency. In essence, the CRN mainly allows the unlicensed users, referred to as secondary users (SU_s), to occupy the allocated spectrum of the licensed users, referred to as primary users (PU_s), during their idle time while ensuring that no interference occurs to affect overall communications performance or cause data loss [1], [2]. Even though the employ of CR in communication systems enhances the efficiency of frequency spectrum, the integration of Non-Orthogonal Multiple Access (NOMA) with it, provides a better use of the spectrum, as this technology allows more than one user to access the frequency spectrum simultaneously. Unlike traditional orthogonal multiple access schemes (OMA), which assign each user a unique time, frequency, or code resource, NOMA allows multiple user signals to be superimposed in the same domain, but after grant a different power allocation for each user and retrieve the transmitted signals at the receiver using advanced decoding techniques such as successive interference cancellation (SIC) [3]–[6].

In [7] the authors proposed the CR-Noma power harvesting system to enhance the 5G spectrum efficiency and productivity performance analysis. However, the system becomes more complex with energy harvesting techs and imperfect SIC that can be a disadvantage in the system's scalability and its application in large networks. More complexity and effort can be found in [8] when the authors present CR-assisted cooperative NOMA UAV system on Nakagami-m fading and power-domain NOMA for efficient spectrum management. These additions further complicate the proposed system implementation and question the possibility of execution it in the real-world scenarios.

However, the integration of the two technologies enhances the efficiency of the spectrum use, but adds complexity to the communications system, and users' signals will be more prone to the inter-symbol interference (ISI) and noise, as the transmitted power is divided among the active users [9], [10].

Undoubtedly, the use of error correction coding techniques improves the overall performance of the communications system, even in harsh noise environments, such as power line communications (PLC), underwater communications, or in ISI as in NOMA [11]–[16].

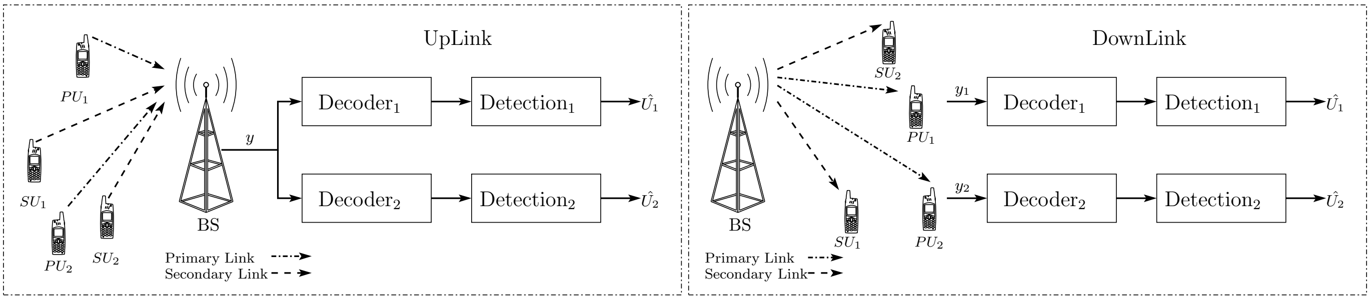
In [17], a turbo iterative detection (TID) algorithm is suggested for multi-user detection in NOMA satellite high-mobility communications to counter problems such as Doppler effects and multi-user interference. Although the 0.9 dB gain in BER may offer better performance, it may not be sufficient to compensate for the increased system complexity and computational requirements in real systems.

In addition, the authors in [18] used low-density parity check (LDPC) codes as error-correcting channel codes within

Wael Abd-Alazi is with College of Computer Science and Information Technology, University of Sumer, Rifaee, Iraq (e-mail: w.abdalaziz@uos.edu.iq).

Safaa N. Awny is with University of Mosul, College of Pharmacy, Mosul, Iraq (e-mail: safaanawny@uomosul.edu.iq).

Bilal A. Jebur is with Department of Computer and Information Engineering, Ninevah University, Mosul, Iraq (e-mail: bilal.jebur@uoninevah.edu.iq).



(a) UpLink Coded-CRNs-NOMA system model (b) DownLink Coded-CRNs-NOMA system model

Fig. 1. Proposed CODED-CRNS-NOMA system

the system. This article examines the uplink transmission situation of a hybrid power domain non-orthogonal multiple access (PD-NOMA) and SCMA system, whereby the suggested system excludes any power allocation considerations. In NOMA systems, communication in challenging situations presents numerous obstacles due to interference, sub-optimal signal quality, and unfavorable propagation conditions.

Consequently, in scenarios like NOMA where the communication environment is challenging, incorporating a code would significantly enhance performance; it should remain uncomplicated due to certain peripheral properties and performance constraints.

In this manuscript, the above communications issues were taken into account, and CR was used to efficiently use the free frequency spectrum by licensed and unlicensed users, and NOMA was added to be used if two users were ready to transmit data together. Moreover, to overcome the interference and complexity challenges that NOMA adds to the communications system, a structured coding technique was employed to substitute the need for complex SIC process, and to prevent interference, which is robust to eliminate the added noise effect.

The main contributions of this work can be listed as follows:

- To the best of our knowledge, this is the first work that derives an analytical expression for the uplink of coded and uncoded NOMA schemes with CRNs in the presence of the AWGN channel.
- The proposed Coded-CRNs-NOMA system is presented to reduce the complexity in the coded NOMA and enhance the throughput in the uplink and downlink phases.
- The proposed system works efficiently in short-distance environments and uses structured Coded-NOMA to overcome signal interference challenges.

Nevertheless, the telecommunication systems are pursuing more performance improvement, high data rate, safe and reliable data transmissions. Our proposed system opens the door to quest more in the field of data privacy and security, as each user gets a copy of the messages addressed to other users due to the employ of NOMA. In addition, the increase in user's number that use the network is a major challenge, and to test the system in a real-world environment to increase reliability.

The rest of the manuscript is structured as follows: the proposed uplink and downlink coded-CRNs-NOMA system is placed in Section II. Then, the closed form of the mathematical expressions of the BER of that system is introduced in Section III. Furthermore, Section IV demonstrates the achieved outcomes of the suggested model along with the discussion of these results. Ultimately, the findings from this research are provided in Section V.

II. Proposed Coded-CRNs-NOMA System

The architecture of the proposed system is described in this section. Foremost,‘ in order to achieve a low complexity, reliable and effective spectrum sensing mechanism, the energy-based detection approach will be utilise. It is widely used and matching the low complexity that required by the proposed system [19]–[22].

In this work, we will use the coded scheme that was presented in [23], in which the output of the first user encoder C_1 is given as

$$\mathbf{C}_1 = \{u_1, u_1\}, \tag{1}$$

and that of the second user, C_2, is expressed as

$$\mathbf{C}_2 = \{u_2, \bar{u_2}\}, \tag{2}$$

where u_i is the message bit of the i-th user, and $i \in \{1, 2\}$. In other words, the first encoder works as a repetitive code with a length of 2 (i.e., mapping each 1 with 11 and each 0 with 00) while the second encoder inserts the inverse value of the currently received bit (i.e., mapping each 1 with 10 and each 0 with 01).

A. Uplink Coded-CRNs-NOMA

Fig. 1(a) illustrates the proposed Coded-CRNs-NOMA block diagram system in uplink mode. The proposed scheme combines the cognitive radio network mechanism with a coded NOMA system, to effectively enhance spectrum efficiency. This system can serve two users at a time, which can be one of the following options: where PU_i, $i \in \{1, 2\}$ denote the primary (licensed) users. On the other hand, SU_i, $i \in \{1, 2\}$ represent the secondary users. Since the proposed scheme enhances the spectrum efficiency of CRNs by combining it with coded NOMA, the focus will be only on cases where the spectrum is reserved by two users as stated in Table I. Hence,

TABLE I
SPECTRUM SHARING OPTIONS

User_1	User_2
PU_1	PU_2
PU_1	SU_1
PU_1	SU_2
PU_2	SU_1
PU_2	SU_2

for convenience, the first user will be referred to as U_1 and the second as U_2 in the rest of the paper. Therefore, if two users are using the spectrum, the received signal y at the base station (BS) will be

$$y = \sqrt{p_1 E_c}\, x_1 + \sqrt{p_2 E_c}\, x_2 + n, \tag{3}$$

where, p_1 and p_2 are the transmission power of U_1 and U_2, respectively. In this paper, we assume that both users send their data with the highest power, which means $p_1 = p_2$. E_c is the energy of the encoded bit and is a complement to $E_b R$, where, E_b is the assigned energy of the uncoded bit, while R is the bit rate of the code. In addition, x_1 and x_2 are the Binary Phase Shift Keying (BPSK) modulated signals of C_1 and C_2 which are calculated as $x_1 = 2 \times C_1 - 1$ and $x_2 = 2 \times C_2 - 1$, respectively. Finally, n represents the complex-valued Additive White Gaussian Noise (AWGN) with zero mean and variance $\frac{\sigma^2}{2}$, as the effective part of the noise in the used modulation scheme is the real part only which follows the distribution of $\mathcal{N}(0, \frac{\sigma^2}{2})$ [24].

The received signal in the proposed system, y, will be passed to Decoder_1 and Decoder_2 to extract $\hat{U}_1$ and $\hat{U}_2$. This can be done by adding each pair of the symbols in Decoder_1 and subtracting them in Decoder_2. As a result, the $2k$ symbols will be reduced to N symbols such that

$$\hat{U}_1(k) = \begin{cases} 1, & \text{if } y(2k-1) + y(2k) > 0 \\ 0, & \text{else} \end{cases}, \tag{4}$$

$$\hat{U}_2(k) = \begin{cases} 1, & \text{if } y(2k-1) - y(2k) > 0 \\ 0, & \text{else} \end{cases}. \tag{5}$$

B. Downlink Coded-CRNs-NOMA

Fig. 1(b) shows the proposed DownLink Coded-CRNs-NOMA block diagram. The coded and superimposed signals at the BS will be broadcasted to the two end users y_1 and y_2, which can expressed as follows

$$y_1 = \sqrt{a_1 E_c}\, x_1 + \sqrt{a_2 E_c}\, x_2 + n_1, \tag{6}$$

$$y_2 = \sqrt{a_1 E_c}\, x_1 + \sqrt{a_2 E_c}\, x_2 + n_2, \tag{7}$$

where a_1 and a_2 represent the power allocation factors assigned to each user by the base station through the superposition processes, where $a_1 + a_2 = 1$. Furthermore, n_1 and n_2 are the AWGN noise at U_1 and U_2, respectively.

Eventually, the sent U_1 and U_2 bits will be recovered according to the conditions in the equations 8 and 9, respectively, as follows

$$\hat{U}_1(k) = \begin{cases} 1, & \text{if } y_1(2k-1) + y_1(2k) > 0 \\ 0, & \text{else} \end{cases}, \tag{8}$$

$$\hat{U}_2(k) = \begin{cases} 1, & \text{if } y_2(2k-1) - y_2(2k) > 0 \\ 0, & \text{else} \end{cases}. \tag{9}$$

For more clarity, algorithm 1 sequentially explains the downlink scenario process.

Algorithm 1 Downlink Coded-CRNs-NOMA System Algorithm

1: **Input:** Data for Primary and Secondary Users
2: **Initialize:** System parameters (e.g., bandwidth, power allocation)
3: **Step 1: User Sensing**
4: Perform energy detection to sense spectrum occupancy
5: Determine the user scenario:
- Case 1: Two Primary Users are present
- Case 2: One Primary User and one Secondary User are present
- Case 3: Two Secondary Users are present
- Case 4: The spectrum is free or only one user is present

6: **Step 2: Downlink Operations**
7: **For all Cases (1:4)**: Perform superposition coding:

$$x = \sum_{i=1}^{N} \sqrt{a_i} \cdot x_i$$

8: **Note:** N is the number of available users
9: Transmit the NOMA signal
10: **Step 3: Decoding and Metrics**
11: Decode the received signals for each user
12: Calculate performance metrics (e.g., throughput, latency, spectral efficiency)
13: **Output:**
- Received signals for users
- Decoded data for Primary and Secondary Users
- Performance metrics

III. BER PERFORMANCE ANALYSIS

To evaluate the proposed system's effectiveness, the error probability (P_e) of that system is examined in various scenarios. First, we need to identify the individual events that lead to incorrect detection of the received signal. Then, integrate the probability density function (PDF) to calculate the BER of the channel model over the error region. In this study, as mentioned earlier, the AWGN can employed to imitate real-world situations, and the PDF will represented as follows:

$$f(\upsilon) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{\upsilon^2}{2\sigma^2}}, \tag{10}$$

where υ is the random variable. Therefore, the P_e can be calculated as

$$P_e = \int_{\mathcal{D}} f(\upsilon)\, d\upsilon, \tag{11}$$

where $\mathcal{D}$ is the region of decision in errors.

In the following two subsections III-A and III-B, the area $\mathcal{D}$ will be identified, and the P_e in (11) will calculated for both uplink and downlink scenarios.

A. BER for Uplink Coded-CRNs-NOMA

To find $\mathcal{D}$ in the Uplink scenario, let's assume that the U_1 transmitting (1) after decoding and modulating it, the output signal will be ($\sqrt{E_c}$ $\sqrt{E_c}$). At the same time, the U_2 might be transmitted (0) or (1), and the corresponding signal after encoding and modulating processes will be either (-$\sqrt{E_c}$ $\sqrt{E_c}$) or ($\sqrt{E_c}$ -$\sqrt{E_c}$). Thus, if we add these signals, the sum always equals $2\sqrt{E_c}$ (i.e., $\mathcal{D} = 2\sqrt{E_c}$) in the uplink-coded NOMA. By substituting $\mathcal{D}$ into equation (11) the P_e will be:

$$P_e = \frac{1}{\sqrt{2\pi\sigma^2/2}} \int_{2\sqrt{E_c}}^{\infty} e^{-\frac{v^2}{2\sigma^2/2}} dv, \tag{12}$$

it is clear that equation 12 is the $Q(\frac{2\sqrt{E_c}}{\sigma^2/2})$, where the $Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^{\infty} e^{\frac{-t^2}{2}} dt$ the BER will be:

$$BER_1 = Q\left(\sqrt{\frac{4E_c}{\sigma^2}}\right) = Q\left(\sqrt{4E_b R\ SNR}\right) \tag{13}$$

After applying equation (5) to obtain $\hat{U}_2$, the result of the subtraction will always lead to $\mathcal{D} = 2\sqrt{E_c}$ as well, and thus the BER_2 is:

$$BER_1 = BER_2 \tag{14}$$

On the other hand, in the uncoded system if U_1 transmits a bit of $\sqrt{E_b}$, then U_2 may transmit $\sqrt{E_b}$ or -$\sqrt{E_b}$, so the addition of these signals at the BS would lead to a $\mathcal{D}$ that either equals to 0 or $2\sqrt{E_b}$, which is the same scenario for U_2. Thus, the Pe of the uncoded system for both users will be:

$$P_e = \frac{\int_{D_1} f(v)dv + \int_{D_2} f(v)dv}{2}. \tag{15}$$

Thus, BER_1 and BER_2 can be written:

$$BER_1 = \frac{Q\left(0\right) + Q\left(\sqrt{4E_b\ SNR}\right)}{2}. \tag{16}$$

The above equation was validated using Monte Carlo simulation. Fig. 2 shows the agreement of the simulated and theoretical results, which demonstrates the accuracy of the mathematical derivation in equations (13) and (16), as will be thoroughly discussed in Section IV.

B. BER for Downlink Coded-CRNs-NOMA

In this section, the mathematical equations for calculating the BER_{c1} and BER_{c2} in the Downlink Coded-CRNs-NOMA will be discussed, as derived by the author in [23] that also works in this context. Note that the mechanism and method of derivation are described in great detail in section III-A as well.

$$BER_{c1} = Q\left(\sqrt{4a_1 RE_b \text{ SNR}}\right), \tag{17}$$

$$BER_{c2} = Q\left(\sqrt{4a_2 RE_b \text{ SNR}}\right), \tag{18}$$

add to that the uncoded BER (BER_{ui}) for the i-th user, which can be calculated as follows

$$BER_{u1} = \frac{Q\left(\sqrt{2A^2\text{SNR}}\right) + Q\left(\sqrt{2B^2\text{SNR}}\right)}{2}. \tag{19}$$

$$BER_{u2} = BER_{u1} + Q\left(\sqrt{2a_2 \text{ SNR}}\right). \tag{20}$$

Given that $A = \sqrt{a_1} + \sqrt{a_2}$ and $B = \sqrt{a_1} - \sqrt{a_2}$. These equations are mentioned to illustrate the consistency of the results of the practical application with the mathematical derivation to prove the validity of the results in an important application; such as the smart spectrum. Fig. 3 illustrates this claim, which will be explained more in the results section.

C. Throughput and spectrum efficiency

To clarify the throughput (T) gain and the spectrum efficiency (SE) gain, two parameters will be introduced in this section for this purpose, (TG) and (SEG), respectively, which are expressed as

$$TG = \frac{T_2 - T_1}{T_2} \times 100\%, \tag{21}$$

where T_1 and T_2 are the throughput of the uncoded and coded systems, respectively, and can be calculated as

$$T_1 = \frac{k - k \times BER_{uncoded}}{time}, \tag{22}$$

$$T_2 = \frac{k - k \times BER_{coded}}{time}. \tag{23}$$

Given that $time$ denotes the transmitting time which can be obtained by dividing the number of samples by the sampling frequency.

$$SEG = \frac{SE_2 - SE_1}{SE_1} \times 100\%, \tag{24}$$

where SE_1 and SE_1 are the spectrum efficiency of the uncoded and coded systems, respectively, and is evaluated such that

$$SE_i = \frac{T_i}{B.W}, \tag{25}$$

where T_i is the i-th system's throughput and $B.W$ is the bandwidth in Hz.

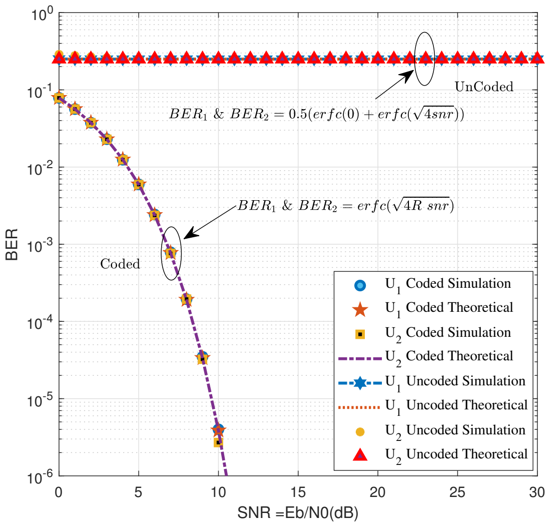


Fig. 2. Uplink BER Comparison between Coded and Uncoded NOMA Systems

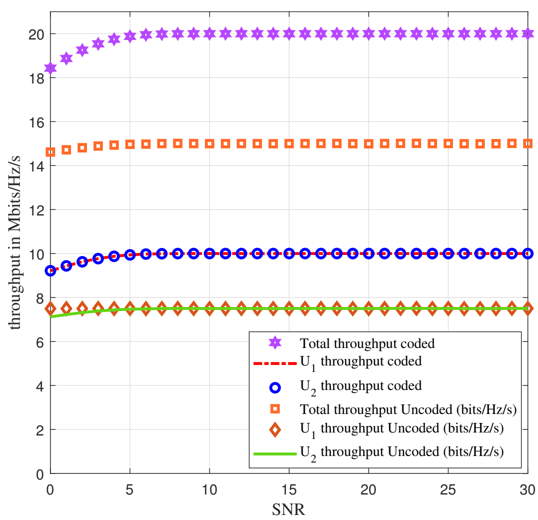


Fig. 4. UpLink Throughput Comparison between Coded and Uncoded NOMA Systems

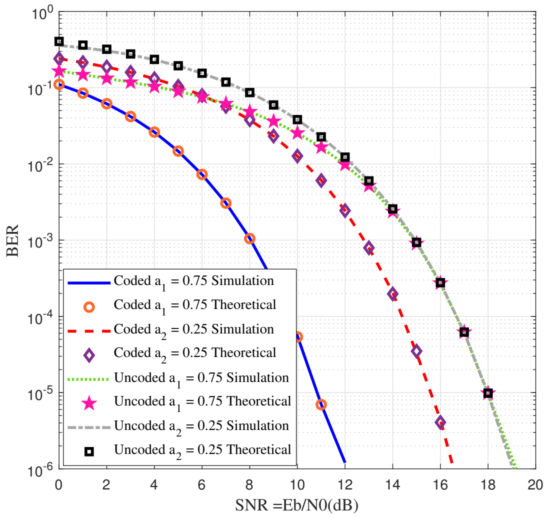


Fig. 3. DownLink BER Comparison between Coded and Uncoded NOMA Systems

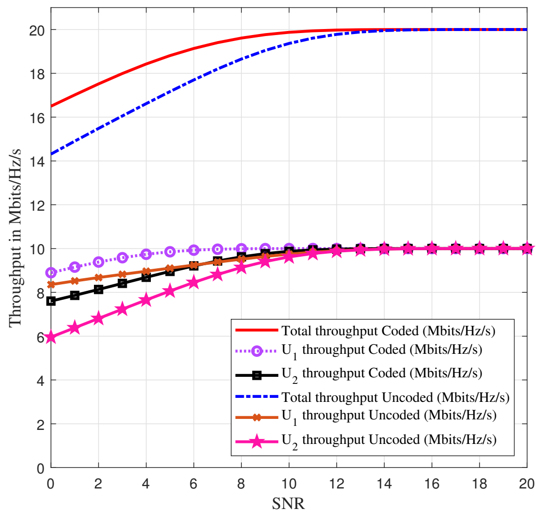


Fig. 5. DownLink Throughput Comparison between Coded and Uncoded NOMA Systems

IV. RESULTS

In this section, the findings of the manuscript will be presented and discussed. The code length for all results is $k = 10^6$ bits and the code rate is $R = \frac{1}{2}$ for the coded system. In addition, the total transmission time is 0.1 s for both systems for fair comparison and the bandwidth is 1 MHz. Fig. 2 displays the BER vs. SNR of the proposed system vs. the uncoded conventional communication system, which demonstrates the superiority of the proposed system in the ability to recover the original message efficiently. A closer look at Fig. 2 shows that it needs 11 dB to reach the BER of 1×10^{-6}. In contrast, the uncoded system can not overcome the harsh environment due to the ISI even if the SNR is raised to any value, as the value of the lower BER remains equal to 0.25.

This high BER will result in poor spectrum efficiency and throughput compared to the coded system as can be observed from Fig. 4, which shows that the total throughput of the proposed system is 20 Mbits/Hz/s, while the total throughput of the uncoded system is 15 Mbits/Hz/s, and the spectrum efficiency of the proposed system is 33% greater than that of the uncoded one.

In the downlink scenario, BER vs. SNR comparison between the two systems, is presented in Fig. 3 when the power allocation parameters are set to $a_1 = 0.75$ and $a_2 = 0.25$ for U_1 and U_2, respectively. Clearly the proposal can conquer this harsh environment successfully for the two users and that

TABLE II
THROUGHPUT, SPECTRAL EFFICIENCY, TG AND SEG VS. a_1

	a_1	Throughput Mbits/Hz/s Spectral Efficiency in bits/Hz/s Uncoded	Throughput Mbits/Hz/s Spectral Efficiency in bits/Hz/s Coded	TG 100% SEG 100%		a_1	Throughput Mbits/Hz/s Spectral Efficiency in bits/Hz/s Uncoded	Throughput Mbits/Hz/s Spectral Efficiency in bits/Hz/s Coded	TG 100% SEG 100%
SNR = 0 dB	0.5	13.185	16.826	27.612	**SNR = 10 dB**	0.5	14.992	19.984	33.298
	0.55	13.455	16.814	24.961		0.55	16.228	19.981	23.126
	0.6	13.707	16.777	22.394		0.6	17.351	19.973	15.113
	0.65	13.938	16.714	19.922		0.65	18.273	19.957	9.217
	0.7	14.141	16.623	17.549		0.7	18.946	19.927	5.175
	0.75	14.311	16.498	15.281		0.75	19.364	19.872	2.622
	0.8	14.440	16.334	13.122		0.8	19.544	19.771	1.162
	0.85	14.512	16.118	11.073		0.85	19.499	19.583	0.430
	0.9	14.502	15.827	9.137		0.9	19.189	19.213	0.121
	0.95	14.349	15.400	7.325		0.95	18.409	18.413	0.021
	1	13.426	14.213	5.858		1	14.999	14.999	0.00026

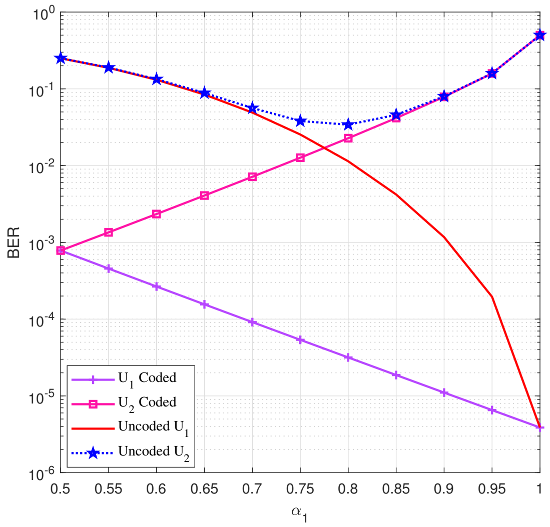


Fig. 6. BER Vs. a_1 DownLink Comparison between Coded and Uncoded NOMA Systems SNR = 10

saved about 7 dB and 2.5 dB for U_1 and U_2, respectively. Furthermore, Fig. 5 displays the throughput for each user and the total throughput for both systems vs SNR in the downlink approach. It can be observed that the proposed system at low SNRs can achieve a good throughput.

The proposed system can serve a reliable communication system service for both users with any values of the power allocation and it is not necessarily to be $a_1 > a_2$ while this is not the case in the uncoded system, which need to apply the complex SIC processes. To show the performance of these two systems for various values of the power allocation parameter, Fig. 6 shows the BER performance vs. a_1 for SNR = 10 and $a_2 = 1 - a_1$.

In addition to see the TG and SEG for variance power allocation Table II shows the throughput and the Spectrum efficiency for both systems when the SNR = 0 and 10, the result shows how the proposed system saved the spectrum and how much the percentage of the throughput gain as compare to the uncoded system.

V. CONCLUSIONS

This manuscript introduced a Coded-CRNs-NOMA system for uplink and downlink transmission schemes. This system improves spectrum utilisation strategy by enhancing the encoding and decoding processes. A simple and cooperative strategy has been devised for data transmission and reception to optimise the system performance in terms of efficiency, speed, complexity, and BER. To this end, the Coded-CRNs-NOMA shows better BER performance over that of the conventional system in the downlink with a 7 dB and 2.5 dB for U_1 and U_2, respectively. In addition, the uncoded system cannot overcome the burst errors in an uplink scenario, while the proposed system in this phase needs only 11 dB to get the almost error-free communication link.

The proposed system exhibits a substantial enhancement in overall throughput and spectrum efficiency relative to the uncoded system, rising from 13.426 to 14.213 Mb/Hz/s, yielding a gain of (5.858% - 27.612%) at SNR=0 dB and a gain of (0.00026% - 33%) at SNR=10 dB.

Ultimately, by addressing the difficulties of the security problems and preserving robust security, we intend to design security mechanisms suitable for NOMA-IoT networks. Design a system capable of supporting a large number of users in a realistic environment to enhance security and scalability.

REFERENCES

[1] J. Mitola and G. Maguire, "Cognitive radio: making software radios more personal," *IEEE Pers. Commun.*, vol. 6, no. 4, pp. 13–18, 1999. [Online]. Available: https://doi.org/10.1109/98.788210
[2] J. Mitola, "Cognitive radio. an integrated agent architecture for software defined radio." *PhD Dissertation, KTH, Stockholm, Sweden*, 2002.
[3] L. Dai, B. Wang, Y. Yuan, S. Han, I. Chih-lin, and Z. Wang, "Non-orthogonal multiple access for 5G: solutions, challenges, opportunities, and future research trends," *IEEE Commun. Mag.*, vol. 53, no. 9, pp. 74–81, 2015. [Online]. Available: https://doi.org/10.1109/MCOM.2015.7263349

[4] L. Dai, B. Wang, Z. Ding, Z. Wang, S. Chen, and L. Hanzo, "A survey of non-orthogonal multiple access for 5G," *IEEE Commun. Surveys & Tut.*, vol. 20, no. 3, pp. 2294–2323, 2018. [Online]. Available: https://doi.org/10.1109/COMST.2018.2835558

[5] Y. Chen, L. Wang, and B. Jiao, "Cooperative multicast non-orthogonal multiple access in cognitive radio," in *2017 IEEE Int. Conf. on Commun. (ICC)*, 2017. [Online]. Available: https://doi.org/10.1109/ICC.2017.7996607

[6] H. T. Huong Giang, P. Duy Thanh, and I. Koo, "Dynamic power allocation scheme for noma uplink in cognitive radio networks using deep q learning," in *2020 Int. Conf. on Inf. and Commun. Technol. Convergence (ICTC)*, 2020, pp. 137–142. [Online]. Available: https://doi.org/10.1109/ICTC49870.2020.9289435

[7] D.-T. Do, A.-T. Le, and B. M. Lee, "NOMA in cooperative underlay cognitive radio networks under imperfect SIC," *IEEE Access*, vol. 8, pp. 86 180–86 195, 2020. [Online]. Available: https://doi.org/10.1109/ACCESS.2020.2992660

[8] T. M. C. Chu and H.-J. Zepernick, "Performance analysis of a cognitive radio assisted cooperative NOMA UAV system," in *2024 IEEE 25th Int. Symp. on a World of Wireless, Mobile and Multimedia Netw. (WoWMoM)*, 2024, pp. 51–56. [Online]. Available: https://doi.org/10.1109/WoWMoM60985.2024.00020

[9] H. B. Salameh, S. Abdel-Razeq, and H. Al-Obiedollah, "Integration of cognitive radio technology in noma-based B5G networks: State of the art, challenges, and enabling technologies," *IEEE Access*, vol. 11, pp. 12 949–12 962, 2023.

[10] H. Yahya, A. Ahmed, E. Alsusa, A. Al-Dweik, and Z. Ding, "Error rate analysis of NOMA: Principles, survey and future directions," *IEEE Open Journal of the Commun. Society*, 2023. [Online]. Available: https://doi.org/10.1109/OJCOMS.2023.3296061

[11] R. G. Gallager, "Low-density parity-check codes," *IRE Trans.Inf. Theory*, vol. 8, no. 1, pp. 21–28, 1962. [Online]. Available: https://doi.org/10.1109/TIT.1962.1057683

[12] F. Baldini and P. Farrell, "Coded modulation based on rings of integers modulo-q. 2. convolutional codes," *IEE Proc.-Commun.*, vol. 141, no. 3, pp. 137–142, 1994. [Online]. Available: https://doi.org/10.1049/ip-com:19941119

[13] C. Berrou, A. Glavieux, and P. Thitimajshima, "Near shannon limit error-correcting coding and decoding: Turbo-codes. 1," in *Proc. of ICC'93-IEEE Int. Conference on Commun.*, vol. 2. IEEE, 1993, pp. 1064–1070. [Online]. Available: https://doi.org/10.1109/ICC.1993.397441

[14] W. Abd-Alaziz, M. Johnston, and S. Le Goff, "Non-binary turbo codes on additive impulsive noise channels," in *2016 10th Int. Symp. on Commun. Syst., Netw. and Digit. Signal Process. (CSNDSP)*. IEEE, 2016, pp. 1–5. [Online]. Available: https://doi.org/10.1109/CSNDSP.2016.7574024

[15] ——, "Non-binary trellis codes on the synthetic statistical MIMO power line channel," in *2018 IEEE Int. Symp. on Power Line Commun. and its Appl. (ISPLC)*. IEEE, 2018, pp. 1–5. [Online]. Available: https://doi.org/10.1109/ISPLC.2018.8360199

[16] W. Abd-Alaziz, B. Abood, R. M. Muttasher, M. A. Fadhel, and B. A. Jebur, "Exact BER performance analysis of an elementary coding techniques for NOMA system on AWGN channel." *Radioengineering*, vol. 33, no. 1, 2024. [Online]. Available: https://doi.org/10.13164/re.2024.0045

[17] J. Wang, C. Jiang, and L. Kuang, "Iterative NOMA detection for multiple access in satellite high-mobility communications," *IEEE J. on Sel. Areas in Commun.*, vol. 40, no. 4, pp. 1101–1113, 2022. [Online]. Available: https://doi.org/10.1109/JSAC.2022.3143254

[18] M. S. Idris, D. M. Ali, N. I. A. Razak, A. Idris, and H. Ahmad, "Performance analysis of NOMA using different coding techniques," in *J. of Phys.: Conf. Ser.*, vol. 1502, no. 1. IOP Publishing, 2020, p. 012002. [Online]. Available: https://doi.org/10.1088/1742-6596/1502/1/012002

[19] T. Yucek and H. Arslan, "A survey of spectrum sensing algorithms for cognitive radio applications," *IEEE commun. surveys & tut.*, vol. 11, no. 1, pp. 116–130, 2009. [Online]. Available: https://doi.org/10.1109/SURV.2009.090109

[20] D. Cabric, S. M. Mishra, and R. W. Brodersen, "Implementation issues in spectrum sensing for cognitive radios," in *Conf. Record of the Thirty-Eighth Asilomar Conf. on Signals, Sys. and Comput., 2004.*, vol. 1. Ieee, 2004, pp. 772–776.

[21] G. Ganesan and Y. Li, "Agility improvement through cooperative diversity in cognitive radio," in *GLOBECOM'05. IEEE Global Telecommun. Conf., 2005.*, vol. 5. IEEE, 2005, pp. 5–pp. [Online]. Available: https://doi.org/10.1109/GLOCOM.2005.1578213

[22] D. Cabric, A. Tkachenko, and R. W. Brodersen, "Spectrum sensing measurements of pilot, energy, and collaborative detection," in *Milcom 2006-2006 IEEE Mil. Commun. Conf.* IEEE, 2006, pp. 1–7. [Online]. Available: https://doi.org/10.1109/MILCOM.2006.301994

[23] W. Abd-Alaziz, B. A. Jebur, H. Fakhrey, Z. Mei, and K. Rabie, "A low-complexity coding scheme for NOMA," *IEEE Sys. J.*, vol. 17, no. 3, pp. 4464–4473, 2023. [Online]. Available: https://doi.org/10.1109/JSYST.2023.3262174

[24] A. Goldsmith, *Wireless communications*. Cambridge Univ. press, 2005. [Online]. Available: https://doi.org/10.1017/CBO9780511841224