Bit error rate analysis of generalized quadrature spatial modulation-based NOMA for 5G communications

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Abstract: Due to the characteristic of transmitting multiplexed signals in superposed mode over the same spectrum, non-orthogonal multiple access (NOMA) technology is deemed as a promising way to improve spectral efficiency in fifth generation (5G) networks. In this paper, we develop a NOMA with generalized quadrature spatial modulation (GQSM) based cooperative system based on the two-path successive relaying concept, in which the data at the source node is divided into two parallel parts and is transmitted to the destination in superposed mode via the assistance of two decode-and-forward (DF) relays. On the condition that the transmit power of the individual nodes and the entire system are all constrained, the maximization of achievable rate is formulated as an optimization problem. Following the guidelines of power optimization, the dual decomposition method is adopted to obtain the closed-form expressions of the optimal power allocation. Moreover, to balance the achievable rate between two superposed signals, which is equivalent to minimizing the required spectrum bandwidth, a power allocation scheme between the superposed signals is proposed. The results demonstrate that the proposed NOMA-GQSM resulted in superior bit error rate (BER) rate performance as compared to conventional methods.

Keywords: Vehicular communications, spatial modulation, index modulation, non-orthogonal multiple access, bit error rate.

1. Introduction

NOMA techniques will be a key technology of fifth generation (5G) cellular networks [1]. Current orthogonal multiple access (OMA) systems result in low spectrum efficiency, when network resources are assigned to mobile users with poor channel conditions. However, if we consider the power domain, NOMA systems can deliver high spectrum efficiency even with poor channel conditions. In the NOMA scheme, the mobile users may share the same frequency, time, and code, yet they should be differentiated in power levels [2]. To this end, the fundamental concept of NOMA scheme is the use of successive interference cancellation (SIC) technique by the mobile users' receivers with rich channel conditions, to significantly reduce the interference level of mobile users with poor channel conditions. As a result, SIC technique cancels the intra- cell or cluster interference on mobile users' receivers [3].

The user association problem is becoming more challenging in NOMA networks, as some unique power levels of traditional OMA networks, such as co-channel interferences, require re-design. The authors in [4] formulate the user association problem in NOMA networks by grouping the users into orthogonal clusters and associating them different resource blocks using a game theoretic approach. However, game theoretic approaches which are commonly used in user association problems have limitations and work under certain assumptions. On the other hand, evolutionary algorithms (EAs) are global optimizers that work well regardless of the optimization problem in hand. We describe the problem formulation with the network sum rate utility function.

A parameter that introduces more complexity to the problem is power control. Usually, as in [4] the power coefficients are considered constant for all network. In our case we find the suitable power coefficients for every NOMA user. Evolutionary algorithms inspired by nature are suitable techniques for solving this problem. In this paper, we apply the GWO [5], which was recently introduced as a population-based algorithm that mimics grey wolf hunting behavior. Additionally, a comparative study between the GWO obtained results and the legacy particle swarm optimizer (PSO) [6] is performed. The derived results indicate that GWO algorithm outperforms the PSO algorithm in general. Moreover, we conclude that NOMA schemes with power control can be successfully utilized.

2. Literature survey

For NOMA-based relaying systems, when relays operate in half-duplex decode-and-forward (DF) mode, many system models and resource allocation schemes already have been proposed. In [7], for a system in which NOMA technique is applied in both direct and relay transmissions, analytical expressions for outage probability and ergodic sum capacity are derived. In [8], a NOMA-based relaying system is proposed to improve spectral efficiency as well as its achievable capacity is investigated. A buffer-aided NOMA relaying system is proposed in [9], its performance is investigated, and an adaptive transmission scheme for such system is proposed in [10]. For a system with slowly faded NOMA-equipped multiple-relay channels, the benefit of joint network channel coding and decoding is studied in [11]. In [12], an analytical framework for a NOMA-based relaying system is developed, and then, its performance over Rician fading channels is studied. In [13], the impact of relay selection on the performance of cooperative NOMA is studied, and then, a two-stage relay selection strategy is proposed. In [14], a novel signal detection scheme for a simple NOMA-based relaying system is proposed, and then, the ergodic sum rate and outage performance of the system are investigated. In [15], based on Alamouti space-time block-coded NOMA technique, a two-phase cooperative DF relaying scheme is proposed. In [16], a dual-hop cooperative relaying scheme using NOMA is proposed, where two sources communicate with their corresponding destinations in parallel over the same channel via a common relay. To maximize the throughput of a NOMA-equipped wireless network with multiple relays, in [17], a novel approach to dynamically select an optimal relay mode and optimal transmit power is proposed.

On the other hand, when relays operate in half-duplex DF (DF) mode, many schemes have been proposed to improve the performance of NOMA-based relaying systems. In [18], a NOMA-based multi-antenna-equipped relaying network is designed, and then, its outage performance is analyzed. When a base station communicates with multiple mobile users simultaneously through the help of a relay over Nakagami-m fading channels, the overall performance is analyzed in [19]. For a NOMA-equipped single-cell relay network, where an OFDM-based DF relay allocates its spectrum and power resources to source-destination (SD) pairs, a many-to-many two-sided SD pair-subchannel matching algorithm is proposed in [20]. In [21], a joint power allocation and relay beamforming design problem is investigated, and

then, an alternating optimization-based algorithm is proposed to maximize the achievable rate. In [22], the outage performance of a cooperative NOMA-equipped relay system is studied, and then, an accurate closed-form approximation of the outage probability is derived. In [23], when multiple users transmit messages to two destinations under the help of multiple DF relays, an optimal relay selection criterion is proposed to improve outage performance, and closed-form analytical expressions for the outage probability are derived. In [24], a relay-aided NOMA technique is proposed for uplink cellular networks, where the cooperative relay transmission is used to accommodate more than one user per orthogonal resource block in the context of interference-limited scenarios.
To enhance system flexibility, in [25], for NOMA-equipped cooperative networks with both the DF and AF relaying protocols, where one base station communicates with two mobile users with the aid of multiple relays, a two-stage relay selection strategy is proposed while considering different quality-of-service (QoS) requirements of the users.

3. Proposed Model

We consider a multi-vehicle single-relay cooperative downlink vehicular communication network, comprising one BS with Nt transmit antennas, vehicle 1 and vehicle 2 both with Nr receive antennas, and one DF relay with Nt transmit and Nr receive antennas operating in the half-duplex mode, where the BS aims to transmit two GQSM signal vectors x1 and x2 generated by m1 and m2 bits to vehicle 1 and vehicle 2, respectively. For simplicity, we assume that m1 = m2 = log2 C(Nt, p) + p log2 M. Note that the vehicle 1 can directly receive the signal from the BS due to the near location, while there is no direct transmission link between the BS and vehicle 2 because of the severe propagation attenuation (long distance). Therefore, one DF relay is assumed to be located between the BS and vehicle 2, which leads to two phases for transmission from the BS to vehicle 1 and vehicle 2. To enable this two-phase transmission, we investigate two relaying transmission schemes, C-NOMA-GQSM with GWO optimization as shown in Figure 1.

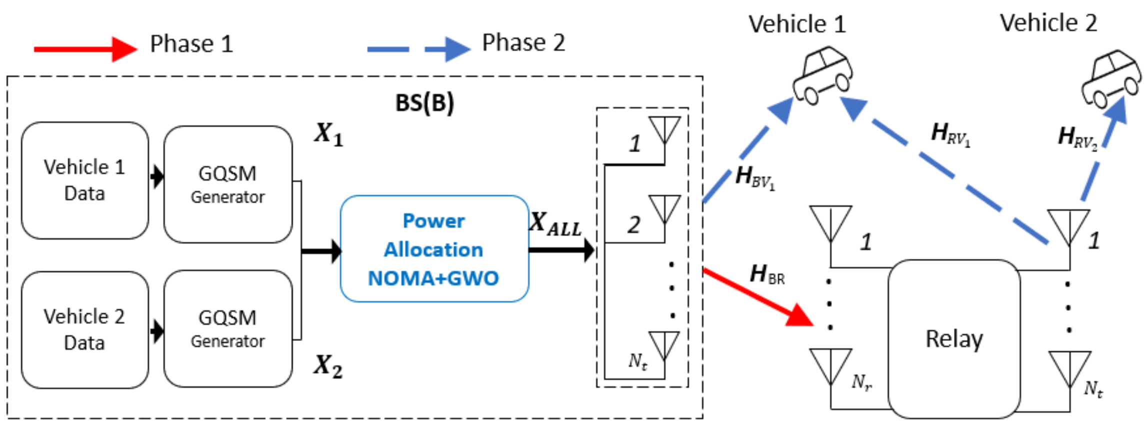

Figure 1. Proposed system model

3.1 GQSM

We first propose the GQSM scheme in Figure 2 in this subsection. We consider an MIMO system with Nt transmit antennas and Nr receive antennas.

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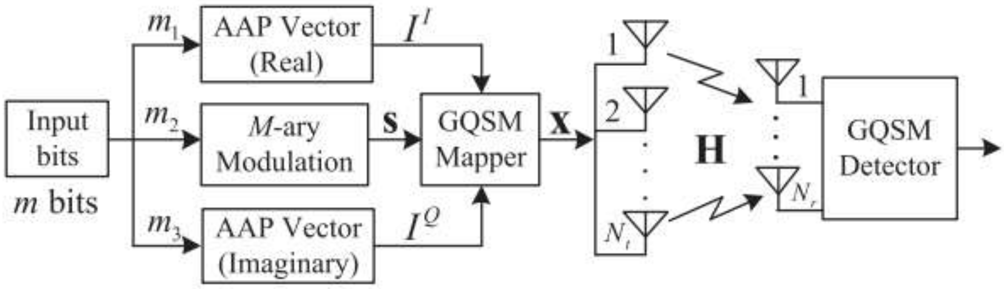

Figure 2. System model for GQSM.

By GQSM, p out of Nt transmit antennas are activated for conveying the real part of the modulated signal vectors with the selected antenna activation permutation (AAP) I^I. Similarly, the imaginary part of the modulated signal vectors is transmitted through another p activated transmit antennas, resulting in the corresponding AAP) I^Q.. Note that the total number of AAPs for the real/imaginary part is C (Nt, p), but only L = 2log2 C(Nt,p) AAPs are adopted for modulation purposes. As can be seen in Figure 2, m input bits are split into three parts, m1, m2, and m3, where m1 and m3 (m1 = m3) bits represent the index bits for the real and imaginary parts, respectively, and m2 bits stand for the modulation bits generating the modulated signal vector. Specifically, the modulated signal vector s = [s1,s2,...,sp] are first generated by m2 = p log2 M bits, where sτ = sI τ + j sQ τ with 1 ≤ τ ≤ p, sτ ∈ X, and X denotes the M-ary constellation set. It should be noted that sI τ and s Q τ are selected from X I and X Q, respectively, where X I and X Q represent the real and imaginary parts of X, respectively. m1 = m3 = log2 C(Nt, p) bits are then utilized to determine the AAP I I and I Q so as to transmit the real and imaginary signals {sI τ } p τ=1 and {s Q τ } p τ=1. Let sI = [sI 1 ,sI 2 ,...,sI p] and sQ = [s Q 1 ,s Q 2 ,...,s Q p] denote the real and imaginary sets of the the modulated signal vector s. Let I I α and I Q β be the αth and βth legal AAPs for real and imaginary parts, respectively.

3.2 Power allocation with NOMA

We have shown the idea of a NOMA-based novel two-path relaying system, where the target information of the source node is divided into two equal streams and they are transmitted to the destination via two half-duplex DF relays in superposed mode. Because of adopting the idea of superposition model in the NOMA technique, intuitively, lower level of system frequency is required compared to a system with OMA scheme. In such system, while targeting on the maximization of the system capacity, the power allocation among the source and relay nodes is an optimization problem given that there are power constraints at the individual nodes as well as the entire system. The dual decomposition method is adopted to obtain the closed form expressions of the optimal power allocation.

Once the optimal power allocation at each node is known, in order to separate the superposed received messages at the destination, the optimal power allocation between the two data streams is formulated as an optimization problem while targeting on the minimization of the required frequency band. Similar to the solution scheme of the first problem, the dual decomposition method is adopted to obtain the closed form expression of the optimal power allocation. The power allocation model is the most important aspire is to make most of the energy efficiency of the system during the proposed optimization method, GWO. For GQSM-NOMA systems the optimal power allocation is done probably with the proposed GWO technique that is attained. The power scheduling is performed exploiting the proposed GWO method so that to allocates power through maximum effectiveness to users in an effectual method. The NOMA while employed utilizing GQSM creates a substantial increase in energy effectual power allocation to users.

3.2.1 NOMA

The architecture model of the proposed method in NOMA-GQSM based systems is demonstrated in fig. 1, which still needs two phases to complete the whole transmission. It should be noted that vehicle 1 is near to the BS, and the DF relay is relatively far from the BS, which leads to σ2 BV1 > σ2 BR. Due to the NOMA principle, the BS will combine two signal vectors by $x_{ALL} = \sqrt{\zeta 1 x1} + \sqrt{\zeta 2 x2},$ where ζ1 and ζ2 denote the power allocation factors for vehicle 1 and vehicle 2, respectively, and ζ1 + ζ2 = 1 as the transmit power constraint. Since vehicle 1 is near to the BS and vehicle 2 as well as the relay are far from the BS, the BS will allocate more power to uesr 2 (x2) and less power to vehicle 1 (x1) by NOMA, which leads to ζ1 < ζ2. By C-NOMA-GQSM, the BS first broadcasts the combined signal xALL to both vehicle 1 and the relay in the first phase. The Nr × 1 received signal vectors at vehicle 1 and the relay can be expressed as

$$\begin{aligned}\mathbf{y}_{\mathrm{BV}_1}^{\mathrm{NOMA}} &= \mathbf{H}_{\mathrm{BV}_1}\mathbf{x}_{\mathrm{ALL}} + \mathbf{n}_{\mathrm{BV}_1} \\ &= \mathbf{H}_{\mathrm{BV}_1}(\sqrt{\zeta_1}\mathbf{x}_1 + \sqrt{\zeta_2}\mathbf{x}_2) + \mathbf{n}_{\mathrm{BV}_1}\end{aligned} \tag{1}$$

$$\begin{aligned}\mathbf{y}_{\mathrm{BR}}^{\mathrm{NOMA}} &= \mathbf{H}_{\mathrm{BR}}\mathbf{x}_{\mathrm{ALL}} + \mathbf{n}_{\mathrm{BR}} \\ &= \mathbf{H}_{\mathrm{BR}}(\sqrt{\zeta_1}\mathbf{x}_1 + \sqrt{\zeta_2}\mathbf{x}_2) + \mathbf{n}_{\mathrm{BR}}\end{aligned} \tag{2}$$

respectively, where nBV1 and nBR denote the the Nr × 1 noise vectors following the distribution CN (0, σ2 BV1) and CN (0, σ2 BR), respectively. Vehicle 1 retains the received signal and waits for another upcoming signal in the second phase for detection purposes. With the help of the relay, the transmitted signal vector to vehicle 2 can be easily detected due its larger transmit power by the ML detection.

4. Simulation Results.

In this section, we present MatlabR2016a based simulation results to evaluate the BER performance of GQSM systems under the assumptions of Rayleigh fading channels and perfect channel estimation.

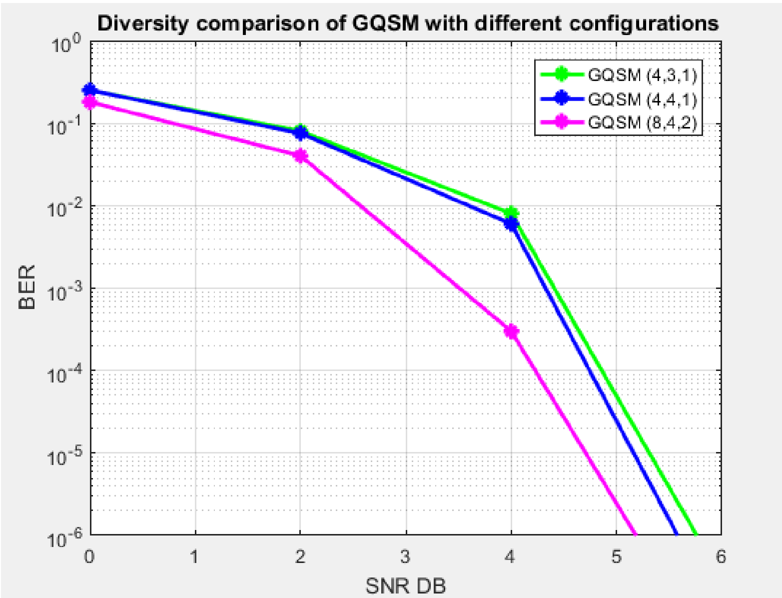

Fig. 4. Diversity comparison of GQSM with different configurations.

For the sake of simplicity, we denote "GQSM (Nt, Nr, p, MQAM)" as the GQSM scheme with Nt transmit antennas, Nr receive antennas, p activated transmit antennas and M-ary

QAM constellation. To evaluate the diversity of the proposed GQSM, we compare the BER performance of GQSM (4, 3, 1, 4QAM), GQSM (4, 4, 1, 4QAM), and GQSM (8, 4, 2, 8QAM) in Fig. 6. It is shown from Fig. 4 that GQSM (4, 2, 1, 4QAM) achieves the smallest diversity order as 2 (Nr = 2). To further explore the diversity property, we compare the BER performance between GQSM (4, 4, 1, 4QAM) and GQSM (8, 4, 2, 8QAM), which shows that GQSM (4, 4, 1, 4QAM) achieves the same diversity order (Nr = 4) as that of GQSM (8, 4, 2, 8QAM) by only changing the number of transmit antennas Nt, the number of activated transmit antennas p and the cardinality of constellation M.

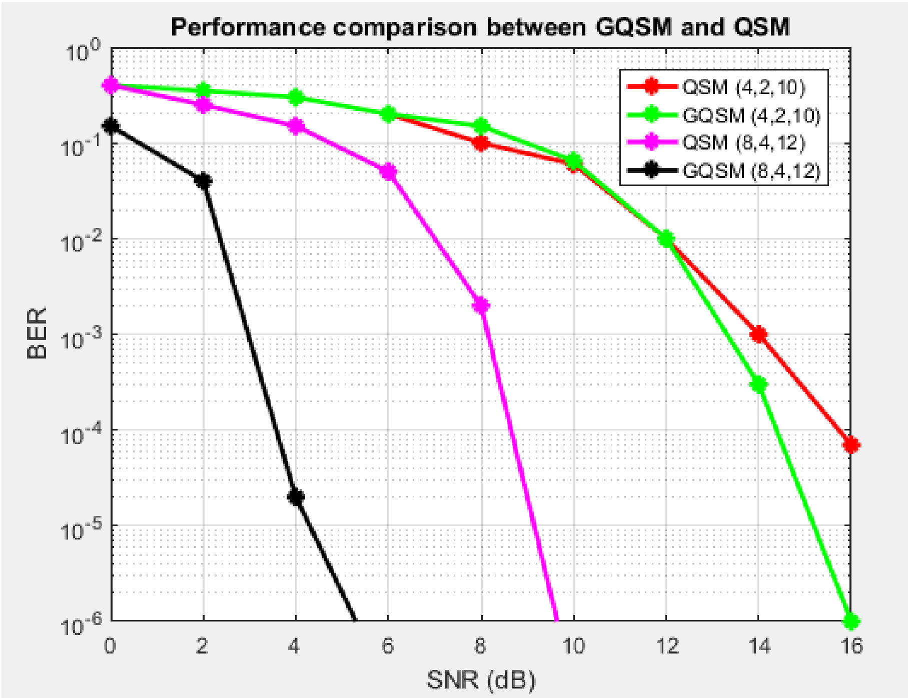

Figure 5. Performance comparison between GQSM and QSM

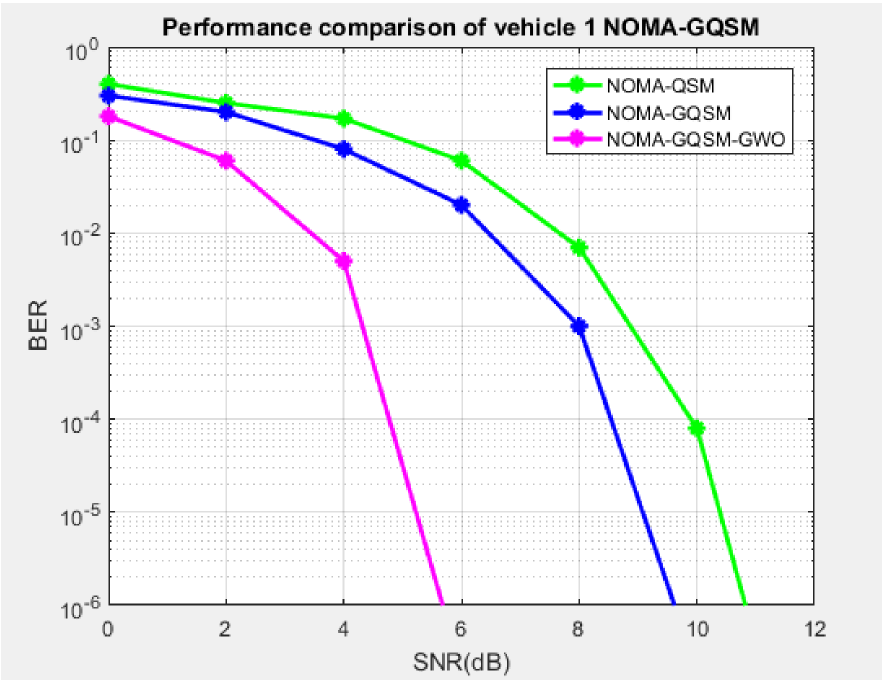

Fig. 6. Performance comparison of vehicle 1

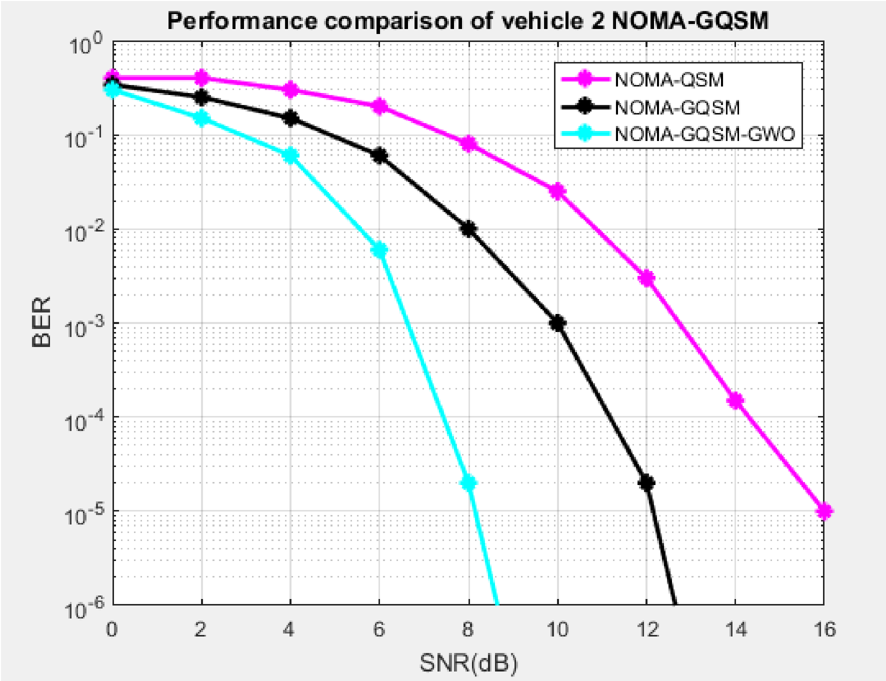

Fig. 7. Performance comparison of vehicle 2

In Fig. 5, we compare the BER performance between GQSM and QSM schemes with Nt = 4 and 8, Nr = 2 and 4. It can be seen that GQSM (4, 2, 3, 4QAM) achieves a large performance gain than QSM (4, 2, 64QAM) both with 10 input bits in the entire SNR region. Specifically, compared to QSM (4, 2, 64QAM), GQSM (4, 2, 3, 4QAM) obtains almost 6 dB SNR gain at BER = 10−2 and obtains up to 8dB SNR gain at BER = 10−4. This is because GQSM significantly increases the length of index bits, which improves the system performance. For both vehicle 1 and vehicle 2, NOMA-GQSM outperformed as compared to conventional NOMA-QSM, NOMA-GQSM, which is presented in Figure 6 and Figure 7.

5. Conclusion

This work proposes GQSM-NOMA Transmitter for multi-user scenario. In the proposed system, a superimposed signal of several constellation symbols is transmitted simultaneously by distinguishing the power domain. Different signal domain is then perceived at each receiver. BER performance is offered in this system when dynamic power allocation is utilized with optimized power coefficients. On the other hand, the spectral efficiency analysis shows that the proposed system outperforms the other existing techniques such as QSM-NOMA system by using the same system configuration over the whole SNR range. In addition, from the simulation results it is shown that the proposed system can cover more users compared with the existing systems. As per the results, it can be concluded that there is a chance to improve the BER by 55% in the new proposed method. As of future research, we would like to extend the single-user scenario to the multi-user one while keeping the same NOMA-GQSM-based cooperative relay idea. Incorporating massive millimeter multiple-input multiple-output (MIMO) technology in such a system could be another possible research direction.

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