J Inno Sci Eng, 2021, 5(2):76-90
https://doi.org/10.38088/jise.829553

Research Article

Transmit Antenna Selection for Spatial Modulation Based on Hexagonal Quadrature Amplitude Modulation

Fatih Cogen[1,2], Erdogan Aydın[2*]

[1] *Turkish-German University, Istanbul, Turkey*

[2*] *Istanbul Medeniyet University, Istanbul, Turkey*

Abstract

There is a tremendous demand from various industries for next-generation 5G networks, which has dramatically increased the need for high data rates and energy efficiency. It is an indisputable fact that next-generation networks should be not only energy-efficient but also resource-efficient. Given the fact that 10% of the current energy consumption in the world is caused by Information and Communication Technology, it is evident that energy-efficiency has become the most crucial performance criteria in the next-generation communication techniques. Based on these needs, we previously suggested the hexagonal quadrature amplitude modulation (HQAM) aided spatial modulation (SM) technique (HQAM-SM) to the literature. In this study, we found it appropriate to do this research to further increase the performance of the HQAM-SM scheme through the antenna selection technique and to investigate the effects of antenna selection technique on HQAM-SM. Moving from this point, in this article, rational capacity-optimized antenna selection (COAS), SM, and energy-efficient HQAM techniques are combined, and a new system called COAS-HSM is presented. Hexagonal constellations are to optimize the constellation points to form a hexagonal constellation to minimize the Hamming distance between the constellation points. This layout not only offers better energy efficiency than traditional QAM constellations but also performs almost the same BER performance as QAM at high signal-to-noise ratio (SNR) values. On the other hand, antenna selection algorithms are one of the transmission schemes that have been frequently encountered in the literature in recent years, and that considerably increases the performance of various multiple-input multiple-output (MIMO) communication structures. In particular, the COAS transmission scheme is an intelligent method of selecting transmission antennas over the highest channel amplitudes. Performance analysis of the proposed COAS-HSM technique is carried out in Rayleigh fading channels.

Keywords: Spatial modulation (SM), hexagonal quadrature amplitude modulation (HQAM), capacity-optimized antenna selection (COAS), multiple-input multiple-output (MIMO) systems.

Cite this paper as:
Cogen, F., Aydın, E. (2021). *Transmit Antenna Selection for Spatial Modulation Based on Hexagonal Quadrature Amplitude Modulation*. Journal of Innovative Science and Engineering. 5(2): 76-90

*Corresponding author: Erdoğan Aydın
E-mail: erdogan.aydin@medeniyet.edu.tr

Received Date: 21/11/2020
Accepted Date: 10/01/2021

1. Introduction

In recent years, besides internet applications such as high data-rated internet usage, online gaming, high definition video broadcasting and watching; many internet of things (IoT) fields such as personal multimedia devices, smart home appliances, wearable devices, audiovisual devices, smart measurement, fleet management is developing day by day. The greatest need for these areas is undoubtedly high data-rates and energy-efficiency, which has become one of the most critical needs of our time. It is a fact that by 2025, the number of devices connected to the internet will reach nearly 80 million. From this point of view, it can be easily understood that the next-generation communication techniques should be energy-efficient as well as high data-rated [1–5].

Novel and high-speed communication structures use big constellations such as *M*-ary amplitude modulation (AM) or *M*-ary phase modulation (PM) constellation systems. Although they are easy to apply and theoretically explained, they cannot conjoin these symbols as energy-efficiently as possible. Due to its straightforwardness and convenience of use, especially quadrature amplitude modulation (QAM) constellations are included in many recent scientific publications. However, it is known that the constellations of QAM are not optimal for a given average transmitted symbol power; QAM constellations are called sub-optimal constellations. It is an indisputable fact that the next-generation communication techniques must be energy-efficient and therefore require the development of next-generation energy-efficient constellations. Moving from this point, this article deals with hexagonal-QAM (HQAM) constellations that minimize the transmitted power for a given average transmitted symbol power. Studies show that HQAM both performs similarly to traditional QAM constellations and is superior to QAM (sub-optimal, not optimal) in terms of energy efficiency [6–9].

Multiple-input multiple-output (MIMO) systems are judicious techniques developed to deal with multi-way fading and are shown as a competitive candidate for new generation communication techniques in many studies. In the structure of MIMO systems, both the transmitting and receiving terminals are equipped with multiple antennas. MIMO is an infrastructure developed for qualified communication, which can transmit data from various antennas as various signals at the same time and use a single signal channel for this. The data to be sent is divided into multiple data streams at the transmission point and recombined on the receiver side with the help of another MIMO module set with the same number of antennas. The receiver is designed to take into account time differences between the reception of each signal, added noise, interference, and loss signals [10–13].

One of the essential methods that belong to the MIMO systems family and constitute the core of this study is undoubtedly the spatial modulation (SM) technique. In the SM system, only one radio frequency (RF) chain is used during a transmission period between the transmitter and the receiver. While part of the communication in SM is provided with traditional modulating symbols, another part is provided through the antenna activated by SM. With this rational technique, inter-channel interference (ICI) is wholly eliminated, signal processing and circuit complexity are reduced, and energy efficiency is increased. Besides, SM does all these benefits with simple equipment, requiring a minimal additional cost [14–16].

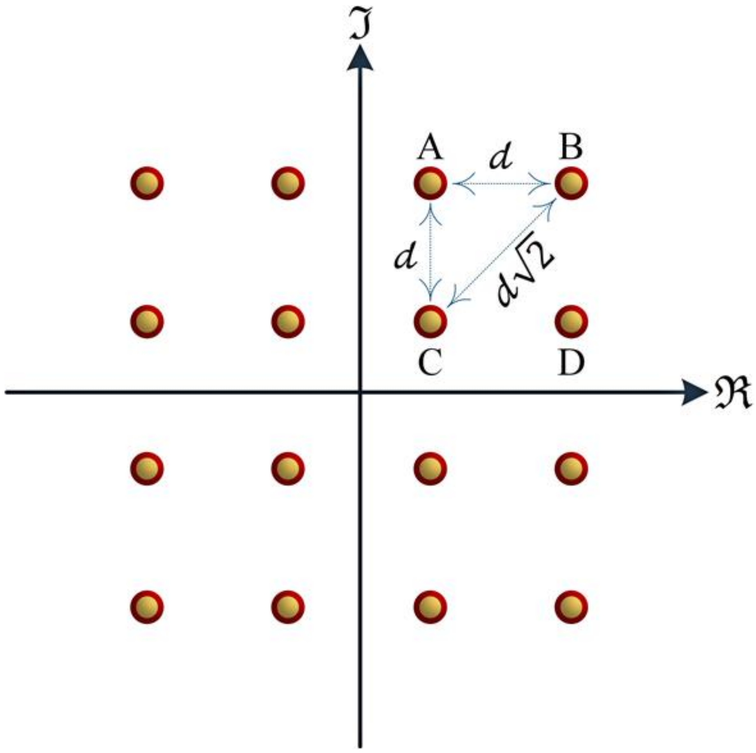

Figure 1. Conventional 16-QAM Constellation

In recent years, much research has been done on antenna selection for MIMO systems. These studies have shown that transmitter antenna selection techniques result in considerable increases in the performance of MIMO systems. Transmitter antenna selection (TAS) is an intelligent logic that emphasizes selecting a subset of antennas from within a particular set of antennas. Thanks to TAS, bit error rate (BER) and symbol error rate (SER) metrics improve, while hardware complexity, cost, and maintenance costs are reduced. Especially in this article, the capacity-optimized antenna selection (COAS) technique is emphasized. The COAS technique is an antenna selection method that shows improvements on the BER and has low complexity, which selects the antennas based on the highest channel amplitudes [12,17–19]. Besides, a technique called HQAM-SM by combining hexagonal constellations and rational SM technique has been proposed by the authors in [9], and this method shows similar BER performances with SM at high signal-to-noise ratio (SNR) values and is energy-efficient.

In this study, a novel capacity optimization antenna selection based HQAM-SM technique called COAS-HSM is proposed for next-generation communication systems. The proposed novel technique provides better performance compared to the SM, quadrature spatial modulation (QSM) and HQAM-SM techniques, provides nearly similar performance compared to the COAS-SM method, and has high energy efficiency compared to these methods. Performance analysis of the considered COAS-HSM technique is carried out in Rayleigh fading channels. Performance analysis of the considered COAS-HSM technique is carried out in Rayleigh fading channels.

The paper is organized as follows: In section 2, hexagonal constellations are introduced. In Section 3, COAS technique for the HQAM-SM scheme is presented. In Section 4, the system model of COAS-HSM is introduced. Performance Analysis for COAS-HSM is presented in Section 5. Finally, the simulation results and discussion are given in Section 6 and in Section 7 the paper is concluded.

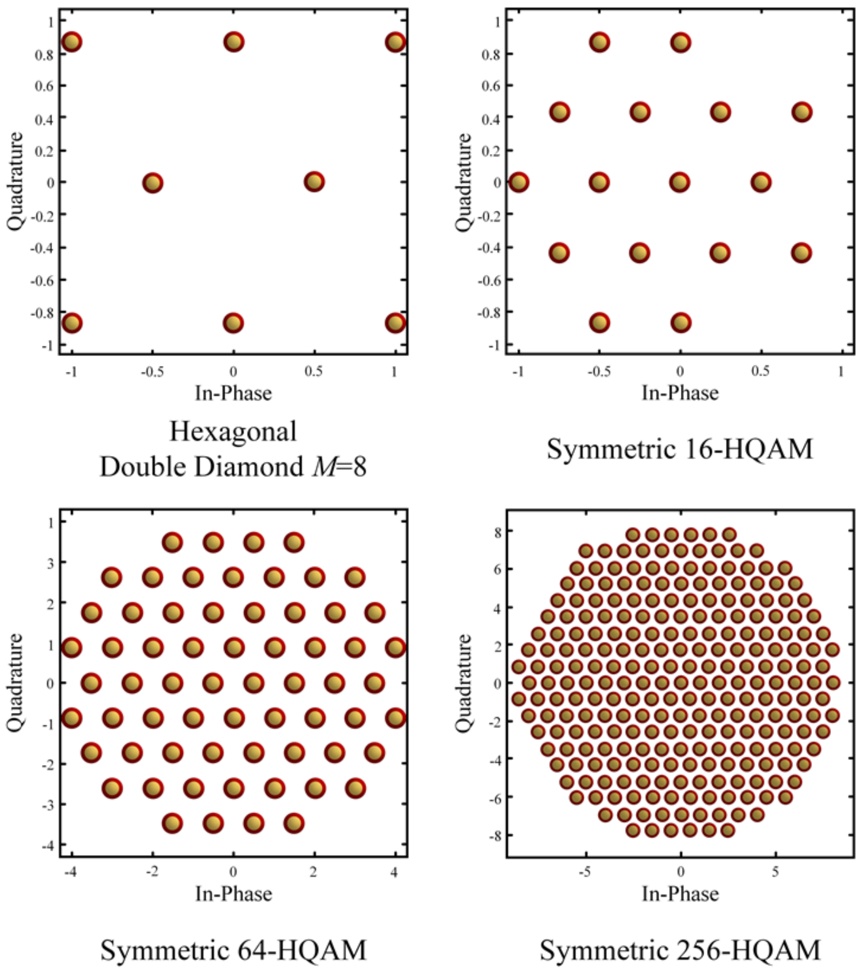

Figure 2. Various HQAM Constellations

Notation: The following notation is used throughout this paper. Bold lower/upper case symbols represent vectors/matrices; $(.)^H$, $(.)^T$, $\|.\|_F$, and $|.|$ denote Hermitian, transpose, Frobenius norm and absolute value operators, respectively, $\mathcal{R}(.)$ and $\mathcal{I}(.)$ are the real and imaginary parts of a complex-valued quantity.

2. Hexagonal Constellations

In this section, HQAM constellations will be explained in detail. Let us simply try to explain the superiority of HQAM constellation as follows. Consider a traditional 16-QAM structure as illustrated in Figure 1. Assume that the minimum distance between the two constellation points is d and the amplitude of the noise is $d/2$ The signal received by the receiver can be accurately detected if it is no more than $d/2$ away from the midpoint. However, considering the distance between $\overline{\mathrm{BC}}$ it can be straightforwardly seen that is $d/\sqrt{2}$ Thus, if the received signal is in the $\overline{\mathrm{BC}}$ range, the transmitted symbol can be obtained in the receiver correctly as long as the amplitude of the noise is less than $d\sqrt{2}/2$ From this point forth, there is no need to limit the noise amplitude of all signals received by the receiver to $d/2$ even if the amplitude of noise between $\overline{\mathrm{BC}}$ is equal to $d\sqrt{2}/2$ this signal could be received correctly in the receiver. If HQAM constellation is considered carefully, it is seen that there is no such inefficiency problem in HQAM constellation

Table 1. Constellation power measurement comparisons for a given unit minimum symbol separation [7]

Constellation Type	$P_{average}$	P_{peak}
64-QAM	10.5	24.5
64-HQAM	8.8125	16.75
128-QAM	20.5	42.5
128-HQAM	17.6366	34.519
256-QAM	42.5	112.5
256-HQAM	35.254	71.77
512-QAM	82.5	188.5
512-HQAM	70.53	143.43
1024-QAM	170.5	480.5
1024-HQAM	141.13	279.9

as in QAM constellation; because distances between constellation points in the HQAM structure are equal. In other words, under the same power assumption, HQAM constellation schemes are called optimal in the literature. Various HQAM constellation schemes such as hexagonal double diamond and symmetric HQAM with $M = 16, 64, 256$ are shown in Figure 2.

In order to show the superiority of HQAM constellations, we have also given a comparison through the Table 1. It can be clearly seen that HQAM constellations provide significant energy efficiency compared to conventional QAM constellations. Therefore, we are of the opinion that the use of these constellations in the next-generation communication systems will be of great benefit in today's world, where the energy problem and the carbon footprint are a huge problem. Here, the power measurements are $Watts / unit^2$ and for detailed information, please see the article [7], where $P_{average} = (M-1)d^2/6$ for MQAM modulation, here $d^2 = 1$ for square constellations and $d^2 = 0.9685$ for rectangular constellations.

3. COAS Technique for HQAM-SM (COAS-HSM)

COAS scheme is an antenna selection technique that selects antennas with channel amplitudes from a sub-antenna group with the maximum absolute value of the channel amplitude among the total transmission antennas. In the proposed system, this choice will be made by selecting antennas among transmit antennas. The COAS technique both improves the performance of MIMO communication systems and offers a low complexity experience.

Under the assumption that the channel state information (CSI) and SNR are well-known at the transmitter terminal, the capacity of the antenna selection based MIMO scheme for N_ψ number of transmission antennas can be expressed as follows [20]:

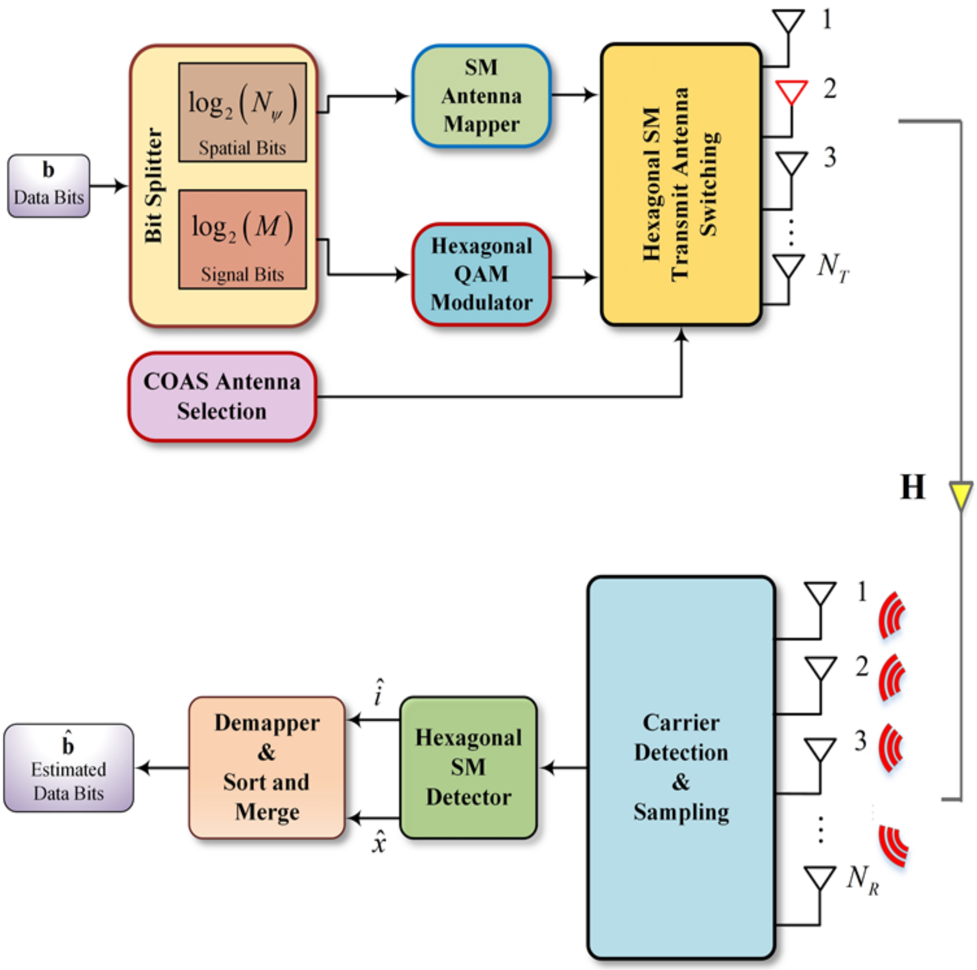

Figure 3. System Model of the COAS-HSM scheme

$$C \le C_{HSM} \le C + \log_2\left(N_\psi\right), \tag{1}$$

where; C_{HSM} depicts the capacity of hexagonal SM system, C can be written as $C = \frac{1}{N_\psi}\sum_{i=1}^{N_\psi}\log_2\left(1+g\|\mathbf{h}_i\|^2\right)$, and γ depicts the SNR value.

In order to maximize the capacity of MIMO system, the C value must be maximized. Therefore, C must be maximized by selecting N_ψ antennas corresponding to the largest channel norms. On the receiver side, N_ψ sub-antenna groups are calculated from N_T antennas and feedback is given to the transmitter. Based on all these described, COAS based antenna set can be easily found as follows [21]:

$$C_{\text{COAS}} = \left\{\alpha_1, \alpha_2, \ldots, \alpha_{N_\psi}\right\}, \tag{2}$$

Here, $\alpha_1, \alpha_2, \ldots, \alpha_{N_\psi}$ represents the index information of the channel vectors in order of magnitude of the norm. These values can be obtained as follows steps.

During the generation of the C_{COAS} set, the following steps are followed:

1. With $C_{\text{COAS}} \in \{1, 2, ..., N_T\}$, the Frobenius norm of each column vector in the $\mathbf{H}$ wireless channel matrix is calculated:

$$\left\| \mathbf{h}_{\alpha_i} \right\|_F^2, \tag{3}$$

2. The Frobenius norm of each channel vector should be arranged in descending order.

$$\left\| \mathbf{h}_{\alpha_1} \right\|_F^2 > \left\| \mathbf{h}_{\alpha_2} \right\|_F^2 > \ldots > \left\| \mathbf{h}_{\alpha_{N_\psi}} \right\|_F^2 > \left\| \mathbf{h}_{\alpha_{N_\psi+1}} \right\|_F^2 > \ldots > \left\| \mathbf{h}_{\alpha_{N_T}} \right\|_F^2, \tag{4}$$

3. Select the highest N_ψ channel gain vectors to create wireless channel channel vector $\mathbf{H}_{\text{COAS}}$'s $N_R \times N_\psi$ channel Matrix expressed as follows: expressed as follows: $\mathbf{H}_{\text{COAS}} = \left[\mathbf{h}_{\alpha_1}, \mathbf{h}_{\alpha_2}, ..., \mathbf{h}_{\alpha_{N_\psi}}\right]$, where $\mathbf{H}_{\text{COAS}}$ is the sub-matrix of $\mathbf{H}$.

After the best antenna set C_{COAS} has been successfully acquired, the hexagonal SM technique is carried out with this set.

4. System Model of COAS-HSM

In this section, COAS-HSM scheme will be mentioned. The system model of the COAS-HSM system is given in Figure 3. In the COAS technique, as mentioned before, a sub-antenna group that gives the highest channel amplitudes among a certain antenna group is selected and the transmission is carried out through these selected antennas. In the proposed COAS-HSM system, among the N_T transmission antennas, N_ψ COAS sub-antenna groups are selected and the transmission is accomplished through these selected antennas. As in the traditional SM system, there are N_R receiver antennas in the COAS-HSM system. In the proposed system, similar to the traditional SM system, active antenna indices are selected over N_ψ transmission antennas and these active antenna indices are used to transmit information with little additional hardware costs. However, unlike the traditional SM technique, in the HSM technique, traditional *M*-QAM constellations are not used to transmit data, but hexagonal constellations are used.

If the COAS-HSM scheme is examined carefully, it is seen that vector $\mathbf{b}$ with the size of $1 \times k$ is the data vector to be transmitted to the receiver terminal. At the transmitter terminal, $\mathbf{b}$ is divided into sub vectors $\mathbf{b}_1$ with the size of $1 \times k_1$ and $\mathbf{b}_2$ with the size of $1 \times k_2$, where $k_1 = \log_2\left(N_\psi\right)$ and $k_2 = \log_2\left(M\right)$, and communication is provided over $\mathbf{b}_1$ and $\mathbf{b}_2$.

If the COAS-HSM scheme is examined carefully, it is seen that vector $\mathbf{b}$ with the size of $1\times k$ is the data vector to be transmitted to the receiver terminal. At the transmitter terminal, $\mathbf{b}$ is divided into sub vectors $\mathbf{b}_1$ with the size of $1\times k_1$ and $\mathbf{b}_2$ with the size of $1\times k_2$, where $k_1=\log_2\left(N_\psi\right)$ and $k_2=\log_2\left(M\right)$, and communication is provided over $\mathbf{b}_1$ and $\mathbf{b}_2$.

The received faded signal with added noise is given as:

$$\mathbf{r}=\sqrt{g}\,\boldsymbol{x}_{ip}\,\mathbf{H}_{\mathrm{COAS}}+\mathbf{w}, \tag{5}$$

here; g expresses the average SNR, $\boldsymbol{x}_{ip}$ is the spatial modulated HQAM symbol vector, $\mathbf{H}_{\mathrm{COAS}}$ expresses the communication channel matrix with the size $N_R\times N_\psi$ and follows the Rayleigh distribution. Also, $\mathbf{H}_{\mathrm{COAS}}$ is the sub-matrix of $\mathbf{H}$ with the size of $N_R\times N_T$. $\mathbf{w}$ is the complex Gaussian random process with size of N_R, zero mean and variance of N_0, i.e., □ $\sim\left(0,N_0\right)$.

As it is well-known, SM uses the antenna indices as an extra dimension to transmit information bits. Thereon, a vector using SM mapper is created which is given as follows:

$$\boldsymbol{x}_{ip}=\begin{bmatrix}0 & \cdots & 0 & \underset{i^{\mathrm{th}}\ \text{position}}{\underset{\uparrow}{x_p}} & 0 & \cdots & 0\end{bmatrix}^T, \tag{6}$$

here, x_p shows the p^{th} symbol of M-ary HQAM and $p=1,\ 2,\ 3,\ \ldots,\ M$; i shows the active antenna index and $i=1,\ 2,\ 3,\ \ldots,\ N_\psi$. Here, only the i^{th} antenna will remain active during the transmission of the corresponding symbol. If the x_p symbol is transmitted by the i^{th} antenna, the channel output in (5) can be rewritten as follows:

$$\mathbf{r}=\sqrt{g}\;x_p\;\mathbf{h}_i+\mathbf{w}, \tag{7}$$

here, $\mathbf{h}_i$ is the i^{th} column of the wireless communication channel $\mathbf{H}_{\mathrm{COAS}}$.

Under the assumption that the channel inputs of SM are approximately equal according to the SM optimal receiver principle, the indices of COAS-HSM system can be obtained according to the maximum-likelihood (ML) principle as follows [21]:

$$
\begin{aligned}
\left[\hat{i},\hat{p}\right] &= \arg\max_{i,p} p_r\left\{\mathbf{r}\,|\,x_{ip},\mathbf{H}_{\text{COAS}}\right\} \\
&= \arg\min_{i,p}\left\{\left\|\mathbf{r}-\mathbf{h}_i\, x_i\right\|_F^2\right\} \\
&= \sqrt{g}\left\|\mathcal{A}_{ip}\right\|_F^2 - 2\Re e\left\{\mathbf{r}^H\mathcal{A}_{ip}\right\},
\end{aligned}
\tag{8}
$$

here; $1 \le i \le N_\psi$, $1 \le p \le M$, and $\mathcal{A}_{ip}$ is in the form of $\mathcal{A}_{ip} = \mathbf{h}_i x_p$. Also, $p_r\left\{\mathbf{r}\,|\,x_{ip},\mathbf{H}_{\text{COAS}}\right\} = \pi^{-N_R}\exp\left(\left\|\mathbf{r}-\mathbf{H}_{\text{COAS}}\,\mathbf{x}_{ip}\right\|_F^2\right)$ is the conditional probability density function according to x_{ip} and $\mathbf{H}_{\text{COAS}}$.

5. Performance Analysis for COAS-HSM System

The performance of the COAS-HSM method can be straightforwardly calculated using the union bound technique. From this point on, the average BER expression of the COAS-HSM system can be given as follows [22]:

$$
\begin{aligned}
P_{\text{COAS-HSM}} &\le E_x\left\{\sum_{\hat{i},\hat{p}} n\left(p,\hat{p}\right)P\left(x_{ip}\rightarrow x_{\hat{i}\hat{p}}\right)\right\} \\
&= \sum_{i=1}^{N_\psi}\sum_{p=1}^{M}\sum_{\hat{i}=1}^{N_\psi}\sum_{\hat{p}=1}^{M}\frac{n\left(p,\hat{p}\right)P\left(x_{ip}\rightarrow x_{\hat{i}\hat{p}}\right)}{N_\psi M},
\end{aligned}
\tag{9}
$$

where; $n\left(p,\hat{p}\right)$ is the number of bits in error between the symbol x_p and $x_{\hat{p}}$. In other words, the number of erroneous bits that occur when x_p is transmitted and $x_{\hat{p}}$ is received is expressed as $n\left(p,\hat{p}\right)$. $P\left(x_{ip}\rightarrow x_{\hat{i}\hat{p}}\right)$ is the pairwise error probability (PEP) of deciding on the constellation vector $x_{\hat{i}\hat{p}}$ while x_{ip} is transmitted. By the help of (8), the PEP conditioned on $\mathbf{H}_{\text{COAS}}$ (CPEP) can be written as [23]:

$$
\begin{aligned}
P\left(x_{ip}\rightarrow x_{\hat{i}\hat{p}}\,|\mathbf{H}_{\text{COAS}}\right) &= P\left(\sqrt{g}\left\|\mathcal{A}_{ip}\right\|_F^2 - 2\Re e\left\{\mathbf{r}^H\mathcal{A}_{ip}\right\} > \sqrt{g}\left\|\mathcal{A}_{\hat{i}\hat{p}}\right\|_F^2 - 2\Re e\left\{\mathbf{r}^H\mathcal{A}_{\hat{i}\hat{p}}\right\}\right) \\
&= Q\left(\sqrt{\frac{g}{2}\left\|\mathcal{A}_{ip}-\mathcal{A}_{\hat{i}\hat{p}}\right\|_F^2}\right),
\end{aligned}
\tag{10}
$$

where, $Q(.)$ stands for Q function.

As shown in (4), in order to minimize the error rate in (10), the N_ψ is highest normed of the channel matrix $\mathbf{H}$ columns are selected to generate $\mathbf{H}_{\text{COAS}}$ matrix. Thus, the antenna group that reaches the highest SNR in the receiver is selected.

As a result, the CPEP expression in (10) is minimized. To the best of the authors' knowledge, the closed form expression of the CPEP expression in (10) does not exist.

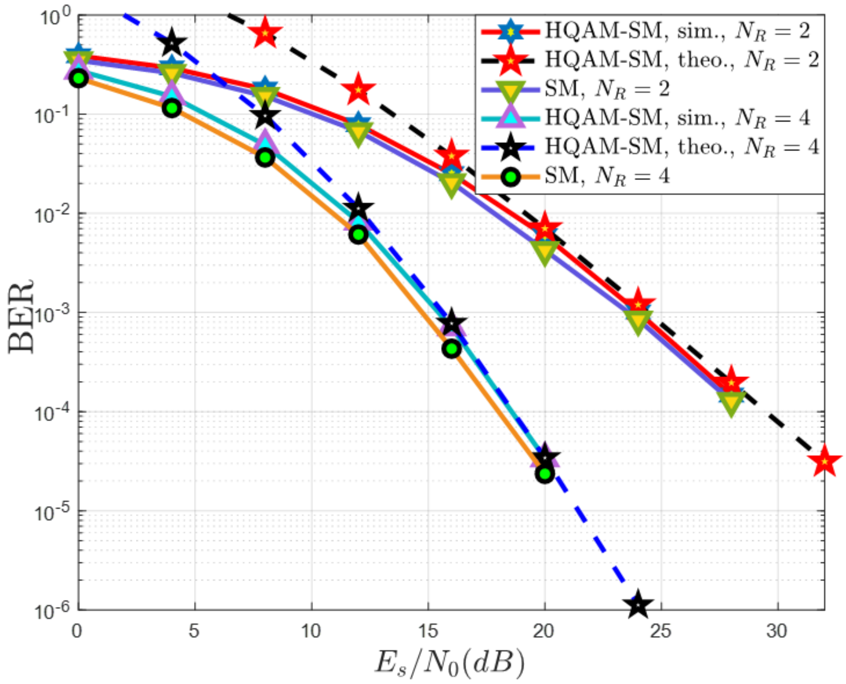

Figure 4. Performance comparisons of SM and HQAM-SM schemes where $M=16$, $N_T=4$ and $N_R=2,4$

On the other hand, for HQAM-SM system unconditional PEP can be written as follows [9]:

$$P\left(x_{ip} \rightarrow x_{\hat{i}\hat{p}}\right) = \zeta_{\alpha}^{N_R} \sum_{k=0}^{N_R-1} \binom{N_R-1+k}{k} \left[1-\zeta_{\alpha}\right]^k, \tag{11}$$

where, $\zeta_{\alpha} = \frac{1}{2}\left(1-\sqrt{\frac{\upsilon_{\alpha}^2}{1+\upsilon_{\alpha}^2}}\right)$ and $\upsilon_{\alpha}^2 = \frac{g\left(\left|x_p\right|^2+\left|x_{\hat{p}}\right|^2\right)}{4}$. Using (11) in (9), average BER of the HQAM-SM technique is given as follows [9]:

$$P_{HQAM-SM} \leq \sum_{p=1}^{M} \sum_{\hat{p}=1}^{M} \frac{N_T n\left(p,\hat{p}\right) \zeta_{\alpha}^{N_R} \sum_{k=0}^{N_R-1} \binom{N_R-1+k}{k} \left[1-\zeta_{\alpha}\right]^k}{M}. \tag{12}$$

6. Simulation Results

In this section, simulation results are given for COAS-HSM, HQAM-SM, QAM-SM and QSM techniques on Rayleigh fading channels. While obtaining the simulation results, the Monte Carlo simulation technique is used. 10^{-5} BER value is used to compare SNR performance gains of the techniques with each other. Also, in all performance comparisons, SNR is given as $\mathrm{SNR(dB)} = 10\log_{10}\left(E_s/N_0\right)$, where E_s represents the average symbol energy. It is also assumed that

CSI is perfectly known at the receiver. Subsequently, the ML detector is used to estimate the transmitted symbols and indices.

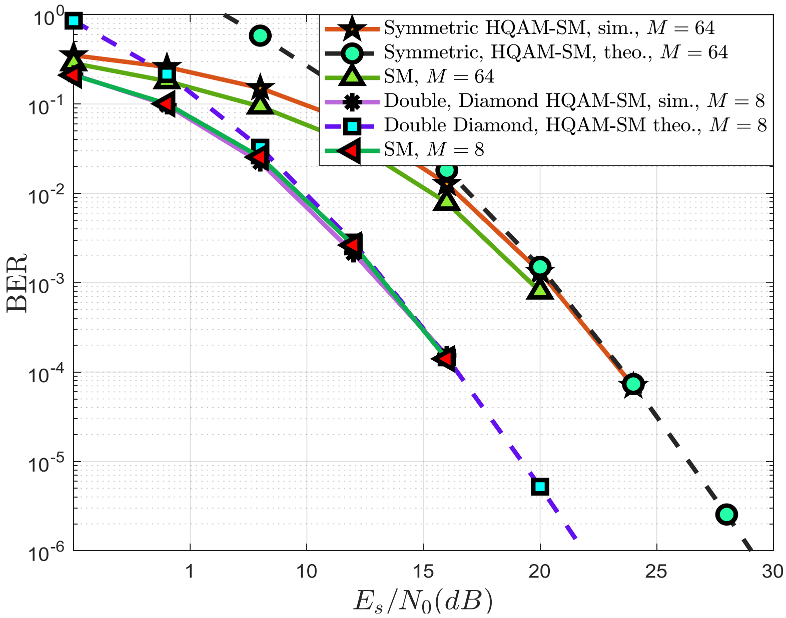

Figure 5. Performance comparisons of SM and HQAM-SM schemes where $N_T = 4$, $M = 8, 64$ and $N_R = 4$

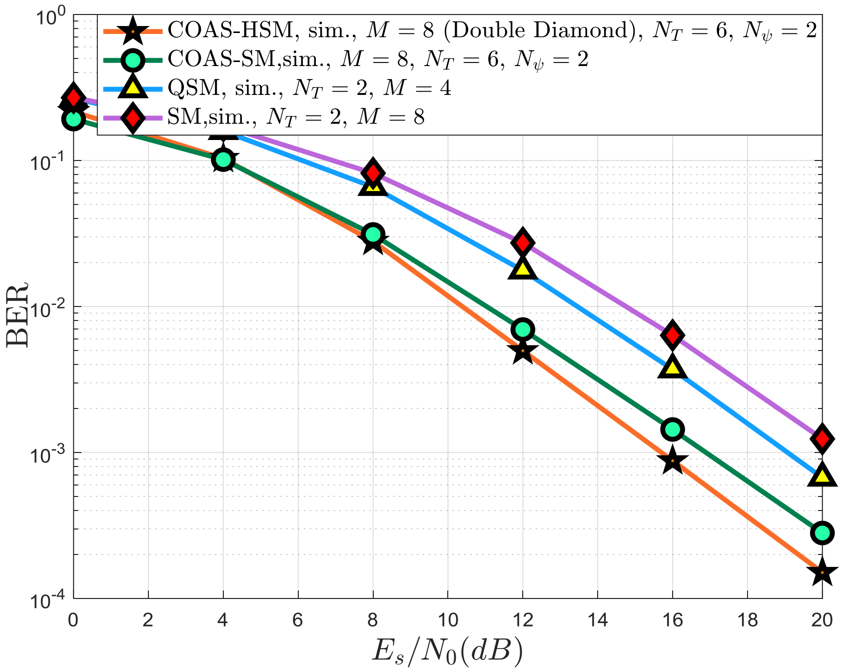

Figure 6. Performance comparisons of COAS-HSM, COAS-SM, SM and QSM systems where $N_T = 6$, $N_\psi = 2$, $N_R = 2$

In Figure 4, both theoretical and simulated performance comparisons of HQAM-SM system with QAM-SM system are given. In these comparisons, $N_T = 4$ and $M = 16$, and the receiver antenna numbers are chosen as $N_R = 2$ and $N_R = 4$. In this comparison, the QAM-SM and HQAM-SM comparisons transmit a total of $k = 6$ bits; 2 bits by antenna index, and 4 bits by 16-QAM/16-HQAM symbol.

In Figure 5, both theoretical and simulated performance comparisons of HQAM-SM system with QAM-SM system are presented. However, in these comparisons $N_T = 4$ and $N_R = 4$, and the modulation degree is chosen as $M = 8$ or $M = 64$. In systems, when $M = 8$ is selected, $k = 5$ bits are transmitted; and when $M = 64$ is selected, $k = 8$ bits are transmitted. If Figure 4 and Figure 5 are examined together, it can be seen that HQAM-SM and traditional QAM-SM

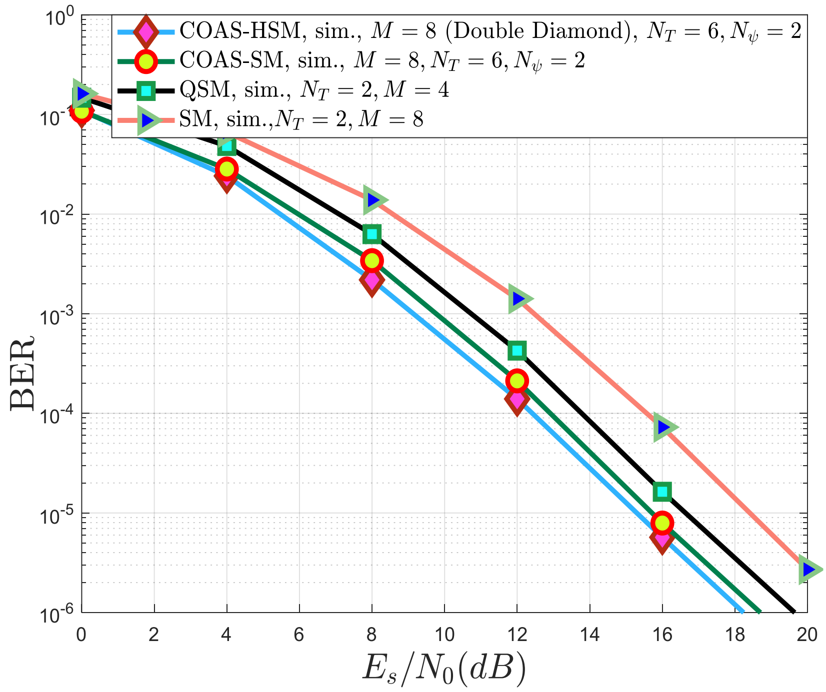

Figure 7. Performance comparisons of COAS-HSM, COAS-SM, SM and QSM systems where $N_T = 6$, $N_\psi = 2$,

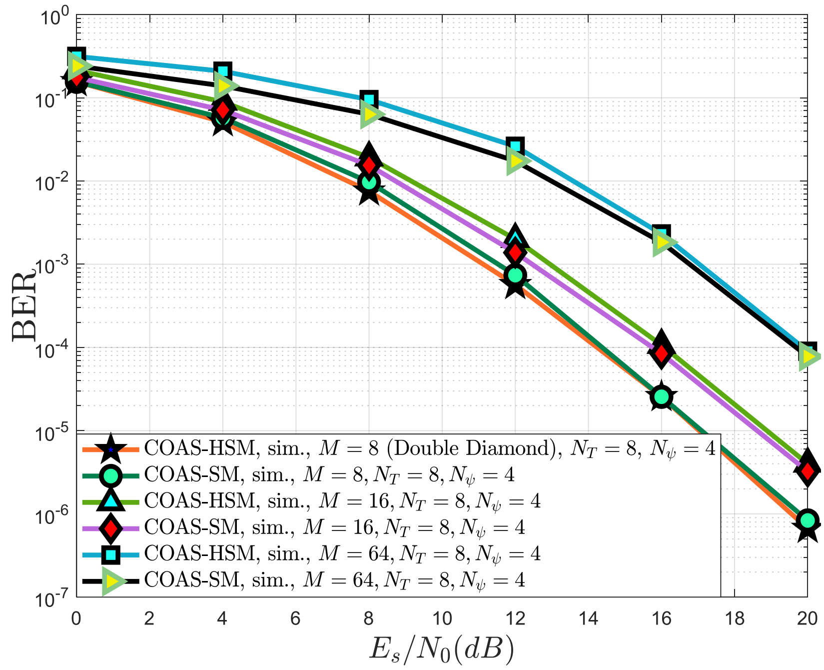

Figure 8. Performance comparisons of COAS-HSM and COAS-SM when $N_T = 8$, $N_\psi = 4$, $M = 8,16,64$ $N_R = 4$

techniques show similar performances, especially in high SNR. Besides, the HQAM-SM system is optimal in terms of energy efficiency.

In Figure 6, performance analyzes of COAS-HSM, COAS-SM, SM and QSM systems were performed for $k=4$. In COAS-HSM and COAS-SM techniques, $N_T=6$ and $N_\psi=2$ are selected, and in all techniques, the number of receiver antennas as $N_R=2$ is selected. As can be seen from the figure, the COAS-HSM technique provides approximately 1.3 dB gain compared to COAS-SM technique, 3.4 dB gain compared to QSM technique and 5.1 dB gain compared to the SM technique. Especially in these simulations, it has been observed that "the double diamond $M=8$" scheme provides better performance in the COAS technique compared to other HQAM schemes, because the double diamond HQAM constellation can separate symbols from each other more accurate.

For other constellation schemes, as mentioned before, HQAM provides almost equivalent performances and is energy efficient. In Figure 7, precisely the systems in Figure 6 are compared. The only difference is that the number of receiver antennas is $N_R=4$. Besides, the COAS-HSM technique provides a gain of about 0.55 dB compared to COAS-SM technique, a gain of 1.5 dB compared to QSM technique and a gain of 3.16 dB compared to the SM technique.

Finally, in Figure 8, performance comparisons for $M=8,16$, and 64 are given when COAS-HSM and COAS-SM systems have $N_T=8$ and $N_\psi=4$. As can be seen from the figure, COAS-HSM and COAS-SM techniques show similar BER performances at high SNR region. In addition, the COAS-HSM technique is an energy efficient next-generation communication technique.

7. Conclusion

In this study, a high data rated and energy-efficient communication technique called COAS-HSM is proposed. Considered method is obtained by adapting HQAM and SM techniques together with COAS based antenna selection scheme. The proposed new technique provides remarkable SNR gains compared to traditional SM, QSM and HQAM-SM techniques, while it offers similar SNR gains compared to the COAS-SM technique. However, the simulation results obtained also prove that the COAS-HSM system consumes less transmission energy, and on the other hand, has the error performance nearly equivalent to the COAS-SM technique. In addition to all these, when hexagonal constellations are used, energy efficiencies of up to 20% are obtained as given in Table 1, and they are potential candidates for next-generation energy-efficient communication systems.

References

[1] Buzzi, S., Chih-Lin, I., Klein, T.E., Poor, H.V., Yang, C., and Zappone, A. (2016) A survey of energy-efficient techniques for 5G networks and challenges ahead. IEEE J. Sel. Areas Commun., 34 (4): 697–709.

[2] Sharma, S.K., Woungang, I., Anpalagan, A., and Chatzinotas, S. (2020) Towards tactile internet in beyond 5G era: recent advances, current issues and future directions. IEEE Access, 1–1.

[3] Navarro-Ortiz, J., Romero-Diaz, P., Sendra, S., Ameigeiras, P., Ramos-Munoz, J.J., and Lopez-Soler, J.M. (2020) A survey on 5G usage scenarios and traffic models. IEEE Commun. Surv. Tutorials, 1–1.

[4] Chen, X., Ng, D.W.K., Yu, W., Larsson, E.G., Al-Dhahir, N., and Schober, R. (2020) Massive access for 5G and beyond.

[5] Aydin, E., Cogen, F., and Basar, E. (2019) Code-index modulation aided quadrature spatial modulation for high-rate MIMO systems. IEEE Trans. Veh. Technol., 68 (10), 10257–10261.

[6] Gunduz, Rugini, L. (2016) Symbol error probability of hexagonal QAM. IEEE Commun. Lett. 20 (8): 1523–1526.

[7] Murphy, C.D. (2000) High-order optimum hexagonal constellations. IEEE Int. Symp. Pers. Indoor Mob. Radio Commun. PIMRC, 1: 143–146.

[8] Gao Xingxin, Lu Mingquan, and Feng Zhenming (2002) Asymmetric hexagonal QAM based OFDM system. IEEE 2002 Int. Conf. Commun. Circuits Syst. West Sino Expo., 1:299–302.

[9] Cogen, F., and Aydin, E. (2019) Hexagonal quadrature amplitude modulation aided spatial modulation. 2019 11th Int. Conf. Electr. Electron. Eng., 730–733.

[10] Huang, H., Papadias, C.B., and Venkatesan, S. (2012) MIMO communication for cellular networks, Springer US, Boston, MA.

[11] Hampton, J.R. (2013) Introduction to MIMO communications, Cambridge University Press, Cambridge.

[12] Kumbhani, B., and Kshetrimayum, R.S. (2017) MIMO wireless communications over generalized fading channels, CRC Press.

[13] Heath Jr, R.W., and Lozano, A. (2018) Foundations of MIMO communication, Cambridge University Press.

[14] Mesleh, R.Y., Haas, H., Sinanović, S., Ahn, C.W., and Yun, S. (2008) Spatial modulation. IEEE Trans. Veh. Technol., 57 (4): 2228–2241.

[15] Mesleh, R., and Alhassi, A. (2018) Space modulation techniques, John Wiley & Sons, Inc, Hoboken, NJ, USA.

[16] Cogen, F., Aydin, E., Kabaoglu, N., Basar, E., and Ilhan, H. (2020) Generalized code index modulation and spatial modulation for high rate and energy-efficient MIMO systems on rayleigh block-fading channel. *IEEE Syst. J.*, 1–8.

[17] Pillay, N., and Xu, H. (2017) Improved generalized spatial modulation via antenna selection. Int. J. Commun. Syst., 30 (10): e3236.

[18] Asaati, B., and Abu-Hudrouss, A. (2020) Transmit antenna selection schemes for STBC-SM. TURKISH J. Electr. Eng. Comput. Sci., 28 (4): 2077–2087.

[19] Aydın, E. (2019) EDAS/COAS based antenna selection for code index modulation aided spatial modulation. Electrica, 19 (2): 113–119.

[20] Rajashekar, R., Hari, K.V.S., and Hanzo, L. (2013) Antenna selection in spatial modulation systems. IEEE Commun. Lett., 17 (3): 521–524.

[21] Cogen, F., and Aydin, E. (2020) Cooperative quadrature spatial modulation with euclidean distance and capacity optimized antenna selection. Int. J. Commun. Syst.

[22] Proakis, J., and Salehi, M. (2008) Fifth edition: digital communications.

[23] Jeganathan, J., Ghrayeb, A., and Szczecinski, L. (2008) Spatial modulation: optimal detection and performance analysis. IEEE Commun. Lett., 12 (8):545–547.