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Signal Selection Considerations for MIMO with One Active Transmit Antenna

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Abstract: This article discusses the issue of signal selection for a multiple-input multiple-output (MIMO) system, when only one of several antennas on the transmitting side is active. To increase the efficiency, in the presented system, constellations of the same size, but of different types, are defined for each transmitting antenna. They are called partner constellations. In such a scheme, the selection of partner constellations is important, and this process is implemented in terms of the minimum squared Euclidean distance between them. To evaluate the results, a computer simulation based on pairs of binary phase-modulated signals with different distance properties and MIMO with one receiving and two transmittting antennas, of which only one is active, is used. The communication channel is represented by additive white Gaussian noise and fading with a Nakagami distribution, which is due to the fact that the fading depth values are represented in a practically full spectrum.

Keywords: multiple-input multiple-output systems, spatial modulation, constellation, signal detector, fading

I. INTRODUCTION

The high interest in multiple-input multiple-output (MIMO) technologies is due to their use in 5G mobile communication networks and the prospect of their widespread use in 6G (see, for example, [1]-[4]). At the same time, in the process of its implementation, a significant hindering factor is the complexity of the system. There are several ways to overcome this problem. One of them is to use a simplified version of MIMO, the so-called spatial modulation (SM), in which only one of the N_t transmitting antennas is active $(N_a = 1)$, that reduces the complexity of MIMO. Many important results have been obtained in the direction of research on such systems

[5]-[7]. In addition, systems have been proposed for which $N_a = 2$, and they are often called generalized SM systems [8]-[11]. They are somewhat more complex than conventional SM systems, although they have better spectral efficiency. In the mentioned systems, each transmitted information symbol is reflected in the indices of the active transmitting antenna(s) and the modulated signal. Accordingly, in the optimal detection process, it is necessary to determine these indices [6], which is associated with certain difficulties, especially with the identification of the active antenna index [12]. In this case, we consider the use of known simple methods with certain losses in the signal-to-noise ratio (SNR), which significantly depends on the channel conditions.

An alternative approach to this issue is presented in [13], where $N_a = 1$ and the transmitted signal is a four-dimensional constellation (signal system) [14]. In this case, N_t constellations of different types, but with the same M size and distance characteristics, are used, and each of them is defined for a specific, single transmitting antenna. In the future, these constellations will be called partner constellations. Obviously, in this case, the antenna index is determined by the type of constellation, and accordingly, the probability of receiving a transmitted information symbol is determined by the partner constellations. To a first approximation, this probability will be determined by the minimum squared Euclidean distance of each partner constellation (MSEDC) and, at the same time, by the minimum squared Euclidean distance (MSEDP) between the partner constellations. As can be seen from the material presented in [13], the new systems in all cases provide some improvements in SNR compared to the previously known traditional SM systems [6], [15]-[18].

The constellations used in [13] were selected according to the maximum values of MSEDC, and the value of MSEDP was taken experimentally, ensuring the minimum possible error probability.

In this article, using computer simulation, it will be more specifically estimated what the value of MSEDP should be to obtain a system close to the desired one. The estimates will be made for simple systems with widely used parameters in the channels with an additive white Gaussian noise (AWGN) and uncorrelated flat Nakagami-*m* fading [19] .

Unlike the traditional ones, since $N_a < N_t$, hereinafter the new systems will be referred to as concretized MIMO-N_a technologies, therefore, in this article the simplest MIMO-1 system will be considered.

II. SYSTEM MODEL

We will consider a system with two transmitters $(N_t = 2)$ and one receiver $(N_r = 1)$ antennas and the option when $N_a = 1$ (i. e., the MIMO-1 system). This is the simplest system, but the worst in terms of signal reception.

For the signal at the receiver output, we have:

$$z(t) = \mathrm{H} \cdot s(t) + n(t), \tag{1}$$

where $z(t)$ is the signal of duration T_s at the receiver output; $s(t)$ is the signal transmitted from one of the active antennas of the same duration; H is the so-called channel gain matrix:

$$\mathrm{H} = [\ \xi_{11}\ \ \xi_{12}\ ], \tag{2}$$

where ξ_{ij} is a real random number and is the fading amplitude of the signal propagating from transmitter j to receiver i. Its distribution density is given in [19]:

$$f(\xi) = \frac{2}{\Gamma(m)} \cdot \left(\frac{m}{\Omega}\right)^m \cdot \xi^{2m-1} \cdot e^{-m\xi^2/\Omega}, \quad \xi \ge 0, \quad m \ge 0.5, \tag{3}$$

where m defines the fading depth of signal amplitude. If $m = 1$, then we have a Rayleigh process. Ω is the average power of Nakagami-*m* process and in our case, the normalization, $\Omega = 1$, is used.

In formula (1), $n(t)$ is AWGN, with a zero mean and a variance of 1.

III. CONSTELLATIONS USED

In the computer simulation, binary phase-phase-shift keying signals are used as $s(t)$, in which case four variants of signal pairs, or partner signals, are selected for a pair of transmitting antennas, which differ from each other in the values of MSEDC. This parameter is the same for the constellations included in the pair. In each of them, the signals are shifted from each other by the phase φ value, which determines the value of MSEDC for a particular constellation. In the simulation, the following values of MSEDC were selected: $\mathrm{MSEDC} = 4$, $\mathrm{MSEDC} = 2$, $\mathrm{MSEDC} = 1$, $\mathrm{MSEDC} = 0.5$. In all cases, the energies of elementary signals are normalized by the condition – $E_s = 1$. The pairs of partner signals (constellations) are shown in Fig. 1 with their φ and MSEDC values.

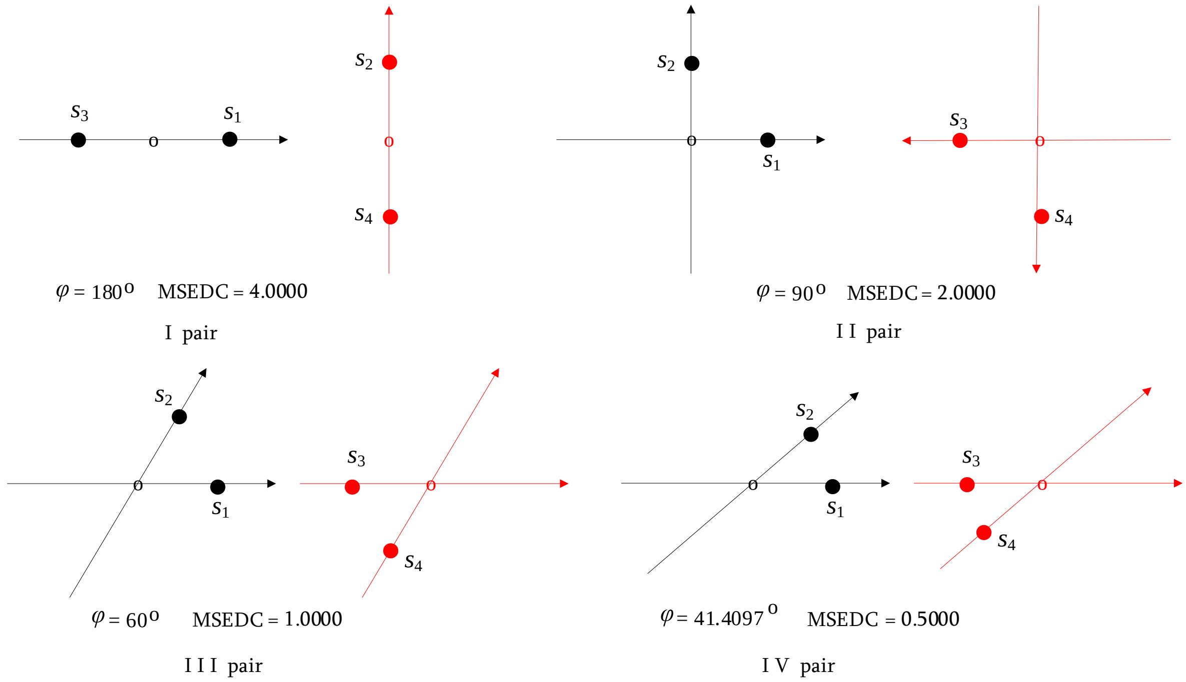

Fig. 1. Pairs of partner constellations used in the simulation

The second and most important parameter, the minimum distance between the constellations in a pair – the value of MSEDP, varies with the change in the value of the phase shift $\Delta\varphi$ (in degrees) between the constellations; all the resulting parameters are given in Table I. The results of the simulations carried out in

TABLE I
DISTANCE PARAMETERS OF PAIR CONSTELLATIONS

I pair		II pair		III pair		IV pair	
$\Delta\varphi$	MDEDP	$\Delta\varphi$	MDEDP	$\Delta\varphi$	MDEDP	$\Delta\varphi$	MDEDP
0.0000	2.0000	0.0000	2.0000				
14.4775	1.5000	14.4775	1.5000				
30.0000	1.0000	30.0000	1.0000	60.0000	1.0000		
48.5903	0.5000	48.5903	0.5000	78.5903	0.5000	97.1806	0.5000
61.0449	0.2500	61.0449	0.2500	91.0449	0.2500	109.6352	0.2500
69.6358	0.1250	69.6358	0.1250	99.6358	0.1250	118.2261	0.1250
75.6384	0.0625	75.6384	0.0625	105.6384	0.0625	124.2287	0.0625

accordance with them are shown in Fig. 2 – Fig. 4. In this case, the signal reception was carried out according to the maximum likelihood principle and using channel state information (CSI) [6].

IV. SIMULATION RESULTS

Simulations, in accordance with the above model, were carried out for the transmitting 10^8 information symbols and the probabilistic parameter of the systems, symbol error rate (SER), was determined accordingly. Three cases of fading were considered: when it is not at all ($m = \infty$, no fading), intermediate, there is fading with a Rayleigh distribution $(m = 1)$ and the deepest, when $m = 0.5$. Estimates are made for the option when the value of SNR is within 13 - 27 dB. Systems with the considered parameters represent practically relatively interesting and useful cases.

In general, the approach to the system is as follows: it is desirable that the condition $\text{MSEDC} = \text{MSEDP}$ be fulfilled and their value be maximum; however, in this study it is assumed that $\text{MSEDP} \le \text{MSEDC}$ and the estimates will be made taking this into account. Below, in Fig. 2, the SER characteristics of the system in the absence of fading are presented, where MSEDC takes the values: MSEDC = 4, 2, 1, 0.5, and $\min(\text{MSEDP}) = 0.0625$. As can be seen from the above characteristics, the influence of MSEDP on the SER characteristics of the system is significant and increases as the SER decreases. In all four cases, within the limits of the change in MSEDP, the maximum SNR degradation is approximately 14.5 dB. The presented case, of course, is for a system with only AWGN, which in practical cases can occur in wireless systems at relatively short time intervals.

Fig. 3 shows the SER characteristics of the system with a fading parameter $m = 1$, which corresponds to the Rayleigh distribution. Here, as in the previous and subsequent cases, MSEDC = 4, 2, 1, 0.5, and $\min(\text{MSEDP}) = 0.0625$. It can be seen from the presented figures that for the given parameters, the maximum SNR degradation is approximately 8 dB and its magnitude has a significant tendency to decrease with increasing SNR and decreasing MSEDC, although the SNR degradation is still significant.

Fig. 4 shows the SER characteristics of the system with a fading parameter $m = 0.5$, which corresponds to the deepest case of fading in the presence of a Nakagami distribution. Here, the maximum SNR degradation varies within relatively small limits and its value is approximately 4.5 dB. The tendency of its value to decrease with increasing SNR, compared to the previous case, can be said to be equal. There is a certain proportion between the values of SNR degradation and, accordingly, the decrease in the given values of MSEDP. From the results of Fig. 3 and Fig. 4, it can be clearly stated that the degree of maximum SNR degradation for the system decreases as fading worsens, when the values of MSEDP decrease compared to the values of MSEDC. It is clear that this point indicates the fact that if CSI is used in detection, increasing the fading depth “helps” us in the process of receiving signals. Regarding the relationship between the influence of MSEDC and MSEDP, the following is evident from the figures: in the MIMO-1 system, the influence of MSEDC on SER is greater than that of MSEDP, and this trend increases with increasing fading depth. Finally, it can be noted that although the presented results may not have a high degree of “generality”, it can still be considered that they can be used in the process of selecting signals (constellations) for wireless systems, especially when, as can be seen from Fig. 2 – Fig. 4, the equal efficiency of wireless systems is ensured for practically the full range of fading depth values.

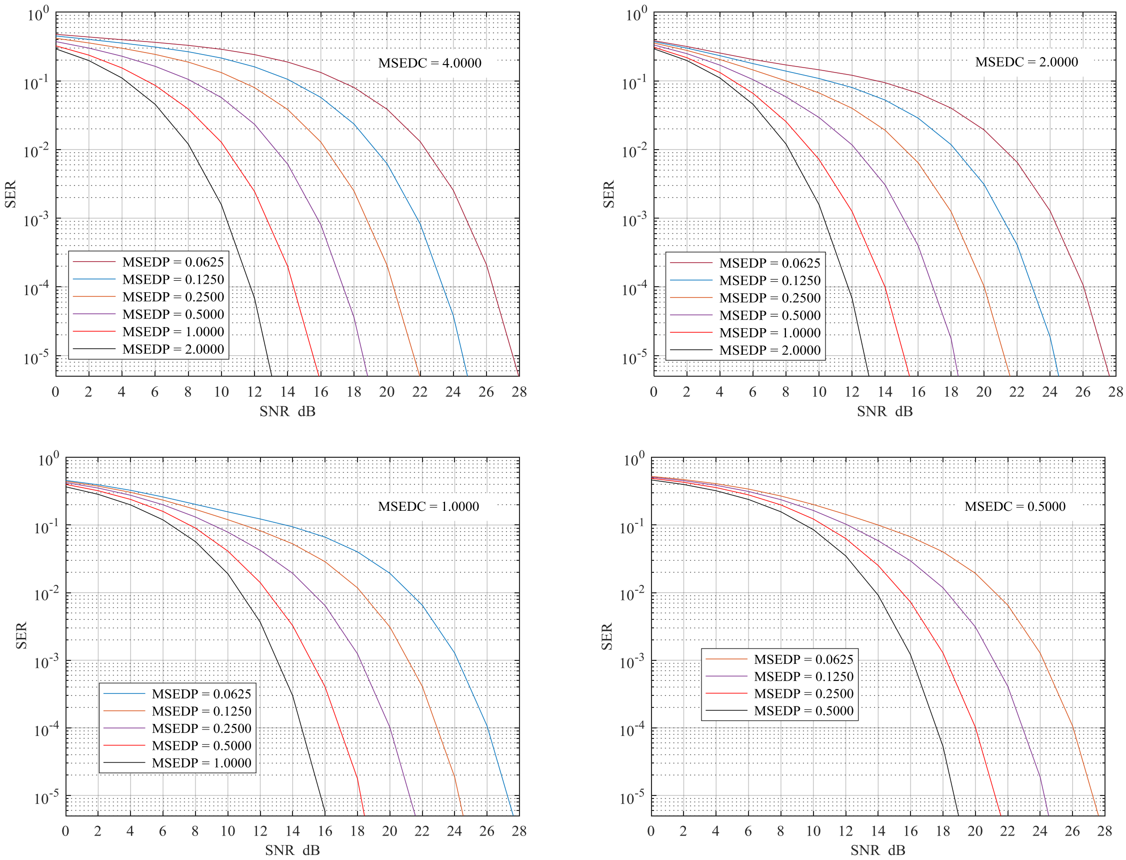

Fig. 2. SER characteristics for MIMO-1 with no fading

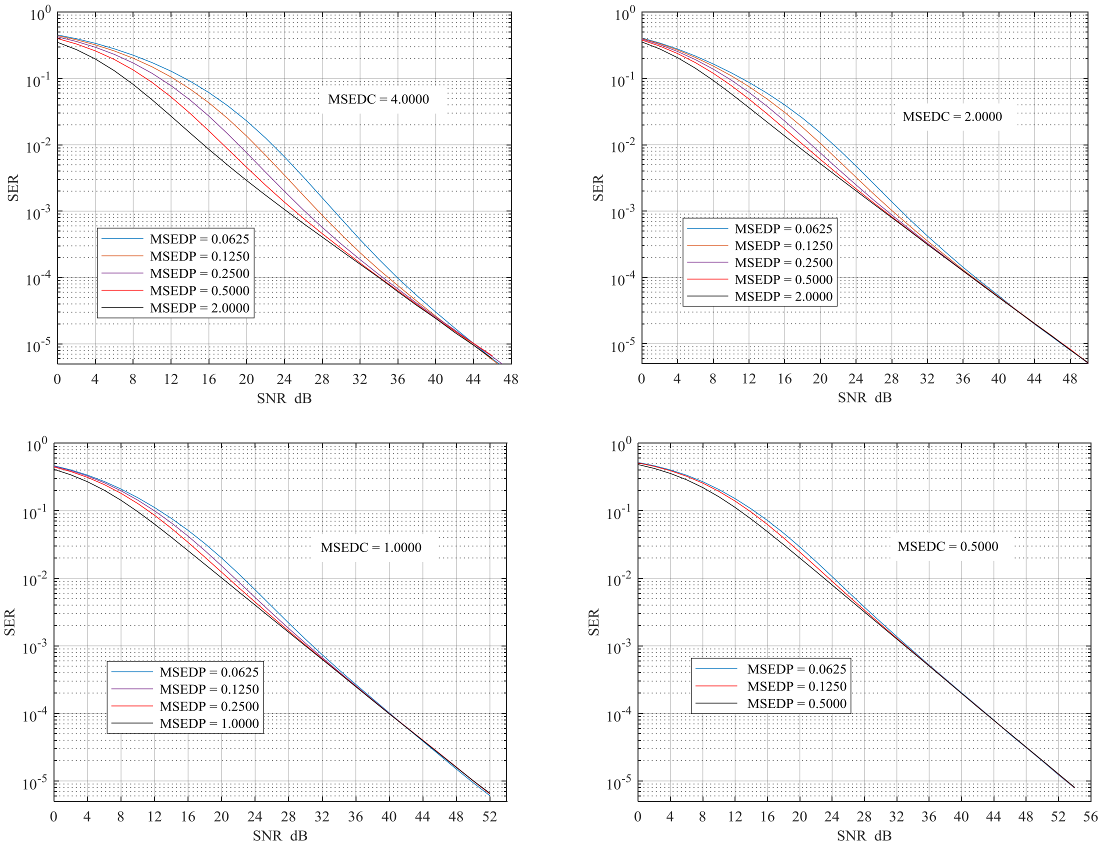

Fig. 3. SER characteristics for MIMO-1 with fading depth $m = 1$

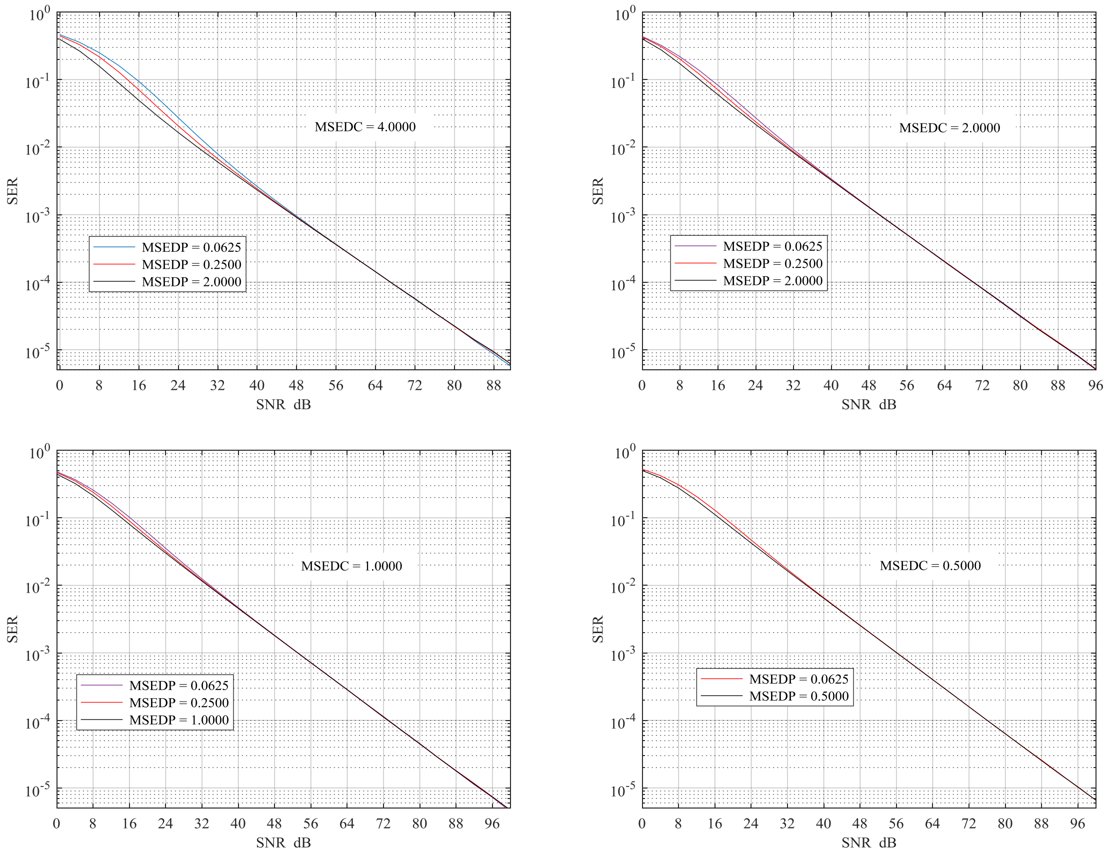

Fig. 4. SER characteristics for MIMO-1 with fading depth $m = 0.5$

According to the results presented in the figures, for guidance, it is possible to select the signal parameters and then the appropriate signals for MIMO-1 systems according to the desired SER and SNR.

V. CONCLUSIONS

The results of computer simulations are presented, which can be used as some estimates in the constellation selection process for a simple MIMO system with one active antenna from several transmitting antennas (the so-called MIMO-1 system). The simulations were conducted for a system that uses the same size, but different types of constellations for different transmitting antennas. In this case, MIMO-1 with two transmitting and one receiving antennas and a pair of binary phase-modulated signals of the same size of different types were considered. The connection channel was represented by AWGN and fading was carried out by the Nakagami distribution, which was due to the fact that it was possible to represent a practically full spectrum of fading depth values.

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