Implications of Power Allocation Factors on the Performance of Ergodic Sum Rate in Cooperative Device-to-Device Systems with NOMA

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Abstract

The power allocation issue for cooperative device-to-device (D2D) systems with non-orthogonal multiple access (NOMA) is examined in this paper. In cooperative device-to-device (D2D) NOMA systems, communication occurs in two phases: the direct transmission slot, or the path from the base station to user destinations, and the relaying slot, or the path from the relay (near the user), with different power allocation factors to improve the ergodic sum rate.It is suggested that power allocation considerations affect how well the ergodic sum rate performs with different decoding techniques. The decoding techniques include Reed Solomon's (RS) encoded single signal decoding technique and Reed Solomon's (RS) encoded maximum ratio combining (MRC) decoding technique. The error probability of successive decoding will increase if any errors occur during the successive interference cancellation (SIC) procedure at any user. In order to detect and correct multiple symbol errors in a Rayleigh fading environment, RS codes are used in the system architecture for error detection and correction.Through the results of the simulation, it is demonstrated that the proposed approach performs much better than the existing work for the fixed values of the power allocation parameters.

Keywords: NOMA, D2D systems, RS codes, MRC, SIC, Ergodic sum rate.

1. Introduction

A crucial enabling method for 5G cellular networks has been identified as NOMA technology. It can boost the system sum rate. The basic idea of NOMA is that the base station sends the combined signal, which is a superposition of the required signals from various users with various power coefficients, to all mobile users. Each user's receiver is considered to undergo SIC processing in phases until the user's signal is recovered. The base station may serve numerous users at the same time, frequency, and code resource because it takes use of a new dimension power domain to provide multiple access.Users' channel conditions determine the impact of various power allocation coefficient selections; those with poor channel conditions receive more transmission power than those with favourable channel conditions.

The cooperative device-to-device communication system is a novel radio access strategy that combines the relaying protocol and NOMA system to combat the deep fading of the wireless channel propagation and increase the network coverage area. The close user with good channel conditions acts as a relay to support the far user with bad channel circumstances in this direct communication between users without the involvement of the base station and with the aid of one or more relays. By using forwarding protocols like amplify and forward (AF) and decode and forward (DF), the relays convey the incoming information signals to the appropriate destination.Therefore, it has been thought that a notable option to further increase the system's effectiveness is the combination of cooperative device-to-device communication and NOMA.

2. Related Study

For the user destinations performances, the power allocation problem is essential. Several research have been conducted in this arena that concentrate on power allocation algorithms for cooperative device-to-device communication networks, including:

Wei Duan et al. in [1] suggested a two-stage NOMA power allocation scheme for cooperative relaying systems. In this technique, the relay decodes and sends a new superposition coded symbol with a new power allocation to the destination after receiving a superposition coded symbol with a power allocation from the source.

When deploying the AF system, Dinh-Thuan Do et al. suggested a fixed power allocation method in [2] to demonstrate the outage performance of individual users in the NOMA scheme. Furthermore, the effect of the source node's transmit SNR in cooperative relaying NOMA on throughput is assessed.

To promote fairness among secondary users in the Internet of Things, Zain Ali et al. introduced the Bisection method-based approach in [3]. The results of the simulation demonstrate that the suggested framework achieves complete fairness with great performance when there is enough transmission power available.

Gau et al. in [4] suggested a unique method for dynamically choosing the best relay node and the best transmission power levels in NOMA wireless networks with relays. Based on the channel status information, the suggested technique switches between the one-relay and two-relay modes to optimise the sum rate.

This study discusses an influence of the power allocation parameters on the performance of the ergodic sum rate under various decoding algorithms, which is distinct from the one in [5]. It is intended that the existing MRC decoding scheme and single signal decoding method without Reed Solomon codes be replaced by the proposed Reed Solomon encoded MRC decoding scheme and single signal decoding scheme with Reed Solomon codes.

Additionally, if any errors are made throughout any user's successive interference cancellation (SIC) operation, the error probability during successive decoding is going to increase. Therefore, in order to prevent error propagation, error detection and correction mechanisms must be implemented in system architecture.

In terms of ergodic sum rate for various transmitting SNRs with given values of power allocation coefficients, the proposed approach is compared to existing decoding systems.

This paper's remaining sections are structured as follows: Section 2 presents the related work and system model for cooperative D2D systems with NOMA. The proposed decoding techniques are described in Section 3. The findings of the simulation are discussed in Section 4. Section 5 concludes to this paper.

System Design

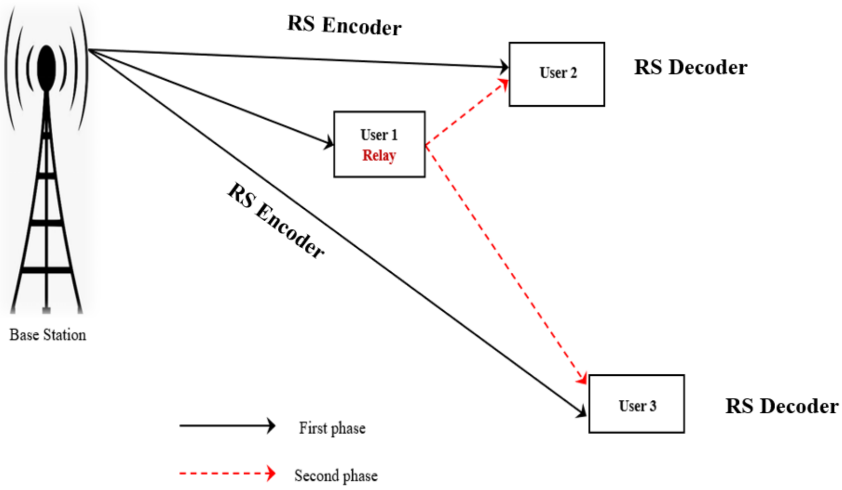

Figure 1: Cooperative D2D systems with NOMA

Figure 1 depicts a straightforward cooperative D2D relaying system with NOMA made up of one base station (BS), one relay, 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'sUE_2 and UE_3, respectively, ish_{BU2}andh_{BU3}.$h_{RU2}$and $h_{RU3}$are used to refer to the channels from the relay to the destination, respectively. These are the average powersα_{BR}, α_{BU2}, α_{BU3}, $\alpha_{RU2}$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.

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.

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

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

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

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

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

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.

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

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

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

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

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

Single Signal Decoding Scheme:

The received signal $x_1$is quickly decoded by UE_2 andUE_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 is

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

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

In second time slot UE_2 and UE_3 decode the received signal $x_2$and x_r.UE_3decodes 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

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

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

UE_3treats x_r as noise when decoding x_2

The received SNR for symbols x_2 at UE_3 is

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

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

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 $x_r$is

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

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

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

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

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 $M_1 = \min\left(\gamma_R^{[x_1]}, \gamma_{U2}^{[x_1]}, \gamma_{U3}^{[x_1]}\right)$, $M_2 = \min\left(\gamma_R^{[x_2]}, \gamma_{U2}^{[x_2]}, \gamma_{U3}^{[x_2]}\right)$, $M_3 = \min\left(\gamma_{U2}^{[x_r]}, \gamma_{U3}^{[x_r]}\right)$

3. Proposed Methodology:

The chance of errors in subsequent decoding will rise if any successive interference cancellation (SIC) process errors occur at any user. It is essential for wireless communication's bit error rate reduction and high-speed data transfer. To reduce the error, the system design must use forward error correction (FEC). Therefore, it is necessary to use error detection and correction procedures while designing systems to prevent error propagation. In fading channel situations, Reed-Solomon encoders and decoders function well. Through the addition of extra bits on the transmitter side, it may identify and fix numerous symbol errors to ensure that the recipient only receives accurate information.

The system performance is enhanced when Reed Solomon encoder and decoder are used with the current decoding techniques in comparison to prior decoding strategies without Reed Solomon codes for the fixed values of power allocation coefficients.

4. Simulation Results:

This section presents an appropriate choice of power allocation coefficients for existing and proposed schemes.

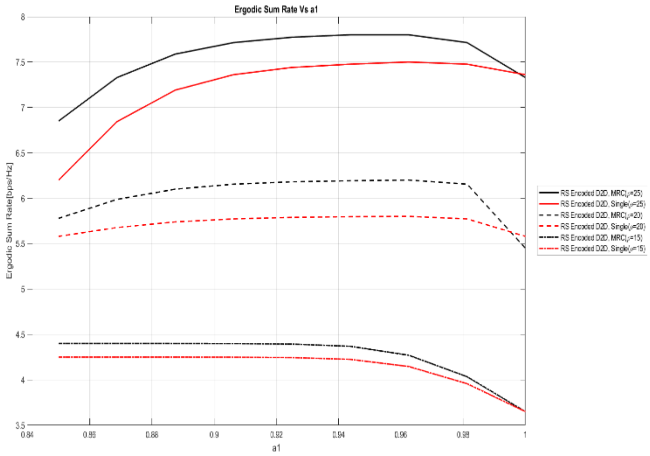

Figure 2: Ergodic Sum rate achieved by the proposed decoding scheme for different transmitting SNRs versus power allocation factor a_1

The Reed Solomon encoded MRC and single signal decoding techniques for varied transmitting SNRs of ρ =15, 20, and 25 dB versus power allocation factor $a_1$are shown in Figure 1 along with the ergodic sum rate they were able to accomplish.

According to figure 1, at high transmitting SNR ($\rho = 25$), for$a_1 = 0.96$, both the RS encoded MRC and the RS encoded single signal decoding technique have increased ergodic sum rates.

Table 1:Ergodic Sum rate achieved by the proposed decoding scheme for different transmitting SNRs

Decoding Scheme	SNR [dB]	Sum Rate (bps/Hz)
RS encoded MRC	$\rho = 25$	7.8
RS encoded single signal	$\rho = 25$	7.5
RS encoded MRC	$\rho = 20$	6.2
RS encoded single signal	$\rho = 20$	5.8
RS encoded MRC	$\rho = 15$	4.4
RS encoded single signal	$\rho = 15$	4.25

Table 1 shows that the achievable total rate for RS-encoded MRC is 7.8 bps/Hz with $a_1 = 0.96$ and for the RS-encoded single signal decoding technique is 7.5 bps/Hz with $a_1 = 0.96$ at high transmitting SNR ($\rho = 25$). According to the table, the ergodic sum rate at high transmitting SNR is the highest possible for the proposed technique.

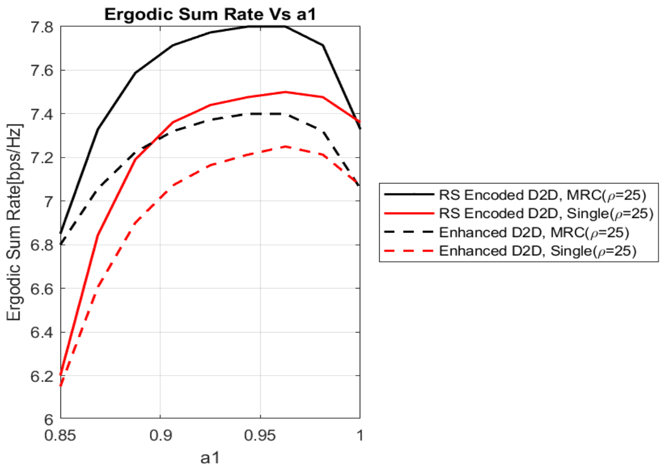

Figure 2: Ergodic Sum rate achieved by the proposed and existing decoding schemes for transmitting SNR$\rho = 25\ dB$versus power allocation factora_1

Figure 2 compares the ergodic sum rates of the existing MRC and single signal decoding techniques with the new Reed Solomon encoded MRC and single signal decoding schemes for transmission SNR of $\rho = 25$ dB vs power allocation factora_1.

According to Figure 2, the proposed decoding strategy performs better than existing decoding algorithms for a_1 =0.96 at high transmitting SNR ($\rho = 25$).

Table 2:Ergodic Sum rate achieved by the proposed and existing decoding scheme for transmitting SNR$\rho = 25$dB

Decoding Scheme	Sum Rate (bps/Hz)
RS encoded MRC	7.8
RS encoded single signal	7.5
MRC Decoding	7.4
single signal Decoding	7.2

According to table 2, at high transmitting SNR (ρ =25), the proposed RS-encoded MRC achieves a sum rate of 7.8 bps/Hz, whereas the existing MRC achieves a sum rate of 7.4 bps/Hz with $a_1 = 0.96$. The achieved sum rate is 7.5 bps/Hz for the proposed RS-encoded single signal decoding strategy and 7.2 bps/Hz with $a_1 = 0.96$ for the existing single signal decoding scheme. According to the table, the ergodic sum rate at high transmitting SNR is the highest possible for the suggested method.

The Reed Solomon encoded MRC and single signal decoding techniques for varied transmitting SNRs of ρ =15, 20, and 25 dB versus power allocation factor $b_1$are shown in Figure 3 along with the ergodic sum rate they were able to accomplish.

According to figure 3, at high transmitting SNR ($\rho = 25$), for$b_1 = 0.5$, both the RS encoded MRC and the RS encoded single signal decoding technique have increased ergodic sum rates.

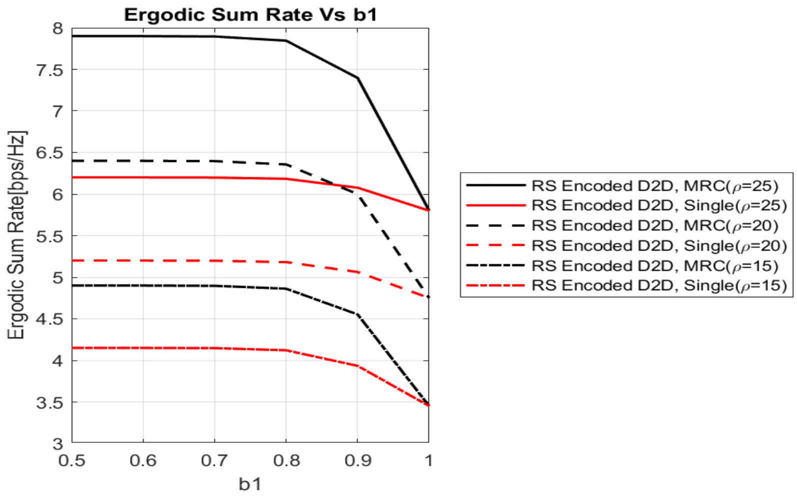

Figure 3: Ergodic Sum rate achieved by the proposed decoding scheme for different transmitting SNRs versus power allocation factorb_1

Table 3:Ergodic Sum rate achieved by the proposed decoding scheme for different transmitting SNRs

Decoding Scheme	SNR [dB]	Sum Rate (bps/Hz)
RS encoded MRC	$\rho = 25$	7.9
RS encoded single signal	$\rho = 25$	6.2
RS encoded MRC	$\rho = 20$	6.4
RS encoded single signal	$\rho = 20$	5.2
RS encoded MRC	$\rho = 15$	4.9
RS encoded single signal	$\rho = 15$	4.15

Table 3 shows that the achievable total rate for RS-encoded MRC is 7.9 bps/Hz with $b_1 = 0.5$ and for the RS-encoded single signal decoding technique is 6.2 bps/Hz with $b_1 = 0.5$ at high transmitting SNR ($\rho = 25$). According to the table, the ergodic sum rate at high transmitting SNR is the highest possible for the proposed technique.

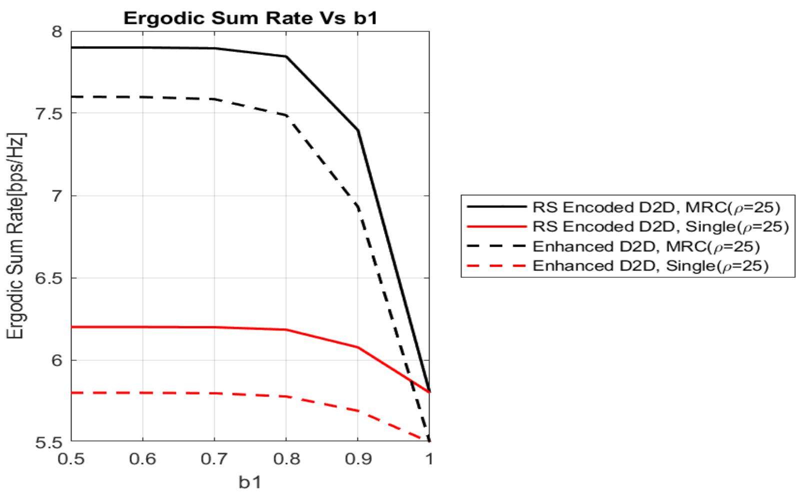

Figure 4: Ergodic Sum rate achieved by the proposed and existing decoding schemes for transmitting SNR$\rho = 25\ dB$versus power allocation factorb_1

Figure 4 compares the ergodic sum rates of the existing MRC and single signal decoding techniques with the new Reed Solomon encoded MRC and single signal decoding schemes for transmission SNR of $\rho = 25$ dB vs power allocation factorb_1.

According to Figure 4, the proposed decoding strategy performs better than existing decoding algorithms for b_1 =0.5 at high transmitting SNR ($\rho = 25$).

Table 4:Ergodic Sum rate achieved by the proposed and existing decoding scheme for transmitting SNR$\rho = 25$dB

Decoding Scheme	Sum Rate (bps/Hz)
RS encoded MRC	7.9
RS encoded single signal	6.2
MRC Decoding	7.6
single signal Decoding	5.8

According to table 4, at high transmitting SNR (ρ =25), the proposed RS-encoded MRC achieves a sum rate of 7.9 bps/Hz, whereas the existing MRC achieves a sum rate of 7.6 bps/Hz with$b_1 = 0.5$. The achieved sum rate is 6.2 bps/Hz for the proposed RS-encoded single signal decoding strategy and 5.8 bps/Hz with $b_1 = 0.5$ for the existing single signal decoding scheme. According to the table, the ergodic sum rate at high transmitting SNR is the highest possible for the suggested method.

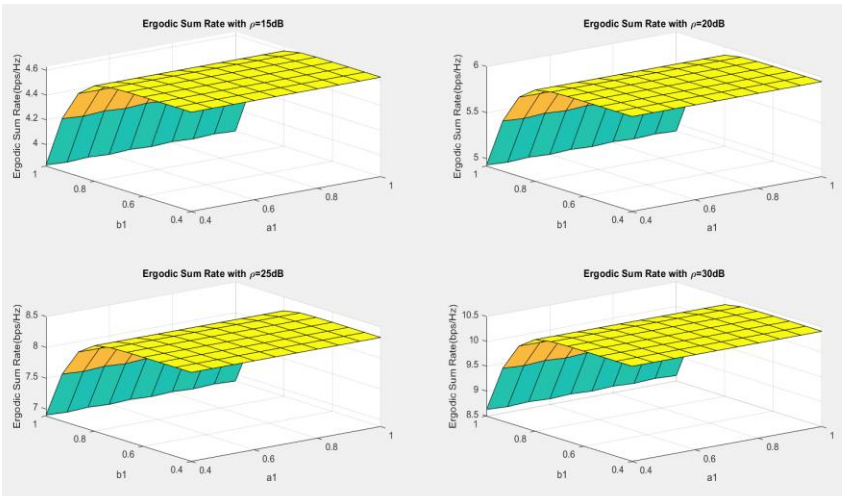

Figure 5: RS encoded MRC decoding scheme: Ergodic sum rate Vs$a_1, b_1$with different transmitting SNR

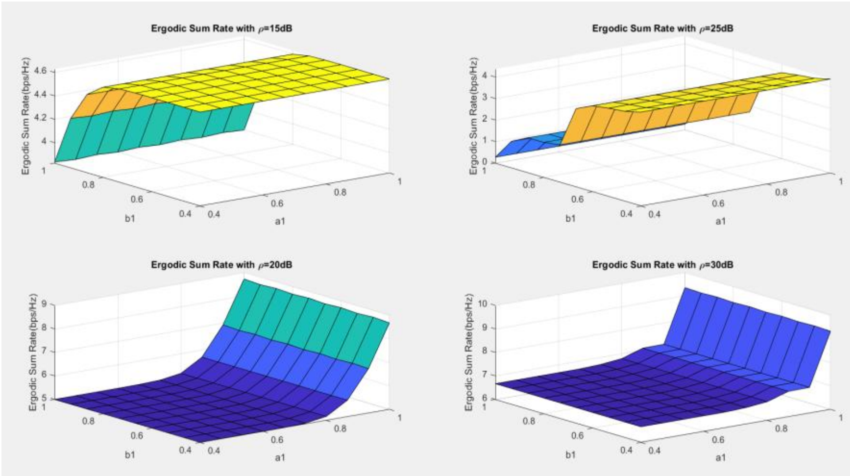

Figure 6: RS encoded single signal decoding scheme: Ergodic sum rate Vsa_1, b_1 with different transmitting SNR

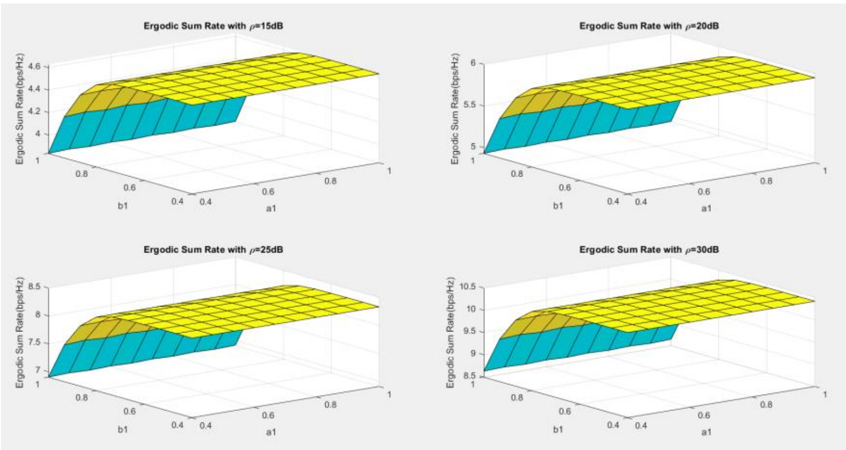

Figure 7: MRC decoding scheme: Ergodic sum rate Vsa_1, b_1 with different transmitting SNR

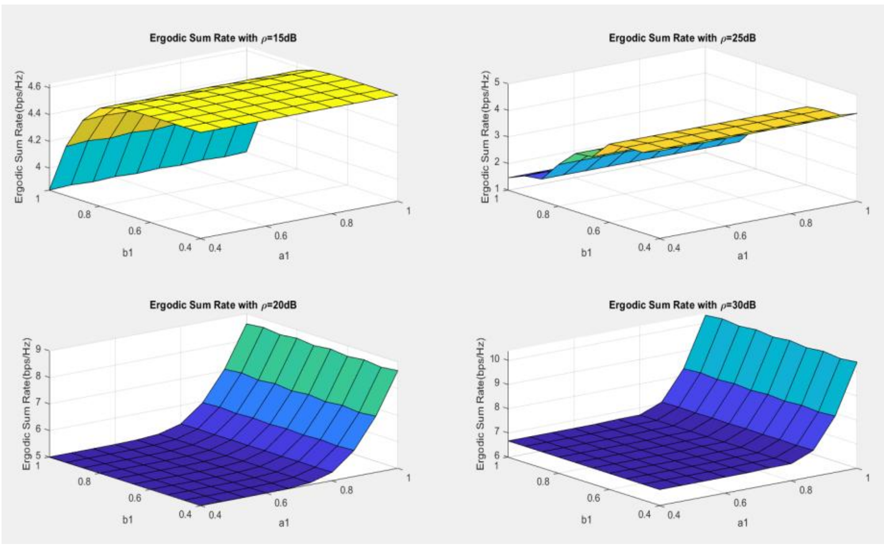

Figure 8: Single signal decoding scheme: Ergodic sum rate Vsa_1, b_1 with different transmitting SNR

The proposed RS-encoded MRC decoding, the proposed RS-encoded single signal decoding scheme, and the existing MRC and single signal decoding scheme are compared in Figures 15 to 18 for their ergodic sum performances versus the power allocation factors a_1 and b_1 for various transmitting SNRs of $\rho = 15$, 20, 25, and 30 dB, respectively. A comparable value of power allocation factors a_1 and b_1 that optimises the performance in terms of ergodic sum rate for proposed decoding algorithms is also demonstrated.

According to the figures, the maximum sum rate is achieved for a value $a_1 = 0.9$ and $b_1 = 0.5$. Finally, the RS-encoded MRC system offers a remarkable advantage over the other schemes thanks to its ergodic sum rate.

5. Conclusions

For cooperative device-to-device systems with NOMA, the effect of power allocation parameters on the performance of the ergodic sum rate under various decoding algorithms was examined in this paper. The proposed RS encoded MRC and RS encoded single signal decoding outperform existing decoding algorithms in terms of ergodic sum rate. Additionally, all the findings demonstrated that the suggested system outperforms the current system in terms of ergodic sum rate while the power allocation variables are fixed to $a_1 = 0.9$ and $b_1 = 0.5$. Future research will still need to look at the most feasible way to distribute power between the base station and users in order to further enhance system performance.

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