Distributed Generalized Spatial Modulation for Relay Networks

Taissir Y. Elganimi, Fatima I. Alwerfly, and Akram A. Marseet
Electrical and Electronic Engineering Department
University of Tripoli, Libya
E-mail: {t.elganimi, f.alwerfly, a.marseet}@uot.edu.ly

***Abstract*—A multi-relay cooperative diversity protocol based on the concept of Generalized Spatial Modulation (GSM) scheme is proposed in this paper, assuming that decode-and-forward relaying protocol is adopted at relays. This scheme is referred to as Distributed Generalized Spatial Modulation (DGSM) with activating more than one relay. The system performance of the proposed diversity protocol in terms of the Symbol Error Rate (SER) is evaluated and compared to the performance of GSM and Distributed Spatial Modulation (DSM) schemes. Simulation results show that DGSM systems with activating more than one relay perform almost the same as DSM systems for the same spectral efficiency. It is also demonstrated that a performance enhancement of about 3 dB is achieved over GSM schemes for the same modulation order, which increases the energy efficiency and the reachability using the proposed model. Therefore, the proposed scheme can be effectively used in various 5G wireless networks.**

***Keywords*—Distributed spatial modulation; generalized spatial modulation; DGSM; relay networks; SER.**

I. Introduction

In recent years, cooperative communications and relaying protocols have been emerged as promising and potential candidate technologies for the future wireless networks and applications [1, 2]. However, it is shown in the literature, *e.g.*, [3, 4], that distributed cooperation is an effective way to overcome the effect of heavy shadowing and multipath fading, to improve the coverage of the Fifth Generation (5G) wireless networks, and to reduce the transmit power consumption. This is achieved with the aid of enabling single-antenna mobile terminals to exploit the advantages of Multiple Input Multiple Output (MIMO) systems by being a part of a distributed antenna-array [4].

Over the last decade, many researchers have extensively studied and investigated the potential benefits of combining MIMO schemes and relay-aided cooperation, as well as the energy efficient techniques for 5G communication systems [5-8]. The emerging Spatial Modulation (SM) technique has shown that it can outperform the other MIMO schemes such as Spatial Multiplexing (SMX) scheme in terms of the computational receiver complexity if many transmit antennas are equipped at the transmitter [9, 10]. This, however, makes SM systems impractical with large number of antennas in the cellular networks and useful only in the downlink scenario where a large number of antennas can be equipped in the base station. In order to overcome this issue, Distributed Spatial Modulation (DSM) scheme is presented in [3, 4] as a cooperative diversity protocol that allows the relays to convey their own data frames while re-conveying the data frames of the source. This protocol is based on the concept of SM systems, and a set of mobile terminals assist the source to transmit the information to the destination regardless of the channel imperfection.

Recently, several research studies have focused on the SM-based relay-aided protocols and leveraged the benefits of applying SM principle in the context of cooperative communications, *e.g.*, [11-13]. All these papers have shown the potential advantages and significant benefits of using SM in the relay-aided transmission protocols compared to the conventional MIMO schemes. However, these relaying protocols treat SM technique as a conventional modulation scheme, and they aim either to enhance the network coverage or to improve the link reliability of SM transmission through distributed diversity.

Despite the fact that SM with single Radio Frequency (RF) chain has significantly improved the spectral efficiency of MIMO systems, the constraint of SM scheme is that the number of transmit antennas has to be a power of two is a major constraint. Therefore, a generalized form of SM is proposed in [14] to release this constraint and improve the spectral efficiency. This scheme is called Generalized Spatial Modulation (GSM) scheme with activating multiple transmit antennas simultaneously, and it magnifies the transmit energy consumption since multiple antennas are activated. This paper leverages the GSM principle to be applied to relay-aided and cooperative communications, and a novel scheme is proposed and referred to as the Distributed Generalized Spatial Modulation (DGSM) protocol. This scheme is based on activating more than one relay at a time.

The rest of this paper is organized as follows. In Section II, the system model of the proposed DGSM scheme is introduced. A comparison between DGSM, DSM and GSM systems in terms of the Symbol Error Rate (SER) performance is presented in Section III. Finally, Section IV concludes the present paper.

II. System Model

The system model of DGSM scheme is depicted in Fig. 1 with considering that there is one transmit antenna at the source which employs M-QAM or M-PSK modulation technique. The key idea of DGSM protocol is that the source conveys $\log_2(M)$ bits to R cooperative relays that share their antennas to form a virtual antenna array. Then the source's information will be forwarded to the destination from a number of R_a relays that will

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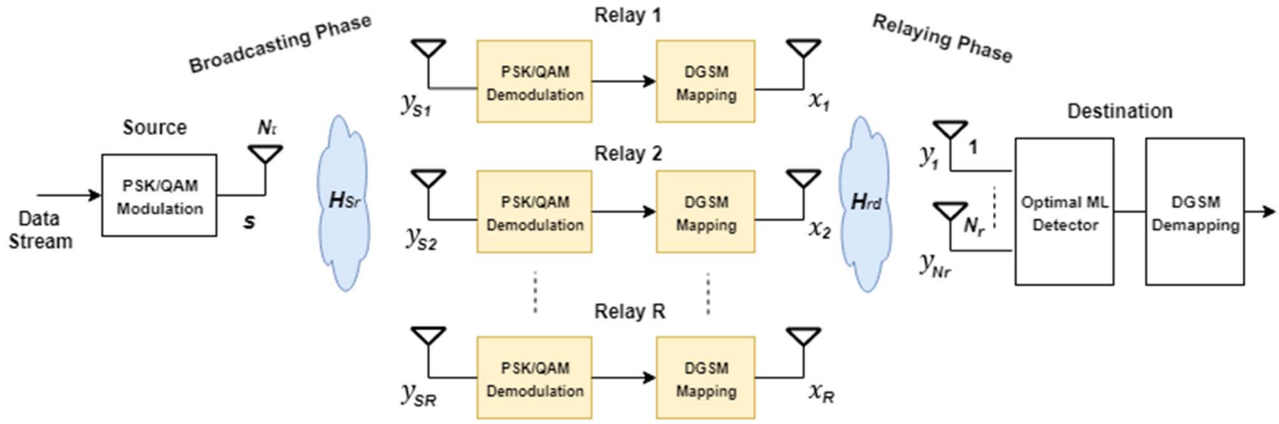

Fig. 1. DGSM system model with one single-antenna source, R relays, and the destination with N_r receive antennas.

be activated based on the principle of GSM-MIMO technique in a distributed manner to forward the estimated bits of the source to the destination, where $R_a \leq R$, thus the overall transmit power of the system is saved. The DGSM scheme reduces the effect of heavy shadowing while expanding the mobile network coverage.

Let us consider the proposed multi-relaying network of DGSM system with one single-antenna source and R relays that use PSK/QAM modulation with constellation size M_r, and R_a relays are selected to send the same complex symbol, where a set of relay combinations can be formed and used as spatial constellation points. The number of possible relay combinations in DGSM scheme is $\binom{R}{R_a} = \frac{R\times(R-1)\times\ldots\ldots\times(R-R_a+1)}{R_a!}$, and the number of relay combinations that can be considered for transmission must be a power of two. Therefore, only $2^{\left\lfloor \log_2 \binom{R}{R_a} \right\rfloor}$ combinations can be used, where $\lfloor . \rfloor$ is the floor operation.

The number of bits that can be transmitted depends on the used constellation diagram and the given number of cooperative relays, where $\log_2(M)$ bits can be transmitted at any particular time instant. Like in DSM systems, each relay in DGSM scheme is assigned a unique digital identifier, and $M = M_r R$, where the number of relays must be a power of two. The mapping procedure in DGSM scheme maps the first $\left\lfloor \log_2 \binom{R}{R_a} \right\rfloor$ bits to the relay combinations, and the remaining $\log_2(M_r)$ bits are modulated using a modulation scheme. Therefore, the average rate (in bpcu) in DGSM systems can be expressed as:

$$\mathcal{R}_{\text{av}} = \frac{1}{2}\log_2(M) = \frac{1}{2}\left(\left\lfloor \log_2 \binom{R}{R_a} \right\rfloor + \log_2(M_r)\right) \quad (1)$$

The achievable rate of DGSM system versus the number of active relays with 16-QAM technique and various numbers of relays is depicted in Fig. 2. This figure shows that the maximum achievable rate can be achieved when the number of active relays is half the number of the total cooperative relays.

The data transmission in the proposed DGSM scheme lasts for two time slots and occurs in two phases as follows:

1) Broadcasting Phase

The broadcasting phase in DGSM scheme is similar to that of DSM systems, where $p = \log_2(M)$ information bits to be transmitted by the single-antenna source, and $s = \psi\,(p)$ is the PSK or QAM complex symbol that transmitted from the source with $s \in \{s_1, s_2 \ldots, s_M\}$, where $\psi\,(.)$ represents the bit-to-symbol modulation mapping function at the source. The received signal y_{Sr} at the relay R_r, where $r = 1, 2, \ldots\ldots R$ is expressed as [3]:

$$y_{Sr} = \sqrt{E_S}h_{Sr}s + n_r \quad (2)$$

where E_S is the average transmit energy per symbol at the source, h_{Sr} is the Rayleigh fading channel coefficient for the r-th source-relay link with zero mean and unit variance, and n_r is the complex Additive White Gaussian Noise (AWGN) at the r-th relay with zero mean and variance σ^2 per dimension.

The received signal y_{Sr} is demodulated in the relay R_r with performing a demodulation rule based on the Maximum Ratio Combining (MRC) technique in order to estimate the transmitted symbol $\hat{g}$ of the source at the relay R_r as follows:

$$\hat{g} = \mathcal{D}\left(\frac{\left|{h_{Sr}}^H y_{Sr}\right|}{\|h_{Sr}\|_F^2}\right) \quad (3)$$

where $\mathcal{D}$ is the constellation demodulator function, $(\cdot)^H$ represents the conjugate transpose operation, $|\,.\,|$ is used for the absolute value, and $\|\,.\,\|_F$ stands for the Frobenius norm of a vector/matrix. The de-mapper obtains an estimate of the transmitted bits by taking $\hat{g}$ as an input.

2) Relaying Phase

In the relaying phase of DGSM scheme, each r-th relay divides the demodulated bits into two groups of information bits. The first group with a length of $\left\lfloor \log_2 \binom{R}{R_a} \right\rfloor$ bits is to determine the indices of the active relays, and the second group of length $\log_2(M_r)$ bits is to determine the constellation size of PSK or QAM symbol that transmitted by each relay. Each relay compares the first group of bits with its own digital identifier. If they match, the relay will modulate the remaining bits of the second group using PSK or QAM scheme, and forwards the modulated symbol to the destination. The received signal at the d-th receive antenna of the destination is formulated as:

$$y_d = \sum_{r=1}^{R}\left(\sqrt{E_r}h'_{l,r,d}x_r + n_d\right) \quad (4)$$

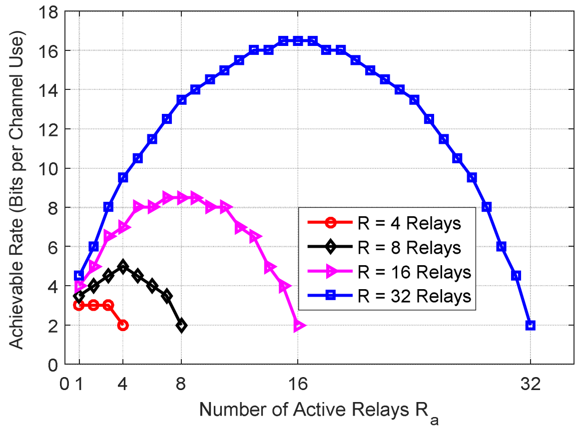

Fig. 2. The achievable rate in DGSM system versus the number of active relays with employing 16-QAM technique.

where E_r is the average transmit energy per symbol of the relay R_r, $h^{'}_{l,r,d} = \sum_{v=1}^{R_a} h_{l,r,d_v}$ is a vector that contains the summation of the active relays channel vectors, h_{l,r,d_v} is the channel vector from the transmit antenna of each active relay to all receive antennas at the destination, x_r is the transmitted symbol at the r-th relay, and n_d is the complex AWGN at the d-th receive antenna with zero mean and variance σ^2 per dimension.

The Maximum Likelihood (ML) optimum detector for DGSM scheme with the assumption of having a perfect Channel State Information (CSI) at the receiver can be written as:

$$[\hat{r}, \hat{x}] = \underset{\substack{r\in\{1\ldots R\} \\ q_n\in\{q_1,q_2,\ldots,q_{M_r}\}}}{\arg\min} \left\{ \sum_{k=1}^{N_r} \left| y_{d,k} - \sqrt{E_r} h^{'}_{l,r,d,k} q_n \right|^2 \right\} \quad (5)$$

where $\hat{r}$ is the estimated index of the active relay, $\hat{x}$ is the estimated symbol that transmitted by the active relay, $h^{'}_{l,r,d,k}$ is the zero-mean and unit variance Rayleigh fading channel coefficient of the link between the r-th relay and the d-th receive antenna of the destination, and $\{q_1, q_2, \ldots, q_{M_r}\}$ is the PSK/QAM complex symbol transmitted from the relay (when active).

III. Simulation Results

In this section, the SER performance versus the Signal-to-Noise Ratio (SNR) of DGSM systems is presented. The DGSM system is denoted in this paper as DGSM (N_t, N_r, N_{Rr}, M-QAM, M_r-QAM, R-Relays) with R_a active relays, where each relay has one transmit antenna and N_{Rr} receive antennas, and similarly for DSM systems where $R_a = 1$. Throughout the simulation, a Rayleigh fading channel with zero mean and unit variance is assumed with AWGN, and the receiver is assumed to have a perfect channel knowledge.

The SER performance of DGSM systems with 2 and 3 active relays out of 4 cooperative relays are compared to DSM systems for different values of spectral efficiency; 3, 4 and 4.5 $bits/sec/Hz$ as shown in Figs. 3, 4 and 5, respectively. It is clear from Fig. 3 that DSM system with 4 relays and DGSM systems with 2 and 3 active relays employing 64-QAM technique have almost the same SER performance. It is also noticeable that with increasing the number of cooperative relays in DSM systems to 8 and 16, an improvement of almost 1 dB and 4 dB can be achieved over DGSM systems, respectively. In addition, the required number of relays in DGSM systems is less than or equal to that of DSM systems to achieve the same spectral efficiency.

It is shown in Fig. 4 that the SER performance of DSM system with 4 cooperative relays and DGSM systems with 2 and 3 active relays are almost the same with $M = 256$. Moreover, increasing the number of cooperative relays to 8 and 16 in DSM systems gives better SER performance than DGSM systems. For example, DSM (1, 4, 4, 256-QAM, 16-QAM, 16-Relays) and DSM (1, 4, 4, 256-QAM, 32-QAM, 8-Relays) systems outperform the other schemes in this comparison by about 4 dB and 2 dB, respectively.

Fig. 5 shows that the SER performance of DSM systems and DGSM schemes with 2 and 3 active relays are almost the same with $M = 512$. Moreover, increasing the number of relays in DSM systems to 8 and 16 shows an improvement of approximately 2 dB and 4 dB as compared to the other schemes in this comparison, respectively. This shows that DGSM systems require more SNR to obtain the same SER performance, or almost the same SNR value for the same number of relays.

In Fig. 6, the SER performance of DGSM systems as compared to GSM schemes with ML detection technique for the same modulation order is shown. This figure compares the SER performance of GSM systems with 2 and 3 active antennas out of 4 antennas, and DGSM systems with 2 and 3 active relays out of 4 cooperative relays, both employing 64-QAM technique. The results show that DGSM (1, 4, 4, 256-QAM, 64-QAM, 4-Relays) systems outperform GSM schemes by about 3 dB.

IV. Conclusion

This paper proposed a distributed cooperative protocol based on GSM-MIMO systems with activating more than one relay to convey the same data. It has been demonstrated from the simulation results that the error performance of the proposed DGSM scheme almost matches that of DSM systems with the same modulation order and spectral efficiency. It is also shown that DGSM scheme outperforms the conventional GSM systems by a gain of almost 3 dB with the same modulation order.

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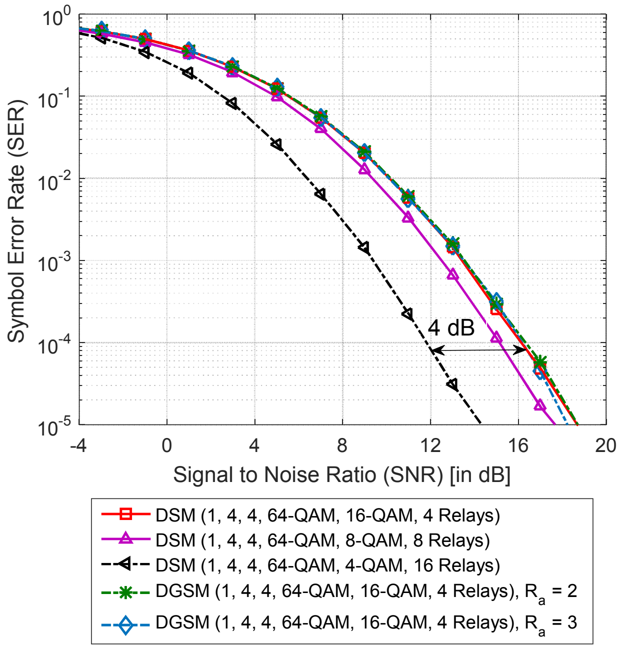

Fig. 3. SER performance of DGSM with 2 and 3 active relays compared to DSM for the same spectral efficiency of 3 $bits/sec/Hz$.

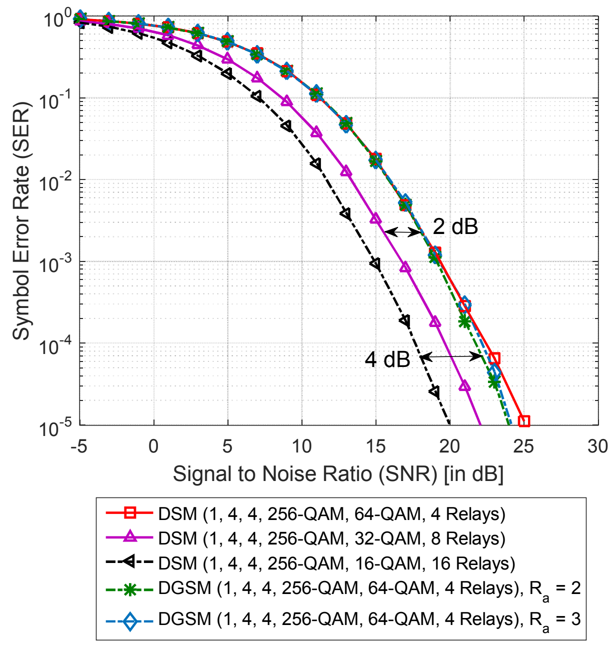

Fig. 4. SER performance of DGSM with 2 and 3 active relays compared to DSM for the same spectral efficiency of 4 $bits/sec/Hz$.

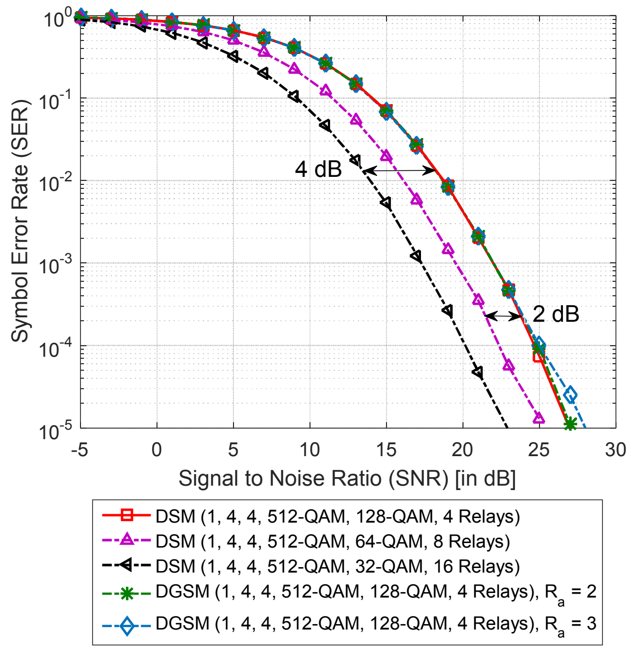

Fig. 5. SER performance of DGSM with 2 and 3 active relays compared to DSM for the same spectral efficiency of 4.5 $bits/sec/Hz$.

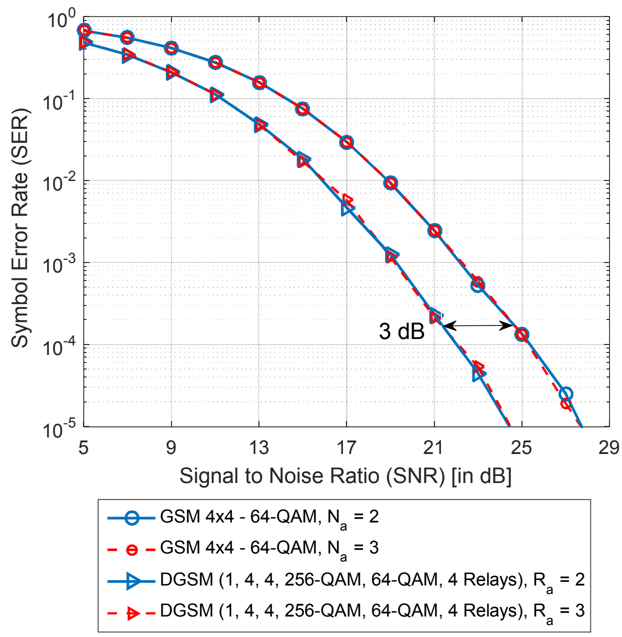

Fig. 6. SER performance of DGSM schemes (Arrow marker) compared to GSM (Circle marker) for the same modulation order, and with 2 active relays/antennas (Solid lines) and 3 active relays/antennas (Dashed lines).

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