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Cooperative quadrature spatial modulation with Euclidean distance and capacity optimized antenna selection

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Summary

In this study, new cooperative-quadrature spatial modulation techniques based on Euclidean distance and capacity optimized antenna selection techniques (EDAS-CQSM and COAS-CQSM) are proposed for cooperative communication systems. The considered cooperative system consists of three terminals that are the source terminal (ST), relay terminal (RT), and destination terminal (DT). The decode-and-forward (DF) cooperative technique is considered to retransmit the signal at the RT. In order to improve the performance of the conventional QSM demodulator in the RT and DT, both antenna selection techniques have been used in both the ST and RT to reduce performance degradation due to error propagation of the DF scheme. Therefore, the overall performance of the considered CQSM system has been increased. Furthermore, computer simulations have shown that the proposed EDAS/COAS-CQSM systems have better the performances than the cooperative spatial modulation (CSM), CQSM, EDAS-CSM, COAS-CSM, and traditional DF-based cooperative system with the same bit rate.

KEYWORDS

cooperative communication, decode and forward, Euclidean distance and capacity optimized antenna selection, quadrature spatial modulation

1 | INTRODUCTION

Nowadays, problems such as slow internet speed, high-power consumption, and and network coverage have been one of the major drawbacks in wireless communication. The increase of multiuser mobile games, online video and audio broadcasting, P2P file sharing, sending large files, listening to high-quality music, and watching high-definition videos is increasing daily.[1,2] Similarly, experts estimate that more than 50 billion devices will be connected to the internet by 2020, and majority will be mobile devices coupled with Internet of things (IOT) devices, which consume high amount of energy compared to a personal computer.[3,4] Therefore, a novel wireless communication system, which can achieve high data rate, high spectral efficiency, wide coverage, and low-latency coupled with energy efficient, is required.[5]

One of the major setbacks in wireless communication affecting the quality of service is the fading effect.[6] Diversity techniques are one of the most important methods that minimize the fading effect affecting the quality of service. Cooperative systems are based on the principle that the information generated by the source is sent to the destination via different independent channels.[7,8] Recently, cooperative diversity techniques have become the techniques of great interest by researchers since cooperative communication has advantages such as coverage improvement, link reliability, long network life, high-energy efficiency, balanced quality of service (QoS), and diversity gain.[6,9,10] Therefore, in this study, instead of the classical quadrature spatial modulation (QSM) based on antenna selection technique mentioned in

Naidu et al. and Kim,[11,12] we have found it appropriate to study cooperative QSM (CQSM) based on antenna selection technique. The idea behind cooperative communication technique is the communication between the source terminal (ST) and the destination terminal (DT), which is carried out with the help of an additional terminal called relay terminal (RT). The main transmission techniques used in RT are decode-and-forward (DF) and amplify-and-forward (AF) techniques. The DF technique is a structure in which the bits in the ST are modulated and sent to the RT, and then the message received in RT is decoded and transmitted to DT, while the AF technique is based on the principle that the signal transmitted from the ST is amplified at RT and then transmitted again to the DT. The problem that affects the total performance of the system in DF-based cooperative communication systems is error propagation. Similarly, the problem that arises in the AF-based cooperative communication systems is the amplification of the noise. To eliminate these undesirable effects, antenna selection techniques can be employed in ST, RT, and DT.[13,14] The error performance of two-hop cooperative communication systems with the help of transmit antenna selection at ST and RT is proposed over $\eta - \mu$ fading channels in Kumbhani and Kshetrimayum.[15]

Multiple-input multiple-output (MIMO) communication systems have played an important role to achieve high data rates and improve system capacity in today's wireless communications systems due to high data rates and capacity increase provided by today's innovative communication techniques.[16] In MIMO systems, multiplexing of data symbols to multiple antennas by the use of multiple antennas on the transmitter and receiver side leads to significant improvements in data rates and spectral efficiency.[17]

The most researched candidates of MIMO systems in recent years have been SM and QSM structures. [18] Because these techniques are both high data-rated and energy-efficient techniques, these techniques are also easy to implement,[5] although the receiver and the transmitter are equipped with multiple antennas to obtain the spatial diversity of the rich scattering environment in the SM technique. However, only a single transmit antenna is employed, which made the use of single radio frequency chain possible. In this way, the problem of interantenna synchronization is eliminated, interchannel interference (ICI) is avoided, and the complexity of the system is significantly reduced. In this technique, the transmitter's active antenna index as well as the modulated symbols are used to convey information. In Kumbhani and Kshetrimayum,[19] for the binary phase shift keying signals, the outage probability of SM-MIMO scheme with transmit antenna selection is derived over Rayleigh fading channels. Thanks to this rational scheme, the data rate increases logarithmically with the number of transmission antennas used in the source.[18,20]

The QSM system, which is one of the most ambitious candidates for MIMO systems, was introduced to improve the data rate and spectral efficiency of the SM system. In the QSM system, the number of active antennas is increased, and the data rate and spectral efficiency increase accordingly.[5] In the structure of the QSM system, the complex-modulated signal is divided into real and imaginary parts, and then the real part is sent to the receiver via one of the selected antennas and the imaginary part via another active antenna. Besides, since the orthogonal I and Q channels are used in QSM, ICI does not occur in a similar manner to SM.[21] In addition to all these, SM and QSM techniques are members of the index modulation (IM) family. In IM techniques, indices are embedded in the transmitted or received signals; usually little or no power is consumed; but additional information data are carried. Similarly, in the SM and QSM techniques, in addition to conventionally modulated symbols, antenna indices are transmitted embedded in the signal, and energy use is reduced.[18,22-24]

As the antenna selection in multiantenna cooperative systems greatly improves the system performance, it has been among the topics most frequently researched in recent studies. In cooperative systems based on antenna selection, communication is carried out via the antenna for the channel with the best conditions.[9,10] In this way, communication quality drastically increases. In recent years, both Euclidean distance-optimized antenna selection (EDAS) and capacity-optimized antenna selection (COAS) techniques have attracted considerable attention.[25] Therefore, these two techniques are considered as antenna selection schemes for CQSM technique. In the COAS technique, the best antennas are selected based on the vector set corresponding to the largest channel norms, while the EDAS technique finds the best antenna selection by maximizing the minimum Euclidean distance.[26,27] In addition to these two techniques, EDAS-based cooperative SM (EDAS-CSM) technique has been proposed by Kim and Aydin.[12,28] In Xu and Pillay,[29] suboptimal low-complexity transmit antenna selection based on amplitude and antenna correlation (LCTAS-A-C) technique is proposed. LCTAS-A-C technique provides better performance than the COAS-based antenna selection method.

In this study, new high-data-rated and energy-efficient DF-assisted CQSM techniques based on EDAS and COAS-aided antenna selection schemes, called EDAS-CQSM and COAS-CQSM, have been proposed. In the system discussed, the EDAS and COAS based antenna selection techniques reduce the error propagation that occurs in DF-based cooperative communication systems, while at the same time reducing the possibility of active antenna error and symbol error occurring in the QSM system. Therefore, the performance of the communication system is considerably improved.

The considered system is high data rated and has better error performance and spectral efficiency than traditional CSM, CQSM EDAS-CSM, COAS-CSM, LCTAS-A-C-CQSM, LCTAS-A-C-CSM systems, and the traditional DF-based cooperative systems. In the proposed system, Rayleigh fading channels is considered between the units. Furthermore, the EDAS and COAS techniques have been applied to ST and RT units with different antenna numbers, and simulation results have been made for the *M*-QAM modulations.

The paper is organized as follows: In Section 2, the system model is introduced. In Section 3, EDAS and COAS techniques for the CQSM scheme are presented. Finally, the simulation results and discussion are given in Sections 4 and 5 the paper is concluded.

Notation: The following notation is used throughout this paper. (i) Bold lower/upper case symbols represent vectors/matrices; (ii) $(\cdot)^H$, $(\cdot)^T$ and $\|\cdot\|_F$, $|\cdot|$ denote Hermitian, transpose and Frobenius norm operators, respectively, and $\Re(.)$ and $\Im(.)$ are the real and imaginary parts of a complex-valued quantity; (iii) $\binom{\cdot}{\cdot}$ denotes the binomial coefficient.

2 | SYSTEM MODEL

Figure 1 presents the system model of EDAS-CQSM and COAS-CQSM. Here, ST and DT are the source and destination terminals, respectively, and RT is the relay terminal that relays the communication between ST and DT. ST equipped multitransmit antennas, DT equipped multireceiver antennas, and on the other hand, RT equipped multireceiver and multi-transmitter antennas. All units in the considered system have a transmission mode with half-duplex, and M-QAM modulation is used for the transmission. In the considered system structure, N_S^t denotes the number of transmit antennas of ST, N_D^r represents the number of receive antennas of the DT, and N_R^t and N_R^r express the number of the transmit and receive antennas of RT, respectively. Let $N_\chi^t \le N_S^t$ and $N_\chi^t \le N_R^t$; N_χ^t indicates the number of antennas to be selected during transmission according to the EDAS/COAS techniques of the considered system. Then, the QSM scheme is carried out over the these selected N_χ^t antennas at ST and RT. Thus, $\mathcal{L} = \{\ell\}_{\ell=1}^{N_\chi^t}$ refers to the set of transmission antenna indices. Let $\mathbb{C}$ represent the complex number space, the channel matrices between ST → DT, ST → RT, and RT → DT links are expressed as $\mathbf{H}_{SD} \in \mathbb{C}^{N_D^r \times N_\chi^t}$, $\mathbf{H}_{SR} \in \mathbb{C}^{N_R^r \times N_\chi^t}$, and $\mathbf{H}_{RD} \in \mathbb{C}^{N_D^r \times N_\chi^t}$, respectively, where each element of the channel matrices between links follows independent and identically distributed (i.i.d) flat Rayleigh fading channel with zero mean and variance of $\sigma_h^2 = 1$, i.e., $\mathcal{CN}(0,1)$. It is assumed that the channel state information (CSI) is perfectly known in all units using pilot symbols. The maximum likelihood (ML) detection technique is used in RT and DT to obtain the transmitted symbol and the active antenna indices of the ST and RT.

Let, respectively, $\ell_{S,\Re}$ and $\ell_{S,\Im}$ indicate the ST's active antenna indices, while $\ell_{R,\Re}$ and $\ell_{R,\Im}$ express the RT's active antenna indices. $x_{S,\Re}$ and $x_{S,\Im}$ indicate the real and imaginary parts of the *M*-QAM-modulated symbol $x_S = x_{S,\Re} + jx_{S,\Im}$ of the ST. On the other hand, $x_{R,\Re}$ and $x_{R,\Im}$ are the real and imaginary parts of the *M*-QAM-modulated symbol $x_R = x_{R,\Re} + jx_{R,\Im}$ of the RT. $\mathbf{x}_S$ and $\mathbf{x}_R \in \mathbb{C}^{N_D^r \times N_\chi^t}$ can be expressed as $\mathbf{x}_S = x_{S,\Re}\mathbf{u}_{\ell_{S,\Re}} + jx_{S,\Im}\mathbf{u}_{\ell_{S,\Im}}$ and $\mathbf{x}_R = x_{R,\Re}\mathbf{u}_{\ell_{R,\Re}} + jx_{R,\Im}\mathbf{u}_{\ell_{R,\Im}}$. Where $\mathbf{u}_{\ell_{S,\Re}}$, $\mathbf{u}_{\ell_{S,\Im}}$, $\mathbf{u}_{\ell_{R,\Re}}$, and $\mathbf{u}_{\ell_{R,\Im}}$ are standard base vectors of N_χ^t-dimension $(1 \le \ell \le N_\chi^t)$,

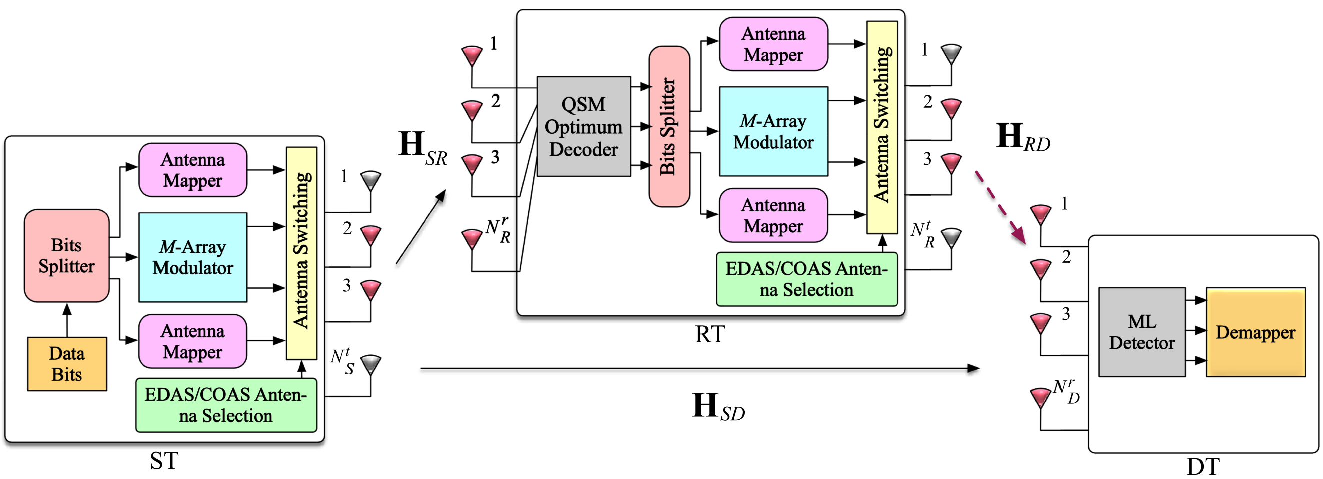

FIGURE 1 System model of the EDAS/COAS-CQSM scheme

where only one element out of N_χ^t is 1, the others are 0. Under these explanations, QSM symbols based on the EDAS/COAS techniques on ST and RT of the considered system can be expressed as follows:

$$\mathbf{x}_S = \Big[00...0 \underset{\underset{\ell^{\text{th}}_{S,\mathfrak{R}}\text{position}}{\uparrow}}{x_{S,\mathfrak{R}}} 0...00\Big]^T + \Big[00...0 \underset{\underset{\ell^{\text{th}}_{S,\mathfrak{I}}\text{position}}{\uparrow}}{jx_{S,\mathfrak{I}}} 0...00\Big]^T = [0...0x_{S,\mathfrak{R}}0...0jx_{S,\mathfrak{I}}0...0]^T, \quad (1)$$

$$\mathbf{x}_R = \Big[00...0 \underset{\underset{\ell^{\text{th}}_{R,\mathfrak{R}}\text{position}}{\uparrow}}{x_{R,\mathfrak{R}}} 0...00\Big]^T + \Big[00...0 \underset{\underset{\ell^{\text{th}}_{R,\mathfrak{I}}\text{position}}{\uparrow}}{jx_{R,\mathfrak{I}}} 0...00\Big]^T = [0...0x_{R,\mathfrak{R}}0...0jx_{R,\mathfrak{I}}0...0]^T, \quad (2)$$

where $E[\mathbf{x}_S^H\mathbf{x}_S] = E[\mathbf{x}_R^H\mathbf{x}_R] = 1$.

In the proposed system model, the communication protocol takes place in two phases. In the first phase, the ST transmits the spatially modulated QSM signal to RT and the DT by using the EDAS/COAS antenna selection technique. At the end of the first phase, the noisy signals received on the DT and RT can be expressed respectively as follows:

$$\mathbf{y}_{SD} = \mathbf{H}_{SD}\mathbf{x}_S + \mathbf{n}_{SD}, \quad (3)$$

$$\mathbf{y}_{SR} = \mathbf{H}_{SR}\mathbf{x}_S + \mathbf{n}_{SR}. \quad (4)$$

By substituting (1) and (2) in (3) and (4), $\mathbf{y}_{SD}$ and $\mathbf{y}_{SR}$ can be expressed as follows:

$$\mathbf{y}_{SD} = \left(\mathbf{h}^{SD}_{\ell_{S,\mathfrak{R}}}x_{S,\mathfrak{R}} + j\mathbf{h}^{SD}_{\ell_{S,\mathfrak{I}}}x_{S,\mathfrak{I}}\right) + \mathbf{n}_{SD}, \quad (5)$$

$$\mathbf{y}_{SR} = \left(\mathbf{h}^{SR}_{\ell_{S,\mathfrak{R}}}x_{S,\mathfrak{R}} + j\mathbf{h}^{SR}_{\ell_{S,\mathfrak{I}}}x_{S,\mathfrak{I}}\right) + \mathbf{n}_{SR}, \quad (6)$$

where the vectors $\mathbf{h}^{SD}_{\ell_{S,\mathfrak{R}}}$ and $\mathbf{h}^{SD}_{\ell_{S,\mathfrak{I}}}$ with the size of $N_D^r \times 1$ are the $\ell^{\text{th}}_{S,\mathfrak{R}}$ and $\ell^{\text{th}}_{S,\mathfrak{I}}$ columns of the $\mathbf{H}_{SD}$, while the vectors $\mathbf{h}^{SR}_{\ell_{S,\mathfrak{R}}}$ and $\mathbf{h}^{SR}_{\ell_{S,\mathfrak{I}}}$ with the size of $N_R^r \times 1$ express the $\ell^{\text{th}}_{S,\mathfrak{R}}$ and $\ell^{\text{th}}_{S,\mathfrak{I}}$ columns of the $\mathbf{H}_{SR}$ channel matrices. These channel matrices can also be expressed as $\mathbf{H}_{SD} = \left[\mathbf{h}_1^{SD}\mathbf{h}_2^{SD}...\mathbf{h}^{SD}_{N_\chi^t}\right]$ and $\mathbf{H}_{SR} = \left[\mathbf{h}_1^{SR}\mathbf{h}_2^{SR}...\mathbf{h}^{SR}_{N_\chi^t}\right]$, respectively. $\mathbf{n}_{SD}$ with the size of $N_D^r \times 1$ and $\mathbf{n}_{SR}$ with the size of $N_R^r \times 1$ are the complex additive white Gaussian noise (AWGN) vectors with distribution $\mathbb{C}\mathcal{N}(0, N_0)$ and variances of $N_0/2$ per dimension.

On the other hand, in the second phase of communication, RT obtains $(\ell_{S,\mathfrak{R}}, \ell_{S,\mathfrak{I}}, x_{S,\mathfrak{R}}, x_{S,\mathfrak{I}})$ indices and symbol with the help of ML-based QSM demodulator (which estimates ST's active index and transmitted symbol jointly) using the signals received in the first phase of communication. Assuming perfect channel knowledge at the receiver, the optimum ML decoder for QSM system can be expressed at RT as follows:

$$\begin{aligned}
\left[\hat{\ell}_{S,\mathfrak{R}}, \hat{\ell}_{S,\mathfrak{I}}, \hat{x}_{S,\mathfrak{R}}, \hat{x}_{S,\mathfrak{I}}\right] &= \arg \max_{\substack{\ell_{S,\mathfrak{R}}, \ell_{S,\mathfrak{I}} \in \mathcal{L} \\ x_{S,\mathfrak{R}}, x_{S,\mathfrak{I}} \in M}} p_Y(\mathbf{y}_{SR}|\mathbf{x}_S, \mathbf{H}_{SR}) \\
&= \arg \max_{\substack{\ell_{S,\mathfrak{R}}, \ell_{S,\mathfrak{I}} \in \mathcal{L} \\ x_{S,\mathfrak{R}}, x_{S,\mathfrak{I}} \in M}} ||\mathbf{y}_{SR} - \mathbf{H}_{SR}\mathbf{x}_S||_F^2 \\
&= \arg \max_{\substack{\ell_{S,\mathfrak{R}}, \ell_{S,\mathfrak{I}} \in \mathcal{L} \\ x_{S,\mathfrak{R}}, x_{S,\mathfrak{I}} \in M}} ||\mathbf{y}_{SR} - \left(\mathbf{h}^{SR}_{\ell_{S,\mathfrak{R}}}x_{S,\mathfrak{R}} + j\mathbf{h}^{SR}_{\ell_{S,\mathfrak{I}}}x_{S,\mathfrak{I}}\right)||_F^2,
\end{aligned} \quad (7)$$

where the expression $p_Y(\mathbf{y}_{SR}|\mathbf{x}_S, \mathbf{H}_{SR})$ is defined as probability function. $\ell_{R,\mathfrak{R}} = \hat{\ell}_{S,\mathfrak{R}}, \ell_{R,\mathfrak{I}} = \hat{\ell}_{S,\mathfrak{I}}, x_{R,\mathfrak{R}} = \hat{x}_{S,\mathfrak{R}}$, and $x_{R,\mathfrak{I}} = \hat{x}_{S,\mathfrak{I}}$ mapping are performed using the index and symbol information estimated in RT. Then, the obtained $\ell_{R,\mathfrak{R}}, \ell_{R,\mathfrak{I}}, x_{R,\mathfrak{R}}$, and $x_{R,\mathfrak{I}}$ information are transferred back to DT by the QSM modulator based on the EDAS/COAS techniques from RT. DT uses the ML-based QSM demodulator to perform data detection from the signals it receives in the first and second phases. In DT, the noisy signal from RT can be expressed as follows:

$$\begin{aligned}\mathbf{y}_{RD} &= \mathbf{H}_{RD}\mathbf{x}_R + \mathbf{n}_{RD} \\ &= \left(\mathbf{h}^{RD}_{\ell_{R,\Re}} x_{R,\Re} + j\mathbf{h}^{RD}_{\ell_{R,\Im}} x_{R,\Im}\right) + \mathbf{n}_{RD}.\end{aligned} \tag{8}$$

Here, $\mathbf{x}_R$ is expressed as in (2), and the $\mathbf{h}^{RD}_{\ell_{R,\Re}}$ and $\mathbf{h}^{RD}_{\ell_{R,\Im}}$ vectors are $N^r_D \times 1$ dimensional and refer to the $\ell^{\text{th}}_{R,\Re}$ and $\ell^{\text{th}}_{R,\Im}$ column of the $\mathbf{H}_{RD}$ channel matrix, respectively. Here, $\mathbf{H}_{RD}$ can be expressed as $\mathbf{H}_{RD} = \left[\mathbf{h}^{RD}_1 \mathbf{h}^{RD}_2 \ldots \mathbf{h}^{RD}_{N^t_\chi}\right]$. Also, the vector $\mathbf{n}_{RD}$ is $N^r_D \times 1$ dimensional, and it is an additive white Gaussian noise vector with $\mathbb{C}\mathcal{N}(0, N_0)$ distribution having two-way power spectral density of $N_0/2$.

At the end of the first and second phases of the communication in the DT, when the ML estimation is applied to the received signals, the active antenna index and the transmitted symbol of the ST are determined as follows:

$$\begin{aligned}\left[\hat{\ell}_{D,\Re}, \hat{\ell}_{D,\Im}, \hat{x}_{D,\Re}, \hat{x}_{D,\Im}\right] &= \arg \max_{\substack{\ell_{D,\Re}, \ell_{D,\Im} \in \mathcal{L} \\ x_{D,\Re}, x_{D,\Im} \in M}} \left(||\mathbf{y}_{SD} - \mathbf{H}_{SD}\mathbf{x}_D||^2_F + ||\mathbf{y}_{RD} - \mathbf{H}_{RD}\mathbf{x}_D||^2_F\right) \\ &= \arg \max_{\substack{\ell_{D,\Re}, \ell_{D,\Im} \in \mathcal{L} \\ x_{D,\Re}, x_{D,\Im} \in M}} \left(||\mathbf{y}_{SD} - \left(\mathbf{h}^{SD}_{\ell_{D,\Re}} x_{D,\Re} + j\mathbf{h}^{SD}_{\ell_{D,\Im}} x_{D,\Im}\right)||^2_F + ||\mathbf{y}_{RD} - \left(\mathbf{h}^{RD}_{\ell_{D,\Re}} x_{D,\Re} + j\mathbf{h}^{RD}_{\ell_{D,\Im}} x_{D,\Im}\right)||^2_F\right).\end{aligned} \tag{9}$$

Finally, with the bit-back matching technique using the detected $\left(\hat{\ell}_{D,\Re}, \hat{\ell}_{D,\Im}, \hat{x}_{D,\Re}, \hat{x}_{D,\Im}\right)$ values, the originally transmitted bit sequence $\hat{\mathbf{b}}$ is reconstructed at the receiver with help of the demapper as shown in the receiver of the EDAS/COAS-CQSM system.

3 | EDAS/COAS TECHNIQUE FOR COOPERATIVE QUADRATURE SPATIAL MODULATION SYSTEM

In this section, EDAS and COAS technique-aided QSM system will be introduced for the cooperative communication system. As seen in recent works, antenna selection-aided wireless communication techniques for cooperative MIMO system improve system performance greatly. In these systems, information bits are transmitted through the best antenna related to the channel with the best conditions.[28]

In the ST and RT, the information bits are firstly divided into blocks of $m_S = 2\log_2(N^t_S) + \log_2(M)$ for ST and $m_R = 2\log_2(N^t_R) + \log_2(M)$ for RT. Then, m_S and m_R bits are divided into $m_1 = 2\log_2(N^t_S)$, $m_2 = \log_2(M)$, and $m_1 = 2\log_2(N^t_R)$, $m_2 = \log_2(M)$ bits of subvectors for ST and RT, respectively. For the traditional CQSM communication system, while the m_2 bits selects the modulated symbol x_S and x_R from the M-QAM signal set at the ST and RT, on the other hand, m_1 bits select the $(\ell_{S,\Re}, \ell_{S,\Im})$ and $(\ell_{R,\Re}, \ell_{R,\Im})$ transmission antenna out of N^t_S and N^t_R, respectively. Thus, transmit antennas having good or bad channel conditions at the ST and RT can also be activated. Since the transmission antennas are chosen randomly according to the information bits and thus reduce the number of symbols transmitted from the antenna with the best channel, the performance of the system will be reduced according to the antenna selection technique.

3.1 | EDAS-based QSM technique

Unlike traditional CQSM, in the EDAS-based CQSM scheme, the QSM scheme is not performed on all the transmit antennas of the ST and RT. When considering the EDAS technique on the transmitter, only the number of N^t_χ out of N^t_S and N^t_R transmit antennas will be activated for the QSM technique. EDAS-based antenna selection technique is carried out as follows[2812]:

Step 1. First, in ST (RT), the set φS φR of enumerations of all possible κS=NStNχt combinations of selecting Nχt out of NSt transmit antennas will be constructed.

Step 2. Then, the best combination φS∗ (φR∗) of the set φS φR is determined,
Step 3. Later, the QSM technique is performed over φS∗ φR∗ set.

In order to give an example for ST, if $N_\chi^t = 4$ transmit antennas out of the $N_S^t = 6$ are selected, the φ_S set has $\kappa_S = \binom{N_S^t}{N_\chi} = 15$ elements, and these are expressed in Table 1.

In the EDAS-based antenna selection method, Euclidean distance is determined by considering all the combinations in the φ_S set. Among the κ possibilities, the specific transmit antenna set φ^*, which maximizes the minimum Euclidean distance of $d_{\min}(\mathbf{H}_\lambda)$ among all possible transmit vectors, is determined. For the ST → DT (or RT → DT) link, the φ^* set based on the EDAS technique is determined as follows[26]:

$$\varphi_S^* = \underset{\lambda \in \varphi_S}{\operatorname{argmax}} \left\{ \min_{\substack{\mathbf{x}_1, \mathbf{x}_2 \in \mathcal{A} \\ \mathbf{x}_1 \neq \mathbf{x}_2}} ||\mathbf{H}_\lambda^{SD}(\mathbf{x}_1 - \mathbf{x}_2)||_F^2 \right\}. \tag{10}$$

Here, $\mathcal{A}$ is the set of all possible transmit vectors given by $\mathcal{A} = \{\mathbf{u}_\ell x_S\}_{\ell=1}^{N_\chi^t}$, where $\mathbf{u}_\ell$ represents a vector with size of N_χ^t having 1 as the only nonzero element at the ℓ^{th} location, and size of $\mathcal{A}$ is defined as $|\mathcal{A}| = N_\chi^t M$. $\lambda = 1, 2, \ldots, \kappa$ and $\mathbf{H}_\lambda^{SD}$ with the size of $N_D^r \times N_\chi^t$ is defined as follows:

$$\mathbf{H}_\lambda^{SD} = \begin{bmatrix} h_{1,1}^{SD} & h_{1,2}^{SD} & \cdots & h_{1,N_\chi^t}^{SD} \\ h_{2,1}^{SD} & h_{2,2}^{SD} & \cdots & h_{2,N_\chi^t}^{SD} \\ \vdots & \vdots & \ddots & \vdots \\ h_{N_D^t,1}^{SD} & h_{N_D^t,2}^{SD} & \cdots & h_{N_D^t,N_\chi^t}^{SD} \end{bmatrix}_{N_D^r \times N_\chi^t}. \tag{11}$$

Here, the euclidean distance of the entire φ_S set is calculated with the help of λ, and the minimum distance of $d_{\min}(\mathbf{H}_\lambda)$ between the symbols is determined. Then, the state with the maximum distance of the minimum set is selected for the transmission. Hence, the system performance can be increased by maximizing $d_{\min}(\mathbf{H}_\lambda)$.

If $d_{\min}(\mathbf{H}_\lambda)$ is defined as $\min_{\substack{\mathbf{x}_1, \mathbf{x}_2 \in \mathcal{A} \\ \mathbf{x}_1 \neq \mathbf{x}_2}} ||\mathbf{H}_\lambda^{SD}(\mathbf{x}_1 - \mathbf{x}_2)||_F^2$, (10) can be rewritten with respect to Euclidean distance as follow[26]:

$$\varphi_S^* = \underset{\lambda \in \varphi_S}{\operatorname{argmax}} \{d_{\min}(\mathbf{H}_\lambda)\}. \tag{12}$$

As a result, since the EDAS scheme maximizes the $d_{\min}(\mathbf{H}_\lambda)$, it improves the system performance compared to traditional cooperative M-QAM, CSM, and CQSM techniques. Consequently, the performance of the EDAS-CQSM technique is greatly improved when the EDAS scheme applied to the CQSM technique in the ST and RT.

TABLE 1 φ_S set for $N_\chi^t = 4$, $N_S^t = 6$

{1,2,3,4}	{2,3,4,5}	{3,4,5,6}
{1,2,3,5}	{2,3,4,6}	
{1,2,3,6}	{2,3,5,6}	
{1,2,4,5}	{2,4,5,6}	
{1,2,4,6}		
{1,2,5,6}		
{1,3,4,5}		
{1,3,4,6}		
{1,3,5,6}		
{1,4,5,6}		

3.2 | COAS-based QSM technique

In the COAS-based CQSM technique as in EDAS, the QSM scheme is not performed on all the transmit antennas of the ST and RT. When considering the EDAS technique on the transmitter, only the number of N_{χ}^{t} out of N_{S}^{t} and N_{R}^{t} transmit antennas will be activated for the QSM technique. The COAS technique is an antenna selection algorithm that selects a subantenna group with a maximum channel amplitude through the total transmission antenna or receiver antennas. Many studies prove that the COAS technique improves both the error performance of MIMO systems, and its computational complexity is very low.

If the CSI and SNR are well known at the ST or RT side, the capacity of the QSM scheme with N_{χ}^{t} transmission antennas can be expressed as follows[26]:

$$\Upsilon \leqslant \mathcal{C}_{\mathrm{QSM}} \leqslant \Upsilon + \log_2(\mathrm{N}_{\chi}^{\mathrm{t}}). \tag{13}$$

Here, $\Upsilon = \frac{1}{N_{\chi}^{t}} \sum_{\ell=1}^{N_{\chi}^{t}} \log_2\left(1 + \rho ||\mathbf{h}_{\ell}||^2\right)$, where ρ expresses the SNR value. It can straightforwardly be seen from (13) that Υ must be maximized in order to maximize the capacity of QSM. For this reason, Υ must be maximized by choosing the N_{χ}^{t} antennas corresponding to the biggest channel norms from the N_{S}^{t} or (N_{R}^{t}) transmission antennas. In line with these explanations, the set of antenna indices corresponding to the N_{χ}^{t} biggest channel norms out of N_{S}^{t} can be calculated on the receiver side; then, the transmitter is notified back. From this point forth, the COAS-based antenna set out of N_{S}^{t} can be expressed as follows:

$$\Psi_{\mathrm{COAS}} = \left\{ \varrho_1, \varrho_2, \ldots, \varrho_{N_{\chi}^{t}} \right\}. \tag{14}$$

Ψ_{COAS} set can be generated three steps as follows:

Step 1. The Frobenius norm of each column vector in the H channel matrix should be calculated as follow:

$$||\mathbf{h}_{\varrho_j}||_F^2, \tag{15}$$

here, $j \in \left\{1, \ldots, N_{S}^{t}\right\}$.

Step 2. The column vectors of H should be arranged in descending order.

$$||\mathbf{h}_{\varrho_1}||_F^2 > ||\mathbf{h}_{\varrho_2}||_F^2 > \ldots > ||\mathbf{h}_{\varrho_{N_{\chi}^{t}}}||_F^2 > ||\mathbf{h}_{\varrho_{N_{\chi}^{t}+1}}||_F^2 > \ldots > ||\mathbf{h}_{\varrho_{N_{S}^{t}}}||_F^2. \tag{16}$$

Step 3. Choose the highest Nχt channel gain vectors to form the NDr×Nχt channel gain matrix of HCOAS; here, HCOAS is the submatrix of H. After the ΨCOAS submatrix has been successfully obtained, the QSM technique is performed with this set.

New researches have shown that the COAS antenna selection technique improves system performance compared to traditional cooperative *M*-QAM, CSM, and CQSM techniques. As a result, the COAS scheme applied to the CQSM technique in ST and RT will significantly improve the performance of the COAS-CQSM technique.

4 | COMPUTATIONAL COMPLEXITY FOR THE EDAS/COAS-CQSM SYSTEM

In this section, we will present the computational complexity analysis for both EDAS-CQSM and COAS-CQSM systems in terms of the number of floating point operations (flops), similar to the calculation in Trefethen and Bau and Ntontin et al.[30,31] One flop is defined as each multiplication, division, subtraction, or addition.[31]

4.1 | Computational complexity for EDAS-CQSM

We can express the total complexity of the EDAS-CQSM system ($\mathcal{O}_{\text{EDAS-CQSM}}$) as follows:

$$\mathcal{O}_{\text{EDAS-CQSM}} = \mathcal{O}_{\text{RT}}^{\text{EDAS}} + \mathcal{O}_{\text{DT}}^{\text{EDAS}}, \tag{17}$$

where $\mathcal{O}_{\text{RT}}^{\text{EDAS}}$ refers to the complexity of RT; on the other hand, $\mathcal{O}_{\text{DT}}^{\text{EDAS}}$ refers to the complexity of DT when EDAS is executed. In order to write $\mathcal{O}_{\text{RT}}^{\text{EDAS}}$, (10) can be rewritten when (7) is considered for ST-RT link as follows:

$$\varphi_S^* = \underset{\lambda \in \varphi_S}{\text{argmax}} \left\{ \min_{\substack{x_1, x_2 \in \mathcal{A} \\ x_1 \neq x_2}} ||\mathbf{h}_{1,\lambda_{\Re}}^{SR} x_{1,\Re} + j\mathbf{h}_{1,\lambda_{1,\Im}}^{SR} x_{1,\Im} - \mathbf{h}_{2,\lambda_{\Re}}^{SR} x_{2,\Re} - j\mathbf{h}_{2,\lambda_{2,\Im}}^{SR} x_{2,\Im}||_F^2 \right\}. \tag{18}$$

Therefore, to calculate the complexity analysis performed at RT, the expression $||\mathbf{h}_{1,\lambda_{\Re}}^{SR} x_{1,\Re} + j\mathbf{h}_{1,\lambda_{1,\Im}}^{SR} x_{1,\Im} - \mathbf{h}_{2,\lambda_{\Re}}^{SR} x_{2,\Re} - j\mathbf{h}_{2,\lambda_{2,\Im}}^{SR} x_{2,\Im}||_F^2$ in (18) must be calculated individually for all possible symbol and transmission antenna combinations. Using the similar approach in Naidu et al and Ntontin et al,[11,31] the computational complexity of (18) is obtained as $4M(4M-1)(9N_R^r-1)$ for each antenna pair within each antenna subset. Since EDAS technique is performed for each antenna pair within each antenna subset, EDAS must be executed $\binom{N_\chi^t}{2}\kappa_S$ times in total. Considering the complexity analysis for all antenna pairs, the complexity expression in RT can written as follows:

$$\mathcal{O}_{\text{RT}}^{\text{EDAS}} = 4M(4M-1)\left(9N_R^r-1\right)\binom{N_\chi^t}{2}\binom{N_S^t}{N}_\chi^t. \tag{19}$$

Similar to getting $\mathcal{O}_{\text{RT}}^{\text{EDAS}}$ in RT, in order to write the computational complexity of DT, i.e., $\mathcal{O}_{\text{DT}}^{\text{EDAS}}$, (10) can be rewritten when (9) is considered for ST-DT and RT-DT links as follows:

$$\begin{aligned} \varphi_S^* = \; & \underset{\lambda \in \varphi_S}{\text{argmax}} \left\{ \min_{x_1, x_2 \in \mathcal{A} x_1 \neq x_2} \left(\left\| \mathbf{h}_{1,\lambda_{\Re}}^{SD} x_{1,\Re} + j\mathbf{h}_{1,\lambda_{1,\Im}}^{SD} x_{1,\Im} - \mathbf{h}_{2,\lambda_{\Re}}^{SD} x_{2,\Re} - j\mathbf{h}_{2,\lambda_{2,\Im}}^{SD} x_{2,\Im} \right\|_F^2 \right.\right. \\ & \left.\left. + \left\| \mathbf{h}_{1,\lambda_{\Re}}^{RD} x_{1,\Re} + j\mathbf{h}_{1,\lambda_{1,\Im}}^{RD} x_{1,\Im} - \mathbf{h}_{2,\lambda_{\Re}}^{RD} x_{2,\Re} - j\mathbf{h}_{2,\lambda_{2,\Im}}^{RD} x_{2,\Im} \right\|_F^2 \right) \right\}. \end{aligned} \tag{20}$$

Hence, to calculate the complexity analysis performed at DT, the expression $||\mathbf{h}_{1,\lambda_{\Re}}^{SD} x_{1,\Re} + j\mathbf{h}_{1,\lambda_{1,\Im}}^{SD} x_{1,\Im} - \mathbf{h}_{2,\lambda_{\Re}}^{SD} x_{2,\Re} - j\mathbf{h}_{2,\lambda_{2,\Im}}^{SD} x_{2,\Im}||_F^2 + ||\mathbf{h}_{1,\lambda_{\Re}}^{RD} x_{1,\Re} + j\mathbf{h}_{1,\lambda_{1,\Im}}^{RD} x_{1,\Im} - \mathbf{h}_{2,\lambda_{\Re}}^{RD} x_{2,\Re} - j\mathbf{h}_{2,\lambda_{2,\Im}}^{RD} x_{2,\Im}||_F^2$ in (20) must be calculated individually for all possible symbol and transmission antenna combinations. Comparing (18) and (20) in terms of computational complexity, the computational complexity in (20) is only as high as the computational complexity of $||\mathbf{h}_{1,\lambda_{\Re}}^{RD} x_{1,\Re} + j\mathbf{h}_{1,\lambda_{1,\Im}}^{RD} x_{1,\Im} - \mathbf{h}_{2,\lambda_{\Re}}^{RD} x_{2,\Re} - j\mathbf{h}_{2,\lambda_{2,\Im}}^{RD} x_{2,\Im}||_F^2$. Hence $\mathcal{O}_{\text{DT}}^{\text{EDAS}}$ can be written as follows:

$$\begin{aligned} \mathcal{O}_{\text{DT}}^{\text{EDAS}} &= 4M(4M-1)\left(9N_D^r-1\right)\binom{N_\chi^t}{2}\binom{N_S^t}{N}_\chi^t + 4M(4M-1)\left(9N_D^r-1\right)\binom{N_\chi^t}{2}\binom{N_R^t}{N}_\chi^t \\ &= 4M(4M-1)\left(9N_D^r-1\right)\binom{N_\chi^t}{2}\left[\binom{N_S^t}{N}_\chi^t + \binom{N_R^t}{N}_\chi^t\right]. \end{aligned} \tag{21}$$

As a result, the overall computational complexity of the EDAS-CQSM system can be expressed final form as follow:

$$\mathcal{O}_{\text{EDAS-CQSM}} = 4M(4M-1)\binom{N_\chi^t}{2}\left[\left(9N_R^r-1\right)\binom{N_S^t}{N}_\chi^t + \left(9N_D^r-1\right)\left(\binom{N_S^t}{N}_\chi^t + \binom{N_R^t}{N_\chi^t}\right)\right]. \tag{22}$$

Note that the computational complexity of the noncooperative case (EDAS-QSM system) is clearly equal to the computational complexity given in (19), i.e., $\mathcal{O}_{\text{EDAS-QSM}} = 4M(4M-1)\left(9N_R^r-1\right)\binom{N_\chi^t}{2}\binom{N_S^t}{N}_\chi^t$. Thus, cooperation only adds to the complexity of Equation (21). Also, when $N_S^t = N_R^t$ and $N_R^r = N_D^r$, the overall computational complexity of the EDAS-CQSM system is $\mathcal{O}_{\text{EDAS-CQSM}} = 3\mathcal{O}_{\text{EDAS-QSM}}$. Hence, it seems clear that the computational complexity is tripled compared to the noncooperative situation.

4.2 | Computational complexity for COAS-CQSM

We can express the total complexity of the COAS-CQSM system ($\mathcal{O}_{\text{COAS-CQSM}}$) as follows:

$$\mathcal{O}_{\text{COAS-CQSM}} = \mathcal{O}_{\text{RT}}^{\text{COAS}} + \mathcal{O}_{\text{DT}}^{\text{COAS}}, \tag{23}$$

where $\mathcal{O}_{\text{RT}}^{\text{COAS}}$ refers to the complexity of RT; on the other hand, $\mathcal{O}_{\text{DT}}^{\text{COAS}}$ refers to the complexity of DT when COAS is executed. Considering the approach used in Naidu et al,[11] the computational complexity of the COAS-CQSM technique is equal to the sum of the number of complexities calculated for Step 1 in RT and DT. For each channel gain vector in (15), the number of flops is equal to $\left(2N_R^r-1\right)$ for RT. Hence, for N_S^t vectors, the computational complexity of RT can be expressed as follows:

$$\mathcal{O}_{\text{RT}}^{\text{COAS}} = N_S^t\left(2N_R^r-1\right). \tag{24}$$

Similar to getting $\mathcal{O}_{\text{RT}}^{\text{COAS}}$ in RT, the computational complexity of DT, i.e., $\mathcal{O}_{\text{DT}}^{\text{COAS}}$ for ST-DT and RT-DT links can be calculated as follows:

$$\mathcal{O}_{\text{DT}}^{\text{COAS}} = \left(N_S^t + N_R^t\right)\left(2N_D^r-1\right). \tag{25}$$

As a result, the overall computational complexity of the COAS-CQSM system can be expressed final form as follow:

$$\mathcal{O}_{\text{COAS-QSM}} = N_S^t\left(2N_R^r-1\right) + \left(N_S^t + N_R^t\right)\left(2N_D^r-1\right). \tag{26}$$

Note that the computational complexity of COAS-QSM system (i.e., without cooperation) is clearly equal to the computational complexity given in (24), i.e., $\mathcal{O}_{\text{COAS-QSM}} = N_S^t\left(2N_R^r-1\right)$. Thus, cooperation only adds to the complexity of (25). Also, when $N_S^t = N_R^t$ and $N_R^r = N_D^r$, the overall computational complexity of the EDAS-CQSM system is $\mathcal{O}_{\text{COAS-CQSM}} = 3\mathcal{O}_{\text{COAS-QSM}}$. Hence, it seems clear that the computational complexity is tripled compared to the noncooperative situation.

5 | SIMULATION RESULTS AND DISCUSSION

In this section, simulation results are presented for the EDAS-CQSM and COAS-CQSM techniques over Rayleigh fading channels. Average BER performances are obtained by the Monte Carlo simulation method. SNR (dB) = $10\log_{10}(E_s/N_0)$ where E_s is the average symbol energy. All performance comparisons are made for a BER value of 10^{-5}. EDAS-CSM, COAS-CSM, CTAS-A-C-CQSM, LCTAS-A-C-CSM, CQSM, and CSM techniques are used as a reference in the performance comparison for the proposed EDAS-CQSM and COAS-CQSM system (Figures 4–6). In addition, the EDAS-QSM and COAS-QSM methods are compared with the traditional QSM, SM,and M-QAM technique using ST → RT link at RT (Figures 2 and 3).

Figure 2 shows the BER performance curves of EDAS-QSM, COAS-QSM, EDAS-SM, COAS-SM, QSM, SM, and QAM systems for spectral efficiency of $m = 4$ bits/s/Hz when $N_R^r = 4$ for all techniques in RT (without cooperative).

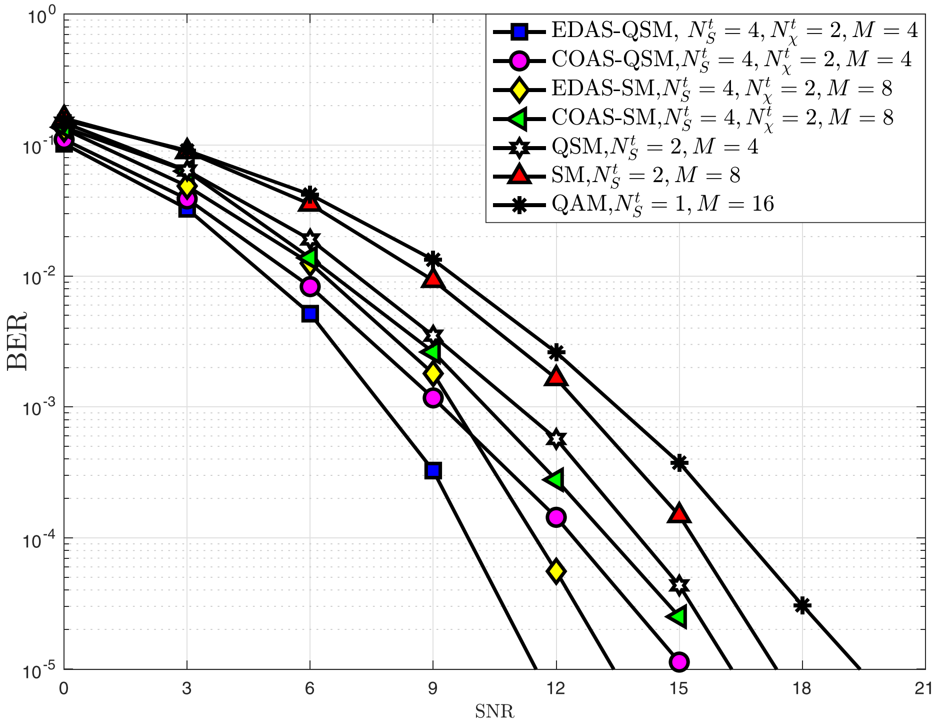

FIGURE 2 Performance comparisons of EDAS-QSM, COAS-QSM, EDAS-SM, COAS-SM, QSM, SM, and QAM systems for $m = 4$ bits/s/Hz when $N_R^r = 4$

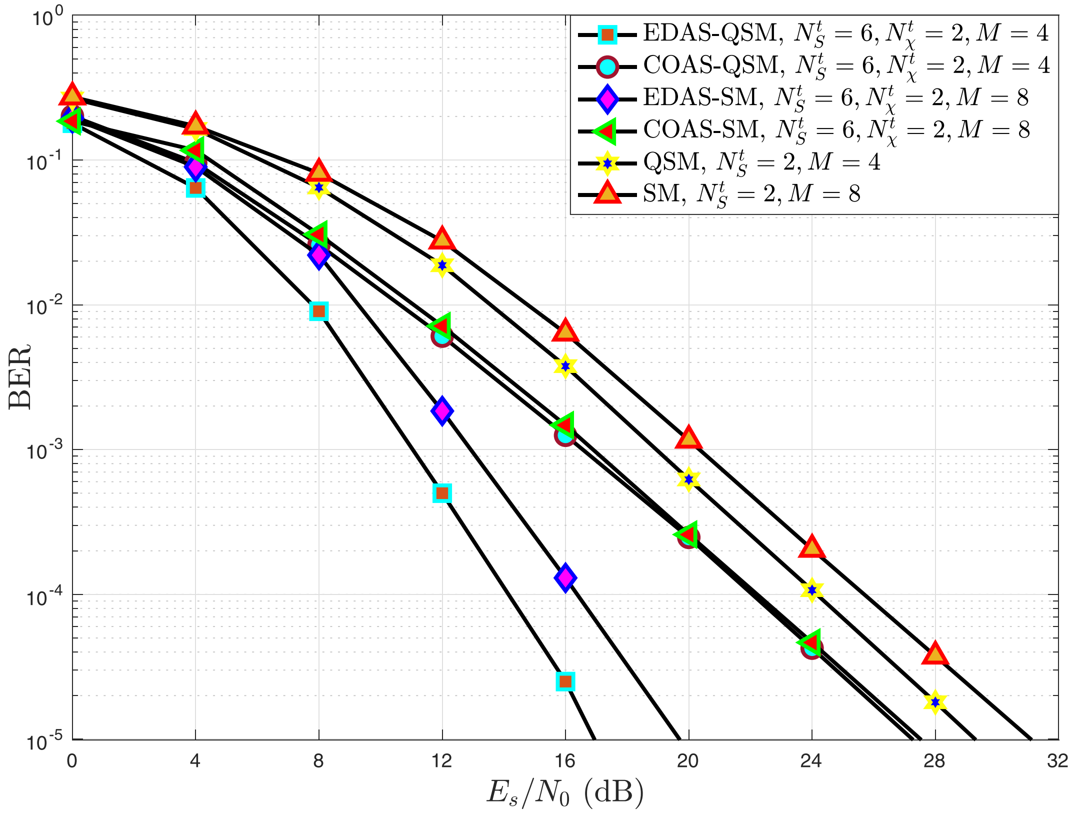

FIGURE 3 Performance comparisons of EDAS-QSM, COAS-QSM, EDAS-SM, COAS-SM, QSM, SM, and QAM systems for $m = 4$ bits/s/Hz when $N_R^r = 2$

Antenna configurations of the EDAS/COAS-QSM system are chosen as $N_S^t = 4$, $N_\chi^t = 2$, and the modulation degree is $M = 4$; Antenna configurations of the EDAS/COAS-SM system are selected as $N_S^t = 4$, $N_\chi^t = 2$, and the modulation degree is $M = 8$; Antenna configurations of the QSM system are set as $N_S^t = 2$ and $M = 4$; antenna configurations of the SM system are $N_S^t = 2$ and $M = 8$; antenna configurations of the QAM system are defined as $N_S^t = 1$ and the modulation degree is chosen as $M = 16$. These transmission schemes are intended to equalize the number of bits sent at the same time. Besides, EDAS-QSM and COAS-QSM systems transmit 2 bits together with active antennas, while transmitting 2 bits with modulated symbols; EDAS-SM and COAS-SM systems transmit 1 bit together with active antennas, while transmitting 3 bits with modulated symbols; QSM system transmits 2 bits together with active antennas, while transmitting 2 bits with modulated symbols; SM system transmits 1 bit together with active antennas, while transmitting 3 bits with modulated symbols; finally, the QAM system only transmits with the modulated symbols and transmits 4 bits.

In Figure 3, similar to the scheme in Figure 2, performance comparisons at RT (without cooperative) are carried out for data rate $m = 4$ bits when $N_R^r = 2$. This time, however, EDAS/COAS based systems choose the best $N_\chi^t = 2$ from $N_S^t = 6$ transmit antennas; QSM and SM systems also communicate with $N_S^t = 2$ transmit antennas. The number of bits sent by all the active antennas and modulated symbols is same as in Figure 2 and given in Table 2.

For the Figure 2 and 3, the SNR gains of the EDAS-QSM scheme with respect to the COAS-QSM, EDAS-SM, COAS-SM, QSM, SM, and QAM systems are tabulated in Table 3. Considering Table 3, it is seen that the SNR gain increases more when the number of receiver antennas in the RT and DT decreases.

Cooperative BER performance comparisons, i.e., EDAS-CQSM, COAS-CQSM, EDAS-CSM, COAS-CSM, LCTAS-A-C-CQSM, LCTAS-A-C-CSM, CQSM, and CSM systems, are depicted in Figure 4. EDAS/COAS-based cooperative systems with QSM/SM have $N_S^t = N_R^t = 4$ and $N_\chi^t = 2$ antenna configurations; meanwhile, CQSM and CSM systems have $N_S^t = N_R^t = 2$ antenna configurations. Also, the data rate of all systems is $m = 4$ bits and has $N_R^r = N_D^r = 4$ at the RT and DT. N_L, detailed in Xu and Pillay,[29] defined as $N_L = (N_\chi^t/2) + 1$. As can be seen from this figure, LCTAS-A-C-CQSM and LCTAS-A-C-CSM techniques provide better performance than the COAS-CQSM and COAS-CSM scheme, respectively. Besides, in Figure 4, the number of bits sent with active antennas and modulated symbols is given in Table 4.

In Figure 5, BER performance curves of EDAS-CQSM, COAS-CQSM, EDAS-CSM, COAS-CSM, CSM, and CSM systems are presented. Antenna configurations for EDAS/COAS-based cooperative systems are selected as $N_S^t = N_R^t = 6$ and $N_\chi^t = 4$; on the other hand, antenna configurations for the traditional CQSM and CSM schemes are determined as $N_R^r = N_D^r = 4$ at the RT and DT. In addition, the spectral efficiency is $m = 6$ bits/s/Hz. Also, in Figure 5, the number of bits sent with active antennas and modulated symbols is given in Table 5 for EDAS-CQSM, COAS-CQSM, COAS-CSM, CSM, and CSM systems.

TABLE 3 SNR gains (dB) of EDAS-QSM over the other systems

	COAS-QSM	EDAS-SM	COAS-SM	QSM	SM	QAM
Figure 2	3.69	1.89	4.25	4.77	5.88	7.9
Figure 3	10.28	2.75	10.6	12.35	14.15	—

TABLE 2 Transmitted bits in antenna index and modulated symbol for Figures 2 and 3

	m_1	m_2
EDAS-CQSM	2 bits	2 bits
COAS-CQSM	2 bits	2 bits
EDAS-CSM	1 bit	3 bits
COAS-CSM	1 bit	3 bits
CQSM	2 bits	2 bits
CSM	1 bit	3 bits

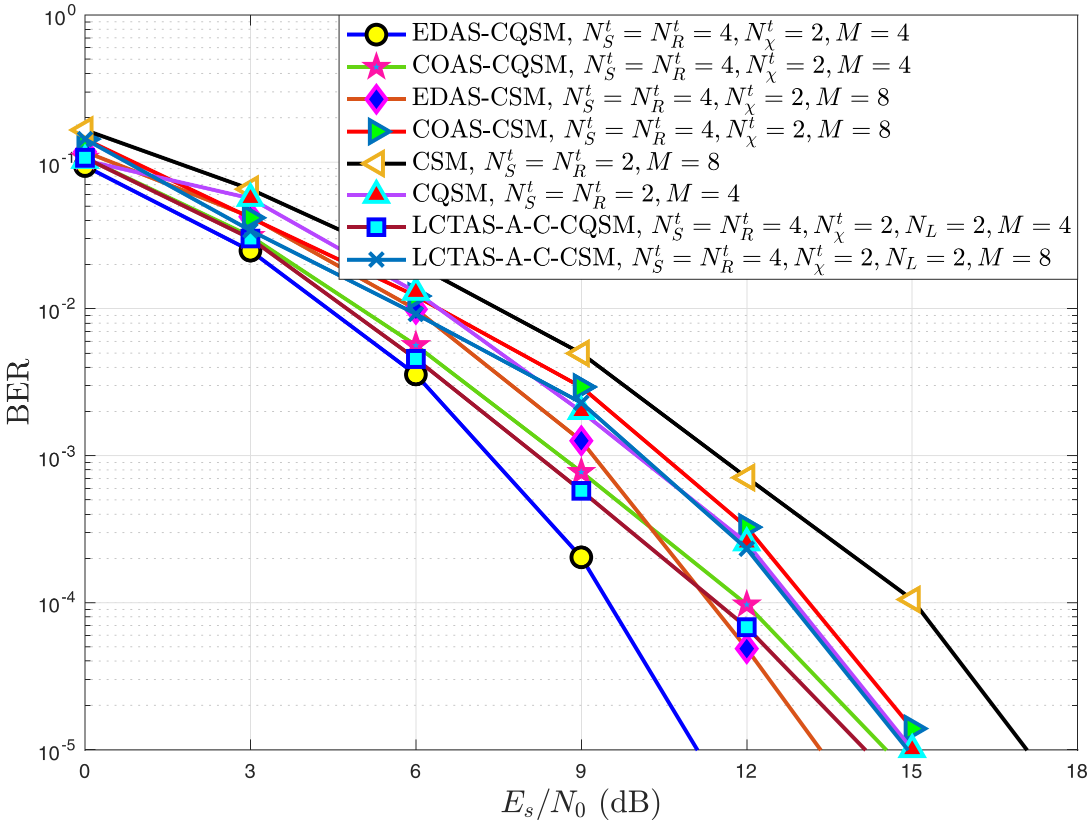

FIGURE 4 Performance comparisons of EDAS-CQSM, COAS-CQSM, EDAS-CSM, COAS-CSM, LCTAS-A-C-CQSM, LCTAS-A-C-CSM, CQSM, and SM systems for $m = 4$ bits/s/Hz when $N_R^r = N_D^r = 4$

TABLE 4 Transmitted bits in antenna index and modulated symbol for Figure 4

	m_1	m_2
EDAS-CQSM	2 bits	2 bits
COAS-CQSM	2 bits	2 bits
EDAS-CSM	1 bit	3 bits
COAS-CSM	1 bits	3 bits
LCTAS-A-C-CQSM	2 bits	2 bits
LCTAS-A-C-CSM	1 bit	3 bits
CQSM	2 bits	2 bits
CSM	1 bit	3 bits

For the Figures 4 and 5, the SNR gains of the EDAS-QSM scheme with respect to the COAS-QSM, EDAS-SM, COAS-SM, QSM, and SM systems are tabulated in Table 6.

In Figure 6, the BER performance curves of CQSM and CSM techniques are given according to the $\mathbf{H}_{SR}$ (ST → RT links) and $\mathbf{H}_{SD}$ (ST → DT links) by selecting the antenna with the EDAS/COAS techniques. While the performance curves with a dotted line are obtained using the $\mathbf{H}_{SR}$, the performance curves with a continuous line are plotted using the $\mathbf{H}_{SD}$. As can be seen from this figure, EDAS/COAS-based CQSM and CSM techniques provide better performance when performed using $\mathbf{H}_{SR}$, on the contrary, when using $\mathbf{H}_{SD}$ the performance of the cooperative system decreases. From this point forth, it can be straightforwardly seen that the performance of cooperative communication based on the EDAS/COAS technique

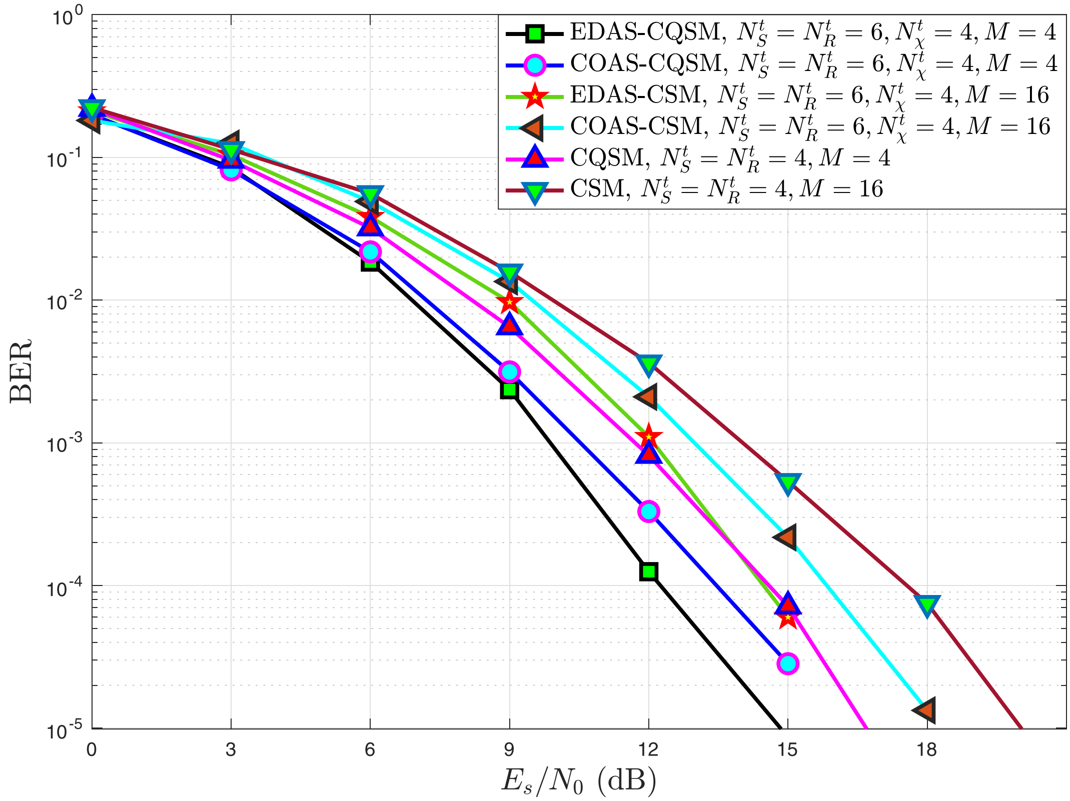

FIGURE 5 Performance comparisons of EDAS-CQSM, COAS-CQSM, EDAS-CSM, COAS-CSM, CQSM, and SM systems for $m = 6$ bits/s/Hz when $N_R^r = N_D^r = 4$

TABLE 5 Transmitted bits in antenna index and modulated symbol for Figure 5

	m_1	m_2
EDAS-CQSM	4 bits	2 bits
COAS-CQSM	4 bits	2 bits
EDAS-CSM	2 bits	4 bits
COAS-CSM	2 bits	4 bits
CQSM	4 bits	2 bits
CSM	2 bits	4 bits

TABLE 6 SNR gains (dB) of EDAS-QSM over the other systems

	COAS-CQSM	EDAS-CSM	COAS-CSM	CQSM	CSM
Figure 4	3.42	2.23	4.1	3.9	6
Figure 5	1.46	1.18	3.38	1.88	5.18

considering ST → RT channel coefficients performs much better compared to the performance of cooperative communication based on EDAS/COAS technique considering ST → DT channel coefficients. Here, spectral efficiency is selected as $m = 4$ bits/s/Hz and $N_R^r = N_D^r = 2$. Antenna configurations of the EDAS/COAS-QSM systems are set as $N_S^t = 6$, $N_\chi^t = 2$, and $M = 4$; on the other hand, antenna configurations of the EDAS/COAS-SM systems are set as $N_S^t = 6$, $N_\chi^t = 2$, and $M = 8$.

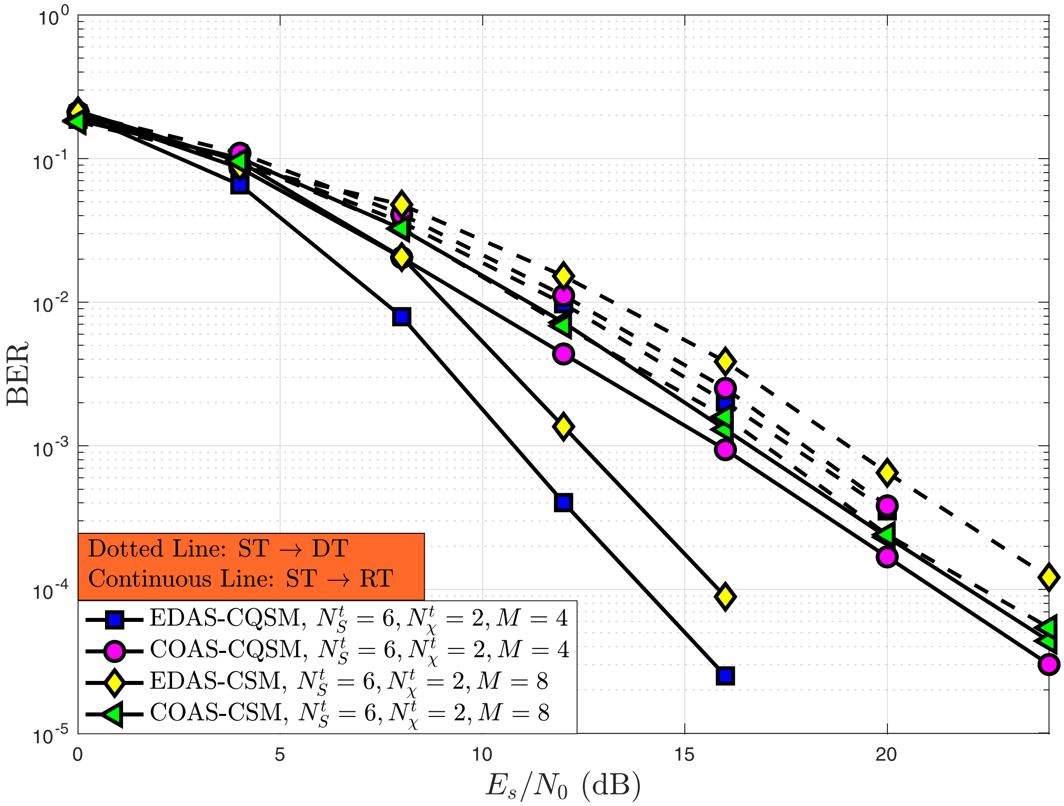

FIGURE 6 Performance comparisons of EDAS-CQSM, COAS-CQSM, EDAS-CSM, and COAS-CSM systems for $m = 4$ bits/s/Hz when $N_R^r = N_D^r = 2$

6 | CONCLUSION

In this study, new high-data-rated and energy-efficient DF-based cooperative QSM (CQSM) techniques with the EDAS and COAS-based antenna selection schemes, called EDAS-CQSM and COAS-CQSM, have been proposed. In the system discussed, the EDAS- and COAS-based antenna selection techniques reduce the error propagation that occurs in DF-based cooperative communication systems, while at the same time reducing the possibility of active antenna error and symbol error occurring in the QSM system. Therefore, the performance of the communication system is considerably improved. The considered system is high data rated, which has better error performance and spectral efficiency than traditional CSM, CQSM EDAS-CSM, COAS-CSM, LCTAS-A-C-CQSM, and LCTAS-A-C-CSM systems, and the traditional DF-based cooperative systems. In the proposed system, Rayleigh fading channels is considered between the units. Furthermore, the EDAS and COAS techniques have been applied to ST and RT units with different antenna numbers, and simulation results have been made for the *M*-QAM modulations.

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