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A Novel Decoding Scheme to Assess the Effects of Weak Channel Conditions in Cooperative D2D Systems with NOMA

Shaik Mohammad Eliyas*[1], Dr. S. Swarnalatha[2]

*[1] M. Tech Student, Department of Electronics and Communication Engineering, Sri Venkateswara University College of Engineering, Tirupati, Andhra Pradesh, India.

[2] Professor, Department of Electronics and Communication Engineering, Sri Venkateswara University College of Engineering, Tirupati, Andhra Pradesh, India.

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ABSTRACT

This paper presents a new decoding method to assess the effects of weak channel conditions in cooperative device-to-device (D2D) communication systems with non-orthogonal multiple access (NOMA). Error reduction is challenging in wireless communication for high-speed data transfer. Effective channel coding methods are necessary for the communication system to identify and fix errors. In the area of "forward error correction," Reed-Solomon (RS) encoders and decoders belong (FEC). Reed-Solomon codes perform best in the fading environment, which has a higher burst error rate. In order to ensure that the receiver only receives error-free data, RS codes add parity bits at the transmitter end. These bits allow RS codes to detect and correct numerous random symbol errors. When the Reed-Solomon encoder and decoder are utilised in the system design, the proposed system outperforms existing systems in terms of sum rate, outage probability, and outage capacity. The performance of the existing system is also constrained, but not that of the proposed system, because of weak channel conditions.

Keywords : Non-Orthogonal Multiple Access (NOMA), Device to Device (D2D) systems, Reed Solomon (RS) codes, sum rate, outage probability, outage capacity.

I. INTRODUCTION

Current wireless mobile communication systems must meet demanding new requirements that include very high spectral efficiency, very low latency, massive device connectivity, a very high achievable data rate, ultra-high reliability, excellent user fairness, high throughput, supporting diverse quality of services

(QoS), energy efficiency, and a dramatic decrease in cost. Due to its ability to increase system capacity, a new radio access scheme is one of the key technologies to satisfy the difficult requirements of 5G networks [1]. Due to its great spectrum efficiency and ability to support many more users, Non-Orthogonal Multiple Access (NOMA) has been envisioned as a promising method. [2].

One of NOMA's most interesting features is how well it integrates with other cutting-edge technologies, like Device to Device (D2D), Cooperative Relaying Systems (CRS), and Multiple Input Multiple Output (MIMO), which enable full duplex communications and heterogeneous networks.

Recently, cooperative communication scenarios have been included in the NOMA concept. In cooperative communication, one or more relays are used to maintain the transmission between the source and the destination. By utilising forwarding protocols, the relays send the information signals they have received to the appropriate destination [3].

In particularly, [4] where the authors suggest a cooperative relaying system based on NOMA, introduces the work of NOMA in coordinated direct and relay transmission. The source-to-destination link constrains the possible rate, which results in information loss and lowers system performance.

The idea of Device to Device (D2D) assisted cooperative communication was presented in [5], but it still suffers from some nontrivial information loss because there is no direct connection between the base station and the users due to the weak channel restriction.

Maximum ratio combining (MRC) is used in [6] to suggest a novel receiving technique for the cooperative relaying scheme, NOMA. The MRC in [6] does not adhere to the NOMA decoding concept and instead mandates that the symbols with low power be initially decoded.

Using a two-stage power allocation, a dual-hop relaying system was proposed in [7]. The destination can jointly decode the information symbols using a simple linear combination in this decoding method, which improves efficiency and follows the NOMA decoding concept.

Two decoding strategies—the single-signal decoding scheme and the MRC decoding scheme—are developed in [8] to characterise the effects of weak channel conditions under various decoding systems. In the former, all users can decode signals received immediately after they are received, whereas in the latter, users are able to hold onto signals and decode them at the proper phase. The MRC decoding strategy outperforms the single-signal decoding scheme, according to the results.

In order to describe the effects of weak channel conditions in cooperative D2D systems with NOMA, this work introduces a novel decoding scheme. For forward error correction, the suggested system uses a Reed-Solomon encoder and decoder. Due to the high bit error rate (BER) of the wireless communication system, various channel coding techniques must be used in order to prevent data symbols from becoming corrupted during transmission due to poor channel conditions. Reed-Solomon codes are very effective and work best for burst error correction. They can be used in a variety of wireless and digital communications scenarios. The most effective method currently being utilised for error detection and correction is Reed Solomon codes [9].

In contrast to the one in [8], the proposed system achieves improved outage probability and outage capacity performance. It also greatly improves the ergodic sum rate. A practical power allocation technique for the base station and users also enhances the system's performance.

II. SYSTEM MODEL

Figure 1(a) depicts a straightforward cooperative D2D relaying system with NOMA made up of one base station (BS), one relay (UE_1), and two users (UE_2 and UE_3). In figure 1, the base station and relay, UE_2 and UE_3 each have a direct link, and all nodes are operating in half-duplex mode. The channel between the base station and the relay is h_{BR}, while the channel between the base station and the user equipment's UE_2 and UE_3, respectively, is h_{BU2} and h_{BU3}. h_{RU2} and h_{RU3} are used to refer to the channels from the relay to the destination, respectively. These are the average powers α_{BR}, α_{BU2}, α_{BU3}, α_{RU2} and α_{RU3}, and so forth.

It is assumed, without losing generality, that the receiving node wants all the symbols and that the channel state information is flawless.

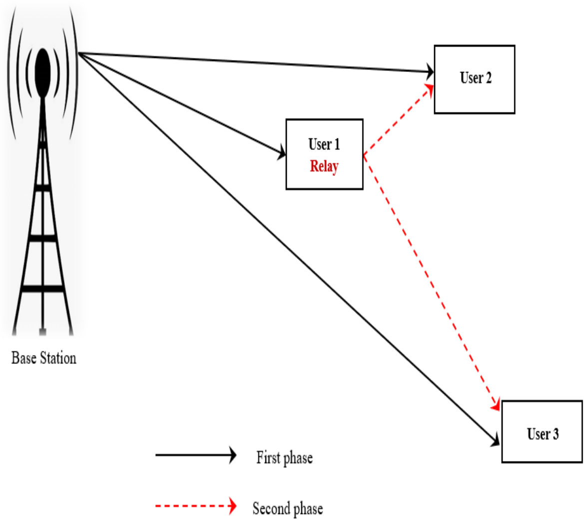

Figure 1(a): Existing System Design

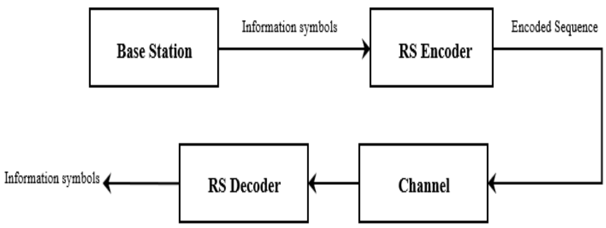

Figure 1(b): Proposed System Design

Each transmission in this system design uses two slots for time. Given that the superposition code has been modified, the signal will be received within the first time slot.

$$x_i = \sqrt{a_1 P_t}\, x_1 + \sqrt{a_2 P_t} x_2 \qquad (1)$$

is transmitted from the base station to the relay and destinations UE_2 and UE_3.

Where, x_i denotes the broadcasted symbols at the base station, and P_t is the total transmit power at the base station a_1 and a_2 with $a_1 + a_2 = 1$ are the power allocation factors.

The received signal at the relay and user can be expressed as

$$y_R = h_{BR}\left(\sqrt{a_1 P_t}\, x_1 + \sqrt{a_2 P_t} x_2\right) + n_r \qquad (2)$$

$$y_{BU2} = h_{BU2}\left(\sqrt{a_1 P_t}\, x_1 + \sqrt{a_2 P_t} x_2\right) + n_{U2} \qquad (3)$$

$$y_{BU3} = h_{BU3}\left(\sqrt{a_1 P_t}\, x_1 + \sqrt{a_2 P_t} x_2\right) + n_{U3} \qquad (4)$$

Where, n_r, n_{U2} and n_{U3} represents the additive white Gaussian noise with zero mean and variance σ^2 during the first time slot.

We further assume that x_1 is decoded first and allocated with more transmit power i.e.., $a_1 > a_2$ and then x_2 is subsequently decoded.

To increase spectrum efficiency, the above technology enables the relay to transmit its own signal to the UE_2 and UE_3 during the second time slot.

To the destination, the relay node sends a fresh superposition of coded signals.

$$y_i = \sqrt{b_1 P_r}\, x_2 + \sqrt{b_2 P_r} x_r \qquad (5)$$

The received signals at UE_2 and UE_3 are provided by the NOMA concept.

$$r_{U2} = h_{RU2}\left(\sqrt{b_1 P_r}\, x_2 + \sqrt{b_2 P_r} x_r\right) + n_{U2} \qquad (6)$$

$$r_{U3} = h_{RU3}\left(\sqrt{b_1 P_r}\, x_2 + \sqrt{b_2 P_r} x_r\right) + n_{U3} \qquad (7)$$

Where, n_{U2} and n_{U3} represents the additive white Gaussian noise with zero mean and variance σ^2 during the second time slot.

A. Existing Decoding Schemes

1) Single Signal Decoding Scheme

The received signal x_1 is quickly decoded by UE_2 and UE_3 during the first time slot by considering symbols x_2 as noise and cancelling them while utilising SIC to acquire symbols.

The received SNR for symbols x_1 and x_2 at the relay are

$$\gamma_{BR}^{[x_1]} = \frac{|h_{BR}|^2 a_1 P_t}{|h_{BR}|^2 a_2 P_t + \sigma^2} \qquad (8)$$

$$\gamma_{BR}^{[x_2]} = \frac{|h_{BR}|^2 a_2 P_t}{\sigma^2} \qquad (9)$$

In second time slot UE_2 and UE_3 decode the received signal x_2 and x_r. UE_3 decodes the received signal x_2 by treating symbol x_r as noise and cancels it using SIC to acquire symbol x_r.

The received SNR for symbols x_2 and x_r at UE_2 is

$$\gamma_{RU2}^{[x_2]} = \frac{|h_{RU2}|^2 b_1 P_r}{|h_{RU3}|^2 b_2 P_r + \sigma^2} \tag{10}$$

$$\gamma_{RU2}^{[x_r]} = \frac{|h_{RU2}|^2 b_2 P_r}{\sigma^2} \tag{11}$$

UE_3 treats x_r as noise when decoding x_2

The received SNR for symbols x_2 at UE_3 is

$$\gamma_{RU3}^{[x_2]} = \frac{|h_{RU3}|^2 b_1 P_r}{|h_{RU3}|^2 b_2 P_r + \sigma^2} \tag{12}$$

The achievable sum rate can be obtained as

$$C_{sum}^{(s)} = \sum_{i=1}^{3} \frac{1}{2} log_2(1 + S_i) \tag{13}$$

Where $S_1 = min\left(\gamma_R^{[x_1]}, \gamma_{RU2}^{[x_1]}, \gamma_{RU3}^{[x_1]}\right)$, $S_2 = min\left(\gamma_R^{[x_2]}, \gamma_{RU2}^{[x_2]}, \gamma_{RU3}^{[x_2]}\right)$, $S_3 = min\left(\gamma_{RU2}^{[x_r]}, \gamma_{RU3}^{[x_r]}\right)$

2) MRC Decoding Scheme:

The destination does not decode the signal it has received from the source in order to increase system performance; instead, it stores it until the second phase time slot.

To jointly decode x_1 and x_2 at UE_2 and UE_3. The received SNR for symbols x_1, x_2 and x_r are

$$\gamma_{RU2}^{[x_1]} = \frac{|h_{BU2}|^2 a_1 P_t}{|h_{BU2}|^2 a_2 P_t + \sigma^2} \tag{14}$$

$$\gamma_{RU3}^{[x_1]} = \frac{|h_{BU3}|^2 a_1 P_t}{|h_{BU3}|^2 a_2 P_t + \sigma^2} \tag{15}$$

$$\gamma_{RU2}^{[x_2]} = \frac{|h_{RU2}|^2 b_1 P_t}{|h_{RU2}|^2 b_2 P_t + \sigma^2} + \frac{|h_{BU2}|^2 a_2 P_t}{\sigma^2} \tag{16}$$

$$\gamma_{RU3}^{[x_2]} = \frac{|h_{RU3}|^2 b_1 P_t}{|h_{RU3}|^2 b_2 P_t + \sigma^2} + \frac{|h_{BU3}|^2 a_2 P_t}{\sigma^2} \tag{17}$$

and

$$\gamma_{U2}^{[x_r]} = \frac{|h_{RU2}|^2 b_2 P_t}{\sigma^2} \tag{18}$$

$$\gamma_{U3}^{[x_r]} = \frac{|h_{RU3}|^2 b_2 P_t}{\sigma^2} \tag{19}$$

The achievable sum rate can be obtained as

$$C_{sum}^{(MRC)} = \sum_{i=1}^{3} \frac{1}{2} log_2(1 + M_i) \tag{20}$$

Where $M_1 = min\left(\gamma_R^{[x_1]}, \gamma_{U2}^{[x_1]}, \gamma_{U3}^{[x_1]}\right)$,

$M_2 = min\left(\gamma_R^{[x_2]}, \gamma_{U2}^{[x_2]}, \gamma_{U3}^{[x_2]}\right)$, $M_3 = min\left(\gamma_{U2}^{[x_r]}, \gamma_{U3}^{[x_r]}\right)$

III. PROPOSED DECODING SCHEME

Error reduction is challenging in wireless communication for high-speed data transfer. Effective channel coding methods are necessary for the communication system to identify and fix errors. In the area of "forward error correction," Reed-Solomon (RS) encoders and decoders belong (FEC). Reed-Solomon codes perform best in the fading environment, which has a higher burst error rate. In order to ensure that the receiver only receives error-free data, RS codes add parity bits at the transmitter end. These bits allow RS codes to detect and correct numerous random symbol errors.

When the Reed-Solomon encoder and decoder are utilised in the system design, the proposed system outperforms existing systems in terms of sum rate, outage probability, and outage capacity.

A. Reed Solomon Encoding and Decoding

BCH codes are divided into Reed-Solomon codes. In a finite Galois field, Reed-Solomon (RS) codes are encoded and decoded.

When transmitting, the Reed-Solomon encoder adds parity symbols to each block of symbols before sending it. The decoder then examines the block to detect flaws and rectify them using the Berlekamp - Massey method [10].

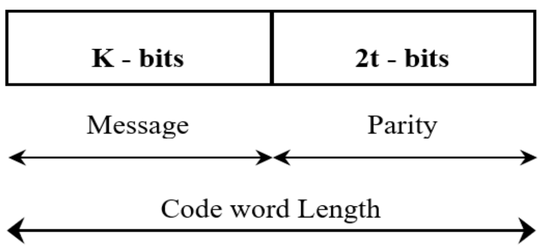

Figure 2. Basic structure of Reed Solomon codes

The Reed Solomon code is denoted as (n, k) where n is the codeword length, k is the message length. The length of parity bits is $(n - k) = 2t$ where t is a set of errors corrected by the RS codes. The minimum distance for such a code is $d = 2t + 1$.

1) Architecture of Reed Solomon (RS) codes

RS codes are constructed by taking different values from $GF(q)$. So that number of codewords is q^k

The message polynomial $p(x)$ from $GF(q)$ is

$$p(x) = m_0 + m_1 x + m_2 x^2 + \cdots + m_{k-1} x^{k-1}$$
$$= [p(0), p(\alpha), p(\alpha^2), \ldots \ldots p(\alpha^{q-1})] \quad (21)$$

Where, α is a primitive element of $GF(q)$

Polynomial Generator:

A generator polynomial for (n, k) RS code can be defined as the polynomial of degree $(n-k)$ such that every code polynomial is exactly divisible by generator polynomial.

The general form of generator polynomial is

$$g(x) = \sum_{i=1}^{2t} (x - \alpha^i)$$
$$= (x-\alpha)(x-\alpha^2)(x-\alpha^3) \ldots (x-\alpha^{2t}) \quad (22)$$

Encoding:

The data sequence in a Galois field $GF(q^m)$ is $[d_0, d_1, d_2, \ldots \ldots \ldots . d_{k-1}]$

$\Longrightarrow d(x) = d_0 + d_1 x + d_2 x^2 + \cdots + d_{k-1} x^{k-1}$

By including parity check polynomial

$p = [p_0, p_1, p_2, \ldots \ldots p_{2t-1}, d_0, d_1, d_2, \ldots . d_{k-1}]$

Therefore, codeword polynomial is given by

$$c(x) = p(x). g(x) \quad (23)$$

Decoding:

The codeword received by the RS decoder consists of transmitted data and errors during transmission.

$$r(x) = c(x) + e(x) \quad (24)$$

The above equation has two components: codeword c(x) and error polynomial e(x)

If $\frac{r(x)}{g(x)} = 0$ then no errors

If $\frac{r(x)}{g(x)} \neq 0$ there is an error and that value is called syndrome.

The syndrome depends upon the errors caused during transmission and

$$s_i = e(\alpha^i)$$
$$= \sum_{k=0}^{n-1} (e_k \alpha^{ik}) \quad where\ i = 1,2,3, \ldots 2t \quad (25)$$

Syndromes are used to calculate the error locator polynomial. This can be done using Berlekamp – Massey Algorithm [10].

Error locator polynomial can be obtained as

$$\Lambda(x) = \sum_{i=1}^{v} 1 - X_i(x) \quad (26)$$
$$= (1 - X_1 x)(1 - X_2 x) \ldots \ldots \ldots \ldots (1 - X_v x)$$
$$= 1 + \Lambda_1 x^1 + \Lambda_2 x^2 + \cdots \ldots \ldots \ldots \ldots .. + \Lambda_v x^v$$

Where X_i = error locators and V= received data

Finding the roots of the above polynomial can be done using Chien search algorithm and magnitude of errors can be obtained using Forney algorithm.

The Forney algorithm first convolves the syndrome polynomial and with the error locator polynomial to get the error evaluator polynomial

$\epsilon(x) = s(x). \Lambda(x)$

the error polynomial coefficients are

$$e_{ik} = \frac{\epsilon({X_{ik}}^{-1})}{\Lambda^1({X_{ik}}^{-1})} \quad (27)$$

B. Performance Analysis of proposed scheme

1) Ergodic sum rate Analysis

$$C_{sum} \cong E[C_{xr}] + E[C_{x1}] + E[C_{x2}] \quad (28)$$

The ergodic sum rate achieved by the proposed system is

$$C_{sum}^{RS-single} = \frac{1}{2ln2}\Bigg(\frac{A}{a_2}(-a_1 E_c - a_1 lnA + lna_2) + lna_2 + \left(1 + \frac{1}{a_2 \rho \alpha_{BR}}\right) lnb_2 + (1+B)E_c + lnB\Bigg)$$

Where,

$$\rho = \frac{P}{\sigma^2}$$

$$A = \frac{1}{\rho}\left(\frac{1}{\alpha_{BR}} + \frac{1}{\alpha_{BU2}} + \frac{1}{\alpha_{BU3}}\right)$$

$$B = \frac{1}{b_2 \rho}\left(\frac{1}{\alpha_{RU2}} + \frac{1}{\alpha_{RU3}}\right)$$

$$C_{sum}^{RS-MRC} = \frac{1}{2ln2}\Bigg(\frac{A}{a_2}\bigg(-(a_1+1)E_c - a_1 lnA + ln\frac{{a_2}^2}{A}\bigg) + lna_2 + B(E_c + lnB + ln\frac{a_2 B}{A}\bigg)$$

2) Outage Probability

Let $R_\tau^{x_1}, R_\tau^{x_2}, R_\tau^{x_r}$ denoted as the predefined target rate thresholds of the symbols x_1, x_2, x_r respectively.

Outage event occurs when $R_{x_1}, R_{x_2}, and\ R_{x_r}$ are less than that of $R_\tau^{x_1}, R_\tau^{x_2}\ and\ R_\tau^{x_r}$

$$P_{RS-Single} = 1 - pr[R_{x_1} > R_\tau^{x_1}, R_{x_2} > R_\tau^{x_2}, R_{x_r} > R_\tau^{x_r}] \quad (29)$$

$$= 1 - pr[M_1 > W_1, M_2 > W_2, M_3 > W_3]$$

Where, $W_1 = 2^{R_\tau^{x_1}} - 1, W_2 = 2^{R_\tau^{x_2}} - 1, W_r = 2^{R_\tau^{x_r}} - 1$

$$P_{RS-MRC} = 1 - \exp[-\frac{W_1}{a_1\rho - a_2\rho W_1}\left(\frac{1}{\alpha_{BR}} + \frac{1}{\alpha_{BU2}} + \frac{1}{\alpha_{BU3}}\right) - \frac{W_r}{b_2\rho}\left(\frac{1}{\alpha_{RU2}} + \frac{1}{\alpha_{RU3}}\right) - \frac{W_2 - \frac{b_1}{b_2}}{a_2\rho}]$$

3) Outage capacity

Let $W_1 = W_2 = W_r = W_s = W_M$

$$C_{out}^{RS} = \frac{1}{2}\log_2(1 + W_M) \quad (30)$$

IV. SIMULATION RESULTS

In this section, the proposed system's performance under the RS-encoded maximum ratio combining and RS-encoded single signal decoding schemes is assessed in terms of ergodic sum rate, outage probability, and outage capacity. The proposed RS-encoded maximum ratio combining and single signal decoding schemes are compared to the current maximum ratio combining and single signal decoding schemes without RS coding.

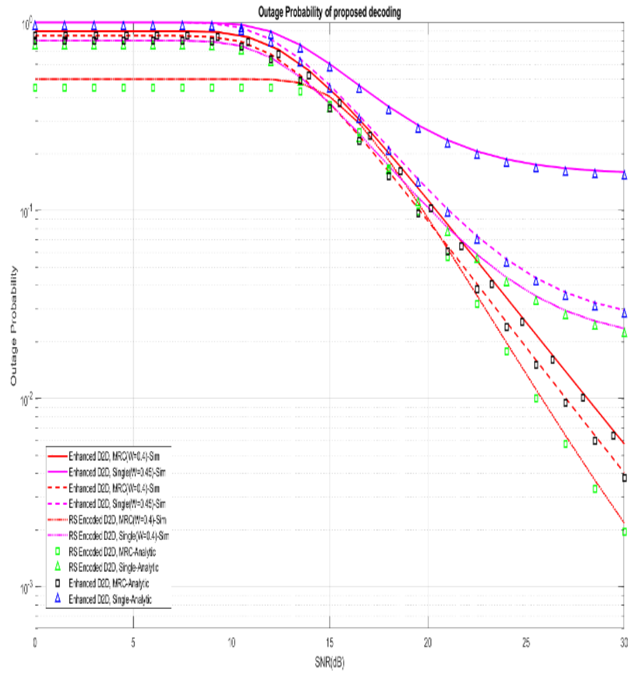

Figure 3 : Outage probability of the proposed RS coding with MRC and single signal decoding, and the existing system without RS Codes.

Figure 3 shows the outage probability performance for the proposed scheme and the existing system with fixed target rates w = 0.4 and 0.45 in simulation and analytical results for the fixed values of $a_1 = 0.9$ and $b_1 = 0.6$, respectively.

As can be seen from the above graph, the outage probability will decrease as transmitting SNR increases. In a Rayleigh-fading environment, the proposed system gets a lower outage rate than do existing systems.

TABLE I : Outage probability versus SNR for fixed target rate w = 0.4.

Decoding Scheme	Target Threshold (bps/Hz)	SNR [dB]	Outage probability
RS Encoded MRC	0.4	30	0.002
RS Encoded single signal decoding	0.4	30	0.023
MRC without RS codes	0.4	30	0.004

Single signal decoding without RS codes	0.4	30	0.1602

According to the table, for the fixed target rate of w = 0.4, the suggested system's outage chance is lower at high SNR than that of the existing systems without RS codes.

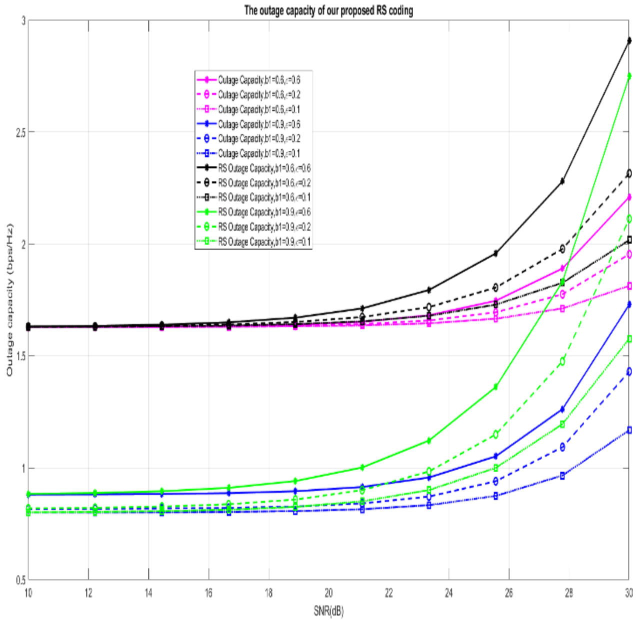

Figure 4 : outage capacity of the proposed RS coding with MRC and single signal decoding, and the existing system without RS Codes.

Figure 4 displays the effectiveness of the outage capacity for the proposed scheme and the existing system with optimal outage chance values of $\in = 0.1$, 0.2, and 0.6 in the simulation results for the fixed values of $a_1 = 0.9$ and $b_1 = 0.6$, respectively.

According to the above graph, outage capacity will increase as transmitting SNR increases. In a Rayleigh-fading environment, the proposed system outperforms current systems in terms of outage capacity.

TABLE II: outage capacity versus SNR for different optimum outage probability values

Decoding Scheme	SNR [dB]	optimum outage probability	Outage capacity (bps/Hz)

		values	
RS outage capacity	30	∈=0.6	3
		∈=0.2	2.3
		∈=0.1	2
Existing system outage capacity	30	∈=0.6	2.2
		∈=0.2	2
		∈=0.1	1.8

The outage capacity at high SNR is assessed using various optimum outage probability values from the above table. In comparison to existing systems without RS codes, the proposed system increases the outage capacity.

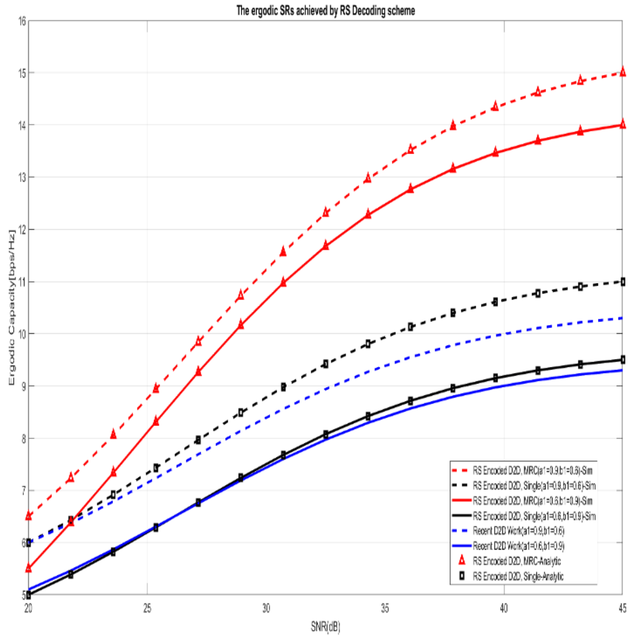

Figure 5 : The ergodic sum rate achieved by the proposed RS coding with MRC and single signal decoding, and the existing system without RS Codes.

Figure 5 shows the ergodic sum rate obtained by the proposed scheme and the existing system with fixed values of $a_1 = 0.9$ and $b_1 = 0.6$, respectively, in both simulation and analytical findings.

According to the above graph, the ergodic sum rate attained by the proposed method will rise as the transmitting SNR rises. Compared to existing systems, the suggested system gets a higher sum rate in a Rayleigh fading environment.

TABLE III: Ergodic sum rate versus SNR for the fixed values of $a_1 = 0.9$ and $b_1 = 0.6$.

Decoding Scheme	SNR [dB]	Achieved sum rate (bps/Hz)
RS Encoded MRC	45	15
RS Encoded single signal decoding	45	11
MRC without RS codes	45	12
Single signal decoding without RS codes	45	8

According to the table, for the fixed values of $a_1 = 0.9$ and $b_1 = 0.6$, respectively, the proposed system's achievable sum rate is higher at high SNR than that of existing systems without RS codes.

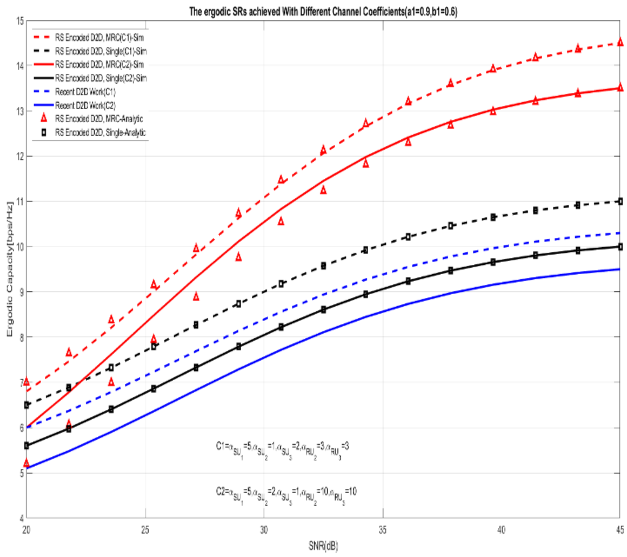

Figure 6 : The ergodic sum rate achieved by the proposed RS coding with MRC and single signal decoding, and the existing system without RS Codes with different channel coefficients.

The proposed scheme and the existing system's ergodic sum rate are shown in Figure 6 for various channel coefficients with fixed values of $a_1 = 0.9$ and $b_1 = 0.6$. The ergodic sum rate attained by the proposed methodology under various channel coefficients will increase as the transmitting SNR increases. Compared to existing systems, the proposed system gets a higher sum rate in a Rayleigh-fading environment.

V. CONCLUSIONS

The implications of weak channel conditions in cooperative device-to-device communication systems with non-orthogonal multiple access (NOMA) were evaluated in this work using a new RS decoding algorithm. It has been demonstrated from the simulation results that the suggested strategy considerably enhances performance in terms of ergodic sum rate, outage probability, and outage capacity. When the power allocation variables a_1 and b_1 were set to 1 and 5, the proposed system performed significantly better. Furthermore, the results demonstrate that an RS-encoded maximum ratio combining scheme outperforms existing single signal decoding and maximum ratio combining systems without RS coding in terms of performance.

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