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On the Performance of MIMO-ANM with Joint Adaptive Transmit Antenna Selection and Maximum Ratio Combination in Future 6G Networks

MUHAMMET KIRIK[1], MEHMET O. SAGMAN[2], JEHAD M.HAMAMREH [3]
[1]WISLAB, Department of Electrical and Computer Engineering, Antalya Bilim University, Antalya, Turkey (e-mail: muhammetkirik1997@gmail.com)
[2]WISLAB, Department of Electrical and Computer Engineering, Antalya Bilim University, Antalya, Turkey (e-mail: mehmet.sagman@std.antalya.edu.tr)
[3]WISLAB, Department of Electrical and Electronics Engineering, Antalya Bilim University, Antalya, Turkey (e-mail: jehad.hamamreh@gmail.com)

Corresponding author: Muhammet Kirik (Lab Link: www.wislabi.com)

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The Matlab simulation codes used to generate the results in this paper can be found at https://researcherstore.com

ABSTRACT Multiple Input Multiple Output with Antenna Number Modulation (MIMO-ANM) has recently been introduced to the literature as an effective, competitive, and reliable transmission technology that can make the selection of antennas at the transmitter to be not just data-dependent as is the case with other spatial modulation methods, but also channel-dependent without the need to share any side information between the communicating parties. This key merit results in having much more improved performance in terms of reliability compared to index/spatial modulation-based transmission techniques, thus making it a very strong candidate technique for meeting the super ultra-reliability requirements of future 6G networks. Motivated by the great potential of MIMO-ANM and the need to study it in more depth to realize its suitability for future wireless networks such as 5G+, 6G, WiFi7, and WiFi8, this work aims to deeply investigate and quantify the performance of MIMO-ANM under the joint, simultaneous utilization of both Adaptive Transmit Antenna Selection (AAS) and Maximum Ratio Combination (MRC). The conducted mathematical analysis of the considered system model is verified by extensive numerical simulation results, which have precisely revealed the exact levels of gains in the bit error rate (BER) performance compared to a conventional MIMO-ANM system not adopting AAS with MRC. Such promising results are anticipated to greatly combat fading in wireless channels and improve the overall performance of future MIMO-ANM-based systems.

INDEX TERMS 5G, 6G, adaptive antenna selection, antenna number modulation, maximum ratio combining, AAS, ANM, MIMO, MIMO-ANM, MIMO-ANM-AAS, MRC, wireless communication.

I. INTRODUCTION

The increasing demand for internet applications and services that have emerged with the growing number of devices with internet connectivity has forced researchers to propose various transmission schemes to achieve higher data rates and better bit error rate (BER) performances against fading [1]–[6]. In order to mitigate the effects of the fading, the spatial diversity concept that contains multiple antenna elements at both the transmission and reception sides of the communication systems has been adopted in many of the wireless communication protocols throughout the years [7]. According to this concept, each of the transmitted signals that is sent from different transmitters is independently received by the receiver [8].

In this manner, Multiple Input Multiple Output (MIMO) systems have provided an undeniable improvement in the channel capacity and error performance [9]. Moreover, such a multi-scattering environment in the MIMO systems can mitigate the channel interference, which can be even more deleterious than white Gaussian noise for data transmission in some of the cases [10]. Thus, a technique known as diversity reception with adaptive array processing is widely used in MIMO systems for wireless communication to combat the effects of channel interference and multiple fading [11]. By implementing such a technique on MIMO systems, the signals from the receiving antennas are aimed to be combined in their best forms by utilizing maximum ratio combining (MRC) to maximize the signal to interference plus noise ratio (SINR) [12], [13].

While the channel interference and the multiple fading were aimed to be minimized by the MRC, the other important notions such as spectral efficiency, data rate, and reliability have also draw researchers' attention to create an ideal communication system in the future. For this reason, many different types of modulation techniques paired with the MIMO system have been offered in the literature such as spatial modulation (SM) [14] and antenna number modulation (ANM) [15]. In this manner, SM aims to map a block of transmitted bits to a symbol and to a certain transmit antenna, by doing so, SM makes the same symbol to be transmitted from different antennas and convey additional data bits according to the indices of the antennas [16]. On the other hand, ANM is another scheme that recently has been proposed in the literature. According to this scheme, the additional data bits are transmitted by exploiting the number of active antennas in the MIMO system as a third dimension along with those bits that are modulated by the conventional $M-$ary modulation. By doing so, the BER performance of the overall communication system is aimed to be improved along with high data reliability [15], [17], [18]. One of the biggest plus sides of the ANM scheme is the fact that unlike the other transmission techniques in the literature [19]–[21], such as SM and index modulation (IM) [22], [23], the ANM scheme does not suffer from the inability to make the selection of the antennas to be channel-dependent as it does not dictate the indices of the active antennas to transmit additional data bits but dictates their numbers instead. Thus, ANM creates an advantage in terms of the antenna selection to make this process channel and data-dependent at the same time. This enables the system to exhibit a better BER performance because of the fact that the system is capable of choosing the most effective antennas for the transmission.

In this paper, the merits of MRC along with adaptive antenna selection (AAS) transmission are exploited to improve the performance of ANM, which is one of the promising modulation techniques in the literature that has been paired with MIMO to achieve better reliability by improving the BER performance. The resulting technique termed as MIMO-ANM-AAS-MRC is shown to achieve better BER performance along with combating both fading and interference as a result of deploying additional antennas at the receiver. Also, since the number of antennas at the reception side is not singular, the proposed MRC adaptive MIMO-ANM-AAS scheme can be utilized to increase the overall spectral efficiency of the system. This can be achieved by transmitting additional data bits not only by the number of active transmit antennas, but also by exploiting the number of active receive antennas. By doing so, the MIMO-ANM-AAS can be applicable on both the transmission and reception sides and the spectral efficiency performance can be doubled.

The following sections of this paper are organized as follows. In section II, the system model of the proposed MRC adaptive MIMO-ANM-AAS scheme is provided in detail. In section III, the performance of the proposed system is analysed. In section IV, the simulation results are exhibited and explained. Lastly, with section V, the paper is concluded.

II. SYSTEM MODEL

In this part of the paper, the proposed MRC structure of MIMO-ANM-AAS is explained in detail. To do this, a point-to-point communication link with a single user is designed with a Rayleigh fading channel. In this scenario, the transmitter is considered to be consisting of T number of antennas, while the number of antennas at the receiver is R. In order to be able to observe the performance differences of the proposed MRC adaptive system as the number of receive antennas changes, the number of transmit antennas is kept constant, (i.e., $T = 4$), whereas the number of receiver antennas is changed as one, two, and four, (i.e., $R \in [1, 2, 4]$).

A. TRANSMITTER STRUCTURE DESIGN OF PROPOSED MIMO-ANM-AAS WITH MRC

Regarding transmission structure for the MIMO-ANM with MRC is provided in Fig. 1. Procedure starts with the separation of the incoming data stream, N, into two sub-streams from the beginning and the end. The sub-stream that is extracted from the first portion of the incoming data is mapped to the signal constellation points, and termed as "Main Bits" and notated as N_1. The sub-stream that is extracted from the second portion of the incoming data is mapped to the antenna number activation patterns, termed "ANM Bits" and notated as N_2.

For the separation of $N = N_1 + N_2$, each value of N_1 and N_2 is calculated as $N_1 = \log_2(M)$ and $N_2 = \log_2(N)$ respectively, where M is the signal constellation modulation order. In this study, the modulation of N_1 is done by BPSK, QPSK, 8-QAM, and 16-QAM, and their performances are investigated separately, whereas N_2 is exploited for the modulation of the number of active transmit antennas by taking advantage of a mapping table that maps the symbols of N_2 into a specific number of antennas.

After this step is concluded, each channel of the transmit antennas $\mathbf{h}$ is sorted in descending order (from largest to lowest) in terms of channel amplitude values. The reason behind this channel capacity ranking is that the transmitter prioritizes the deployment of the antennas which show the highest channel gains after the number of active transmit antennas is defined by the ANM mapper for receiver reliability improvement, to maximize the SNR, and relatively reduce

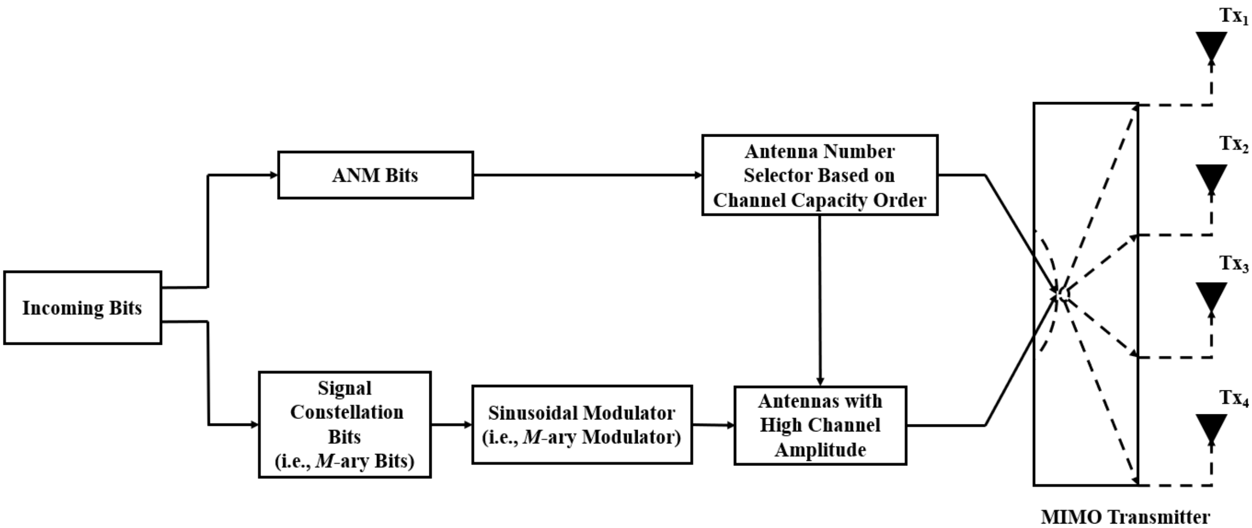

FIGURE 1. Transmitter Structure of MIMO-ANM-AAS with MRC.

TABLE 1. Mapping table of MIMO-ANM-AAS where N_2=2 bits & number of transmit antennas is four (T=4), and the antenna activation patterns are defined by the highest channel gains among all possible antennas in the system.

ANM Bits (N_2)	Antenna Activation Patterns ($\mathbf{v}$)
[0 0]	[1 0 0 0]
[0 0]	[0 1 0 0]
[0 0]	[0 0 1 0]
[0 0]	[0 0 0 1]
[0 1]	[1 1 0 0]
[0 1]	[1 0 1 0]
[0 1]	[1 0 0 1]
[0 1]	[0 0 1 1]
[0 1]	[0 1 0 1]
[0 1]	[0 1 1 0]
[1 0]	[1 1 1 0]
[1 0]	[1 1 0 1]
[1 0]	[1 0 1 1]
[1 0]	[0 1 1 1]
[1 1]	[1 1 1 1]

the BER. Simply, after the number of transmit antennas for the transmission of main bits are defined by the ANM bits, the positions/indices of this specific number of antennas are defined by the channel coefficient ranking of the transmit antennas. The possible antenna activation cases for different channel capacity orders are given in Table 1.

As the next step, after each symbol of the main bits, N_1, is modulated by one of the $M-$ary PSK/QAM signal modulation schemes and the ANM bits, N_2 has been successfully exploited to modulate the number of active transmit antennas, where individual formed complex data symbol (x) of N_1 is transmitted over the antennas that offer the highest channel qualities. Then, each symbol of N_1 is multiplied by the flat fading channels that correspond to their respective active antennas. Subsequently, the noise $\mathbf{w}$ with zero mean and N_0 variance is appended on top of the transmitted signal $\mathbf{y}$. This procedure is mathematically formulated as

$$\mathbf{y} = \sqrt{\frac{P}{V}} \times \mathbf{h} \times \mathbf{v} \times \mathbf{x} + \mathbf{w}, \tag{1}$$

where P represents the power of transmission for each data symbol, and $V = \|\mathbf{v}\|_2 = \sum_{i=1}^{T}\sum_{j=1}^{R} v_i^2$ is the total number of active antennas selected for transmission out of T available transmit antennas and R available receive antennas in each channel use. The flat fading channel vector is represented by $\mathbf{h} = [h_{11}\ \ , h_{12},\ \ ...,\ \ h_{43},\ \ h_{44}]$, in which, each element of the matrix represents a circularly symmetric complex Gaussian channel coefficient with zero mean and unity variance, corresponding to the response between the R^{th} receive antenna and the T^{th} transmit antenna, whereas $\mathbf{v} \in \mathbb{R}^{4\times4}$ is the vector that represents the patterns of activation for the transmit antennas, in which the inactive antennas are represented by zeros, while the active antennas are represented by ones. This procedure is done based on the N_2 bits and Table 1 shows the mapping process for this procedure.

B. RECEIVER STRUCTURE DESIGN OF PROPOSED MIMO-ANM-AAS WITH MRC

The fundamental difference between MIMO-ANM-AAS and the proposed MRC adaptive MIMO-ANM-AAS is the multiple antenna elements at the reception side. By increasing the number of receiving antennas, R, it is aimed to increase the performance of BER and the receiver reliability. The reception structure of the proposed multi-user OFDM-SNM scheme is given in Fig. 2.

The receiving procedure of data in the proposed scheme is operated by a maximum likelihood (ML) detector individually for both the main bits and the ANM bits in each receiving antenna. Consequently, each symbol of the ANM bits sub-stream is de-mapped by detecting the number of active transmit antennas and these symbols are extracted in each of the receiver antennas. After that, each main bits

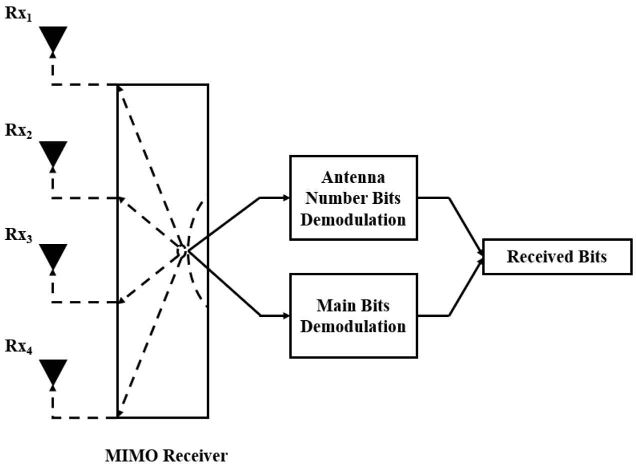

FIGURE 2. Receiver Structure of MIMO-ANM-AAS with MRC.

symbol that is conveyed from the active transmit antennas is detected by the $M-$ary demodulation, and these symbols are extracted in each receiver. After both the main bits and the ANM bits sub-streams are demodulated in each receiver the final received data is considered to be the average value of these received signals. The mathematical correspondences of the ML detectors that are deployed in these procedures can be formulated as

$$J_v = \min_{\hat{v}} \left(||y - \left(\sum_{i,j=1}^{\hat{v}} h_{ij} \right) x||^2 \right), \tag{2}$$

$$J_x = \min_{\hat{x}} \left(||y - \left(\sum_{i,j=1}^{v} h_{ij} \right) \hat{x}||^2 \right). \tag{3}$$

III. PERFORMANCE ANALYSIS

In this section, the performance of the proposed MRC adaptive MIMO-ANM-AAS scheme is analyzed in terms of effective instantaneous SNR and symbol error probability under different numbers of receive antennas.

A. STATISTICS OF THE EFFECTIVE INSTANTANEOUS SNR

The mathematical formulation of the the amplitude channel distribution function is given as

$$f_\alpha\left(\alpha\right) = \frac{\alpha}{\beta^2} \exp\left(-\frac{\alpha^2}{2\beta^2}\right), \tag{4}$$

where $\alpha = |H_{eff}|$ is the magnitude of the effective Rayleigh channel distribution and $\beta \in [0.71, 1.0, 1.23, 1.42]$ is the scale parameter.

In order to calculate the symbol error rate (SER) of the proposed MRC adapted MIMO-ANM-AAS scheme, the power distribution function (PDF) of the effective instantaneous SNR $\gamma = \frac{|H_{eff}|^2 P}{\sigma^2}$ must be determined. In this SNR formula, P represents the power allocated to each transmitter, whereas σ represents the variance at the receiver. The PDF function of regarding SNR for a singular receive antenna is given as

$$f_\gamma\left(\gamma\right) = \frac{f_\alpha\left(\sqrt{\frac{\Omega\gamma}{\bar{\gamma}}}\right)}{\frac{1}{\beta^2}\sqrt{\frac{\bar{\gamma}\gamma}{\Omega}}}, \tag{5}$$

where $\Omega = \overline{\alpha}^2$ is the mean square variable of α.

The PDF function of the SNR value of γ for multiple receive antennas is given as

$$p(\gamma) = \frac{1}{(R-1)!\left(\sqrt{\frac{\bar{\gamma}\gamma}{\Omega}}\right)^{\text{R}}} \left(\gamma^{\text{R-1}}\right) \exp\left(\frac{-\gamma}{\sqrt{\frac{\bar{\gamma}\gamma}{\Omega}}}\right), \tag{6}$$

where R represents the number of antennas at the reception side.

For the case where the number of receive antennas is two ($R = 2$), equation (6) becomes

$$p(\gamma) = \frac{1}{\left(\sqrt{\frac{\bar{\gamma}\gamma}{\Omega}}\right)^2} \left(\gamma\right) \exp\left(\frac{-\gamma}{\sqrt{\frac{\bar{\gamma}\gamma}{\Omega}}}\right). \tag{7}$$

B. ERROR PERFORMANCE ANALYSIS OF MIMO-ANM

Because of the fact that the estimation process in MIMO-ANM is operated in two different parts, which these parts can be classified as the estimation of the number of transmit antennas, and the estimation of the transmitted symbol, the analytical performance evaluation is not as simple as the conventional MIMO. Even though in the theoretical calculations these two parts of estimation are considered to be separated from each other, this assumption is not applicable in practice. For example, in a case where the channel paths are correlated, the two parts of the estimation process will be depending on each other.

The recovery of the transmitted data can only be achieved in the case where the both parts of the estimation are correctly operated. For the computation of the overall probability of error P_E, let $A1$ is defined as the first part of the estimation, and $A2$ is defined as the second part of the estimation. Because of the fact that the first part of bit-substream, named as Main Bits, which its modulation is operated by BPSK, and the second part of bit-substream named as ANM Bits, don't have the same length in terms of bit sequence, the probability for $A1$ will be $P(A1) = 1/3$, while the probability for $A2$ is $P(A2) = 2/3$. Now, if the error probability for $A1$ is defined as $P_{BPSK}(E)$ and the error probability for $A2$ is defined as $P_{ANM}(E)$, the overall error probability $P_{tot}(E)$ can be formulated as

$$P_{tot}(E) = P_{tot}(E|A_1)P(A_1) + P_{tot}(E|A_2)P(A_2) \tag{8}$$

$$P_{tot}(E) = \frac{1}{2}P_{BPSK}(E) + \frac{2}{3}P_{ANM}(E) \tag{9}$$

C. ANALYTICAL SYMBOL ERROR RATE OF THE TRANSMITTED SYMBOL

In the proposed MRC adaptive MIMO-ANM-AAS scheme, there are different possible scenarios for the construction of the transmission environment. These scenarios are created by deploying different numbers of antennas at the reception side of the system and using different types of modulation orders. Thus, for each of the cases where the number of constellation points varies, a different mathematical process has been followed by taking the number of antennas at the receiving end under consideration.

The mathematical formulation of the SER derivation for $M-$ary QAM over a Rayleigh fading channel for one antenna at the receiving side is given as [15]

$$P_s = 2\left(\frac{\sqrt{M}-1}{\sqrt{M}}\right)\left(1-\sqrt{\frac{1.5\bar{\gamma}_s}{M-1+1.5\bar{\gamma}_s}}\right)-\left(\frac{\sqrt{M}-1}{\sqrt{M}}\right)^2 \times\left[1-\sqrt{\frac{1.5\bar{\gamma}_s}{M-1+1.5\bar{\gamma}_s}}\left(\frac{4}{\pi}\tan^{-1}\sqrt{\frac{M-1+1.5\bar{\gamma}_s}{1.5\bar{\gamma}_s}}\right)\right], \tag{10}$$

where $\bar{\gamma}_s = \bar{\gamma}\log_2(M)$ represents the average SNR per symbol.

The mathematical SER derivation over a Rayleigh channel for multiple antennas at the reception side is given as follows.

$$P_b = \int_0^\infty \frac{1}{2} erfc(\sqrt{\gamma}) \frac{1}{\left(\sqrt{\frac{\bar{\gamma}\gamma}{\Omega}}\right)^2}(\gamma)\exp\left(\frac{-\gamma}{\sqrt{\frac{\bar{\gamma}\gamma}{\Omega}}}\right)d\gamma. \tag{11}$$

In this equation, the error function can be converted into integral form and replaced by equation (12).

$$erfc(\gamma) = \frac{2}{\sqrt{\pi}}\int_{\sqrt{\gamma}}^\infty e^{-t^2}dt = \frac{e^{-\gamma}}{\sqrt{\pi\gamma}}. \tag{12}$$

By substituting a k_1 variable instead of $\frac{1}{2}\left(\frac{1}{\sqrt{\frac{\bar{\gamma}\gamma}{\Omega}}}\right)$ in equation (11), the integral form of the error function can be formulated as

$$P_b = \int_0^\infty k_1\gamma\frac{e^{-\gamma}}{\sqrt{\pi\gamma}}\exp\left(\frac{-\gamma}{\sqrt{\frac{\bar{\gamma}\gamma}{\Omega}}}\right)d\gamma. \tag{13}$$

By introducing a k_2 variable to be substituted in place of $\left(\frac{1}{\sqrt{\frac{\bar{\gamma}\gamma}{\Omega}}}\right)$, equation (13) can be written as

$$P_b = \int_0^\infty k_1\gamma\frac{1}{\sqrt{\pi\gamma}}\exp\left(-k_2\gamma\right)d\gamma. \tag{14}$$

The result of the equation (14) is given as

$$P_b = \frac{1}{k_1\sqrt{\pi}}\int_0^\infty \sqrt{\gamma}e^{-k_2\gamma}d\gamma \tag{15}$$

$$P_b = \frac{\sqrt{\gamma}}{k_1\sqrt{\pi}}\frac{-1}{k_2}e^{-k_2\gamma}\frac{-\sqrt{\pi}(erfc(\sqrt{k_2\gamma}+1)}{\sqrt{2}k_2^{\frac{3}{2}}} \tag{16}$$

Open forms of k_1 and k_2 values are written in place of equation (16). The resulting formula is found as

$$P_b = \frac{1}{2}-\frac{1}{2}\frac{1}{\sqrt{1+\sqrt{\frac{\bar{\gamma}\gamma}{\Omega}}}} \tag{17}$$

If equation (17) is multiplied by the square root of the number of receive antennas, and the first line of equation (10), the final formulation of the mathematical SER derivation for $M-$ary QAM over a Rayleigh channel for multiple antennas at the reception side can be derived as

$$P_b = \sqrt{R}\left(\frac{\sqrt{M}-1}{\sqrt{M}}\right)\left(1-\sqrt{\frac{1.5\bar{\gamma}_s}{M-1+1.5\bar{\gamma}_s}}\right)- \left(\frac{\sqrt{M}-1}{\sqrt{M}}\right)^2\times\left(\frac{1}{2}-\frac{1}{2}\frac{1}{\sqrt{1+\sqrt{\frac{\bar{\gamma}\gamma}{\Omega}}}}\right) \tag{18}$$

D. ERROR ANALYSIS OF THE NUMBER OF ACTIVE TRANSMIT ANTENNAS

In this part, $P_{ANM}(E)$ is computed. In this case, number of transmit antennas (T) is considered as four for simplicity of the derivation.

When four different antenna activation patterns are available, the analytical error expression over a Rayleigh fading channel can be formulated as

$$P_{e/\gamma_s} = 2\frac{(T-1)}{T}Q_f\left(\sqrt{2G\times\gamma_s}\right) \tag{19}$$

where $G = 3/(T^2-1)$ and $Q_f(x)$ is the Q function defined as

$$Q_f(x) = \frac{1}{\sqrt{2\pi}}\int_x^\infty e^{-\frac{u^2}{2}}du. \tag{20}$$

If the alternative form of the Gaussian function is used instead of the above equation, the SER formula can be obtained in the product form as

$$P_{e/\gamma_s} = 2\frac{(T-1)}{T\pi}\int_0^{\frac{\pi}{2}}\exp\left(\frac{-G\bar{\gamma}_s}{\sin^2(\phi)}\right)d\phi \tag{21}$$

The analytical error probability for a single receive antenna is derived as [15]

$$P_e = \int_0^\infty P_{e/\gamma_s}p_\gamma(\gamma_s;\beta,\alpha)d\gamma_s \tag{22}$$

$$P_e = \int_0^\infty 2\frac{(T-1)}{T}Q_f\left(\sqrt{2G\times\gamma_s}\right)p_\gamma(\gamma_s;\beta,\alpha)d\gamma_s \tag{23}$$

$$P_e = P_{ANM}(E) = \frac{T-1}{T}\left(1-\sqrt{\frac{G\bar{\gamma}_s}{1+G\bar{\gamma}_s}}\right), \quad (24)$$

Now, the multiple receive antennas variable, R, can be included into the (24) to calculate the analytical error probability for multiple receive antennas as given below

$$P_e = P_{ANM}(E) = \frac{(T-1)\times R}{T}\times \left(1-\frac{\log(R^2)}{\log(R^2-1)}\sqrt{\frac{G\bar{\gamma}_s R(R+1)}{1+G\bar{\gamma}_s R(R+1)}}\right), \quad (25)$$

where $\bar{\gamma}_s = \frac{\overline{\alpha^2}}{2\beta^2}\frac{\bar{E}_s}{N_o^s}$ is the average value of SNR for each symbol and α represent the amplitude of fading, whereas E_s is the energy of the average symbol.

If the (18), and (25) are substituted into (9), the error probability of the whole system can easily be obtained.

IV. PERFORMANCE DEMONSTRATIONS

In this section, simulation results of the proposed MRC adaptive MIMO-ANM-AAS are provided in terms of bit error rate (BER) by conducting Monte-Carlo simulations over a wireless Rayleigh fading channel. Table 2 shows the simulation parameters that are used for each simulation setup.

TABLE 2. System Parameters

Type of Modulation	BPSK (M=2), QPSK (M=4), 8-QAM (M=8)
Number of Symbols	10^6 per iteration
Antennas Used for Transmission	4
Antennas Used for Reception	[1,2,4]
Antennas Dedicated for ANM	4
Bits Used for Mapping of ANM	2
Type of the Channel	Block Rayleigh fading

It should also be noted that the number of transmit antennas is held constant at a value of four. The reason why this parameter is purposefully selected is to create a convenient environment to impartially observe all the cases, where the number of receive antennas varies within the given receiver antenna values.

The first simulation setup is established on four transmit antennas ($T = 4$) and one receive antenna ($R = 1$). The reason why such a setup is considered in the first simulation is to exhibit the performance of the single receive antenna system and create an adequate environment to be able to compare the performance of the proposed scheme for different number of receive antennas under different modulation orders. Fig. 3 shows the SER results of the first simulation setup, where $T = 4$, $R = 1$. As it can be inferred from this figure, the BER performance of the proposed scheme under the BPSK modulation shows the same characteristics with [15] since both of the schemes use a singular antenna element at the receiver. However, as the modulation order gets higher from BPSK to 8-QAM, the performance of SER dramatically decreases, which is also shown in Fig. 3.

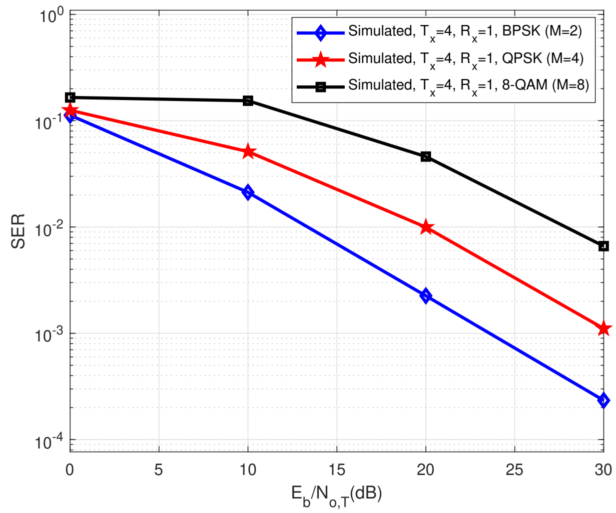

FIGURE 3. Symbol Error Rate of the Proposed MRC Adaptation of MIMO-ANM-AAS Scheme Under Different $M-$ary Modulation Orders with Four Transmit Antennas ($T = 4$) and One Receive Antenna ($R = 1$).

The second simulation setup is established on four transmit antennas ($T = 4$) and two receive antennas ($R = 2$). By using these parameters it is aimed to display the performance improvement of the proposed MRC adaptation. Fig. 4 shows the SER results of the second simulation setup, where $T = 4$ and $R = 2$. When this figure is compared with Fig. 3, it can be seen that when the number of transmit antennas is increased from one to two, there is a drastic improvement in the performance of the BER, since at the same SNR level, 20, while the BER performance of the single receive antenna setup can achieve a BER result between 10^{-2} and 10^{-3}, the double receive antennas setup achieves a performance better than 10^{-5}. Also, even in the case in which the worst SER performance is achieved in Fig. 4, namely the case in which 8-QAM modulation is used, it is shown that the results outperform the best case of the single receive antenna setup, which is shown in Fig 4.

The third simulation setup is established on four transmit and receive antennas ($T = 4$, $R = 4$). The reason why such a setup is adopted is for the performance investigation of the proposed scheme under equal number of transmit and receive antennas and analyze the performance difference when the receive antennas' number is increased. Fig. 5 shows the SER results of the third setup, where $T = 4$ and $R = 4$. From this figure, it can be inferred that when the number of receive antennas is increased from two to four there is a dramatic change in the SER results in both modulation orders. In fact, when the results of the case where the worst SER performance is achieved using this setup,namely when 8-QAM modulation is used and marked by the black line in Fig.

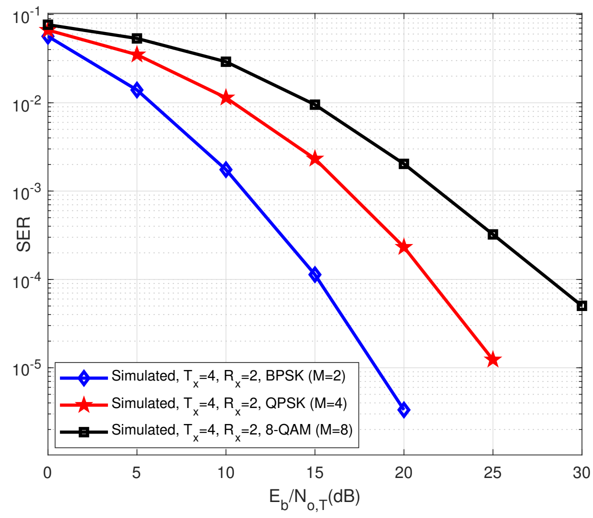

FIGURE 4. Symbol Error Rate of the Proposed MRC Adaptation of MIMO-ANM-AAS Scheme Under Different $M-$ary Modulation Orders with Four Transmit Antennas ($T = 4$) and Two Receive Antennas ($R = 2$).

5, is compared with the best result of the first setup, which utilizes BPSK modulation and is marked by the blue line in Fig. 3, where the number of receive antennas is one, it can be seen that at the same SNR level, the SER performance of the four receive antenna system using $8-$QAM, outperforms the BER performance of the one receive antenna system using BPSK.

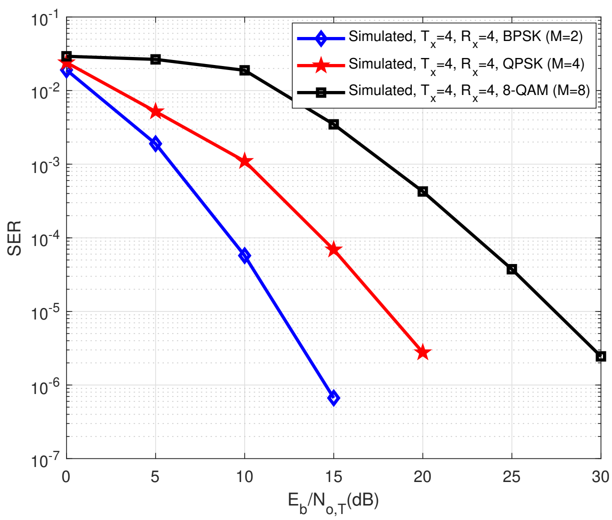

FIGURE 5. Symbol Error Rate of the Proposed MRC Adaptation of MIMO-ANM-AAS Scheme Under Different $M-$ary Modulation Orders with Four Transmit Antennas ($T = 4$) and Four Receive Antennas ($R = 4$).

In Fig. 6, the theoretical BER performances of the proposed scheme are given. The black color dashed curve represents the theoretical BER calculation of the case, where the number of receive antennas is one, red color dashed curve represents the theoretical BER calculation of the case, where the number of receive antennas is two. Lastly, the blue color dashed curve represents the theoretical BER calculation of the case, where the number of receive antennas is four. It should be noted that the adopted modulation order for the calculation of the theoretical derivations in this figure is BPSK ($M = 2$), while the number of transmit antennas is considered to be four ($T = 4$).

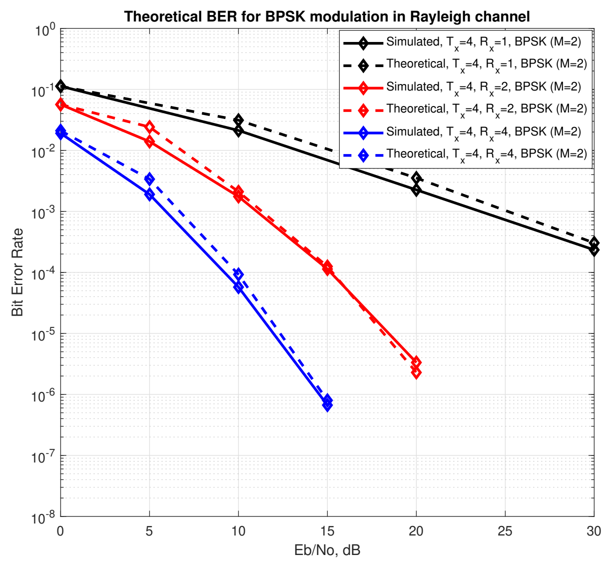

FIGURE 6. Theoretical Bit Error Rate of the Proposed MRC Adaptation of MIMO-ANM-AAS Scheme Under BPSK Modulation Order with Four Transmit Antennas ($T = 4$) and Different Numbers of Receive Antennas ($R = 1, 2, 4$).

V. CONCLUSION

In this paper, the MIMO-ANM-AAS scheme is interrogated under MRC conditions. The underlying principle of this application is exploiting increased number of antenna elements at the receiver to achieve better BER performance. Simulation results and mathematical calculations prove that the proposed MRC application on the MIMO-ANM-AAS scheme leads the system to achieve a substantial improvement in the BER performance thanks to the increased number of antennas at the receiver. Furthermore, the proposed MRC application creates a possibility to transmit additional data bits not only by exploiting the number of active transmit antennas but also by exploiting the number of active receive antennas to increase the spectral efficiency along with the BER performance. This makes the proposed application a strong candidate to be used in future 5G, 6G, and beyond technologies where the low BER and high spectral efficiency are desired.

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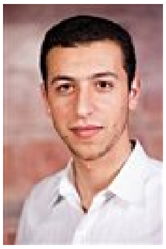
MUHAMMET KIRIK received the B.Sc. degree in electrical and electronics engineering from Antalya Bilim University, Turkey in 2020, and the Master degree in Telecommunication Engineering and Wireless Security Systems in 2022. He is currently continuing his PhD studies at Medipol University. His current research interests include orthogonal frequency division multiplexing multiple input multiple output systems, multi-dimensional modulation techniques, wireless physical and MAC layers security, and orthogonal/non-orthogonal multiple access schemes for future wireless systems.

MEHMET O. SAGMAN received the B.Sc. degree in electrical and electronics engineering from Antalya Bilim University, Turkey in 2020. He is currently completing his master studies and working as a software developer. His current research interests include orthogonal frequency-division multiplexing multiple-input multiple-output systems, multi-dimensional modulation techniques, and orthogonal/non-orthogonal multiple access schemes for future wireless systems.



JEHAD M. HAMAMREH is the Founder and Director of WISLABi.com, Editor at Researcherstore.com, FCN, & RS-OJICT, as well as A. Professor with the Electrical and Computer Engineering Department, Antalya International (Bilim) University. He received a Ph.D. degree in Telecommunication Engineering and Cyber-Systems from Medipol University. Previously, he worked as a Researcher at the Department of Electrical and Computer Engineering at Texas AM University. He is the inventor of more than 20 Patents and the author of more than 85 peer-reviewed scientific papers along with several book chapters. His innovative patented works won the gold, silver, and bronze medals by numerous international invention contests and fairs. (web: https://wislabi.com)

His current research interests include Wireless Communication, Wireless Security, Wireless Sensing, 5G/6G, IoT, AI/ML, wireless physical and MAC layers security, orthogonal frequency-division multiplexing (OFDM), multiple-input multiple-output systems (MIMO), advanced waveforms design, multidimensional modulation techniques, and orthogonal/non-orthogonal multiple access schemes for future wireless systems. He is a regular investigator and a referee for various scientific journals as well as a TPC member for several international conferences. He is an Editor at RS-OJICT and Frontiers in Communications and Networks. (web: https://wislabi.com).