Antenna Selection and STC Coding Technologies Perspectives for MIMO Systems with Large Number of Antennas

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***Abstract*—This report covers joint application of antenna selection and space-time coding technologies in MIMO systems. Antenna selection technology makes possible to reduce the complexity and cost of radio communications equipment, and under certain conditions allows to provide energy gain in such systems. STC technology is also perspective for increasing the efficiency of MIMO technology. The results of computer simulation of the system with joint use of these technologies were presented, and prospects for using these technologies for MIMO systems with a large number of antennas were outlined.**

I. Introduction

At present, the use of Multiple-Input Multiple-Output (MIMO) technology is very popular in data transmission radio communications systems. This technology allows multiple antennas to be used on the transmitting side and receiving side to achieve the best transmission quality and throughput in urban areas. In addition, as the number of antennas increases, the throughput of the communication system increases as well [1], [2].

MIMO technology, however, is not without flaws – when number of antennas increases the cost and complexity of the equipment for the digital processing of the transmitted and received information grows too. The use of antenna selection technology makes possible to reduce the complexity of the equipment while retaining many of the advantages of MIMO technology [3], [4].

The use of Space-Time Coding (STC) technology in MIMO systems is also perspective to increase the efficiency of MIMO technology. There are various matrices of space-time coding proposed in modern standards of radio communication systems (LTE-Advanced, WiMax, 802.11ac, etc.), which allows to provide energy gain in such systems [4], [5]. It is proposed to explore the use of STC technology together with antenna selection technology for MIMO systems with large number of antennas [6].

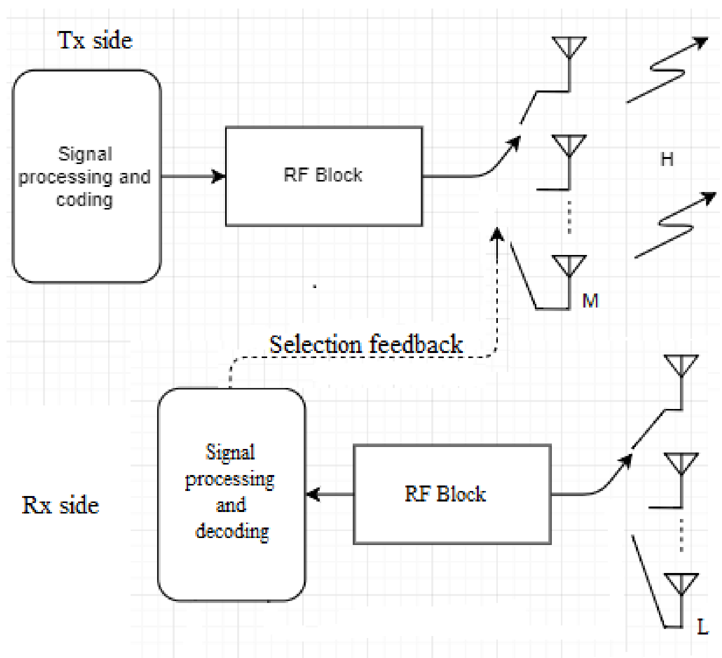

Fig. 1. MIMO system with antenna selection block diagram

II. Technology Description

The technology of antenna selection is of great interest and is constantly evolving [7], [8]. Here we first briefly consider antenna selection technology and its perspectives for radio communication systems and then consider how we can combine it with STC technology. Figure 1 represents simple block diagram of MIMO system with antenna selection technology with M transmitting antennas and L receiving antennas (***H*** denotes radio channel matrix). This system has feedback of the information for antenna selection from the receiving side (selection feedback) [3]. It should be noted, that antenna selection technology can apply at the receiving side too.

The purpose of using antenna selection technology is to increase the efficiency of MIMO systems while reducing the complexity of equipment for digital signal processing and number of RF chains. Antenna selection technology in some MIMO applications not only reduces the RF complexity, but also enhances the security performance [9].

The main idea of antenna selection technology is that not all antennas are used for signal transmission, but only those which are most suitable for particular selection criteria (provide maximum throughput or best signal-to-noise ratio at the receiver input, etc.) [1], [3]. This allows not only to achieve best noise immunity, but also to obtain energy gain due to the fact that only antennas with the best characteristics are used [2].

Figure 2 illustrates the expected gain of antenna selection technology – the dependences of bit error ratio (BER) versus signal-to-noise ratio (SNR). These dependences show noise immunity of MIMO system with antenna selection versus MIMO system without antenna selection. For the case of use of antenna selection technology in MIMO system energy gain is expected.

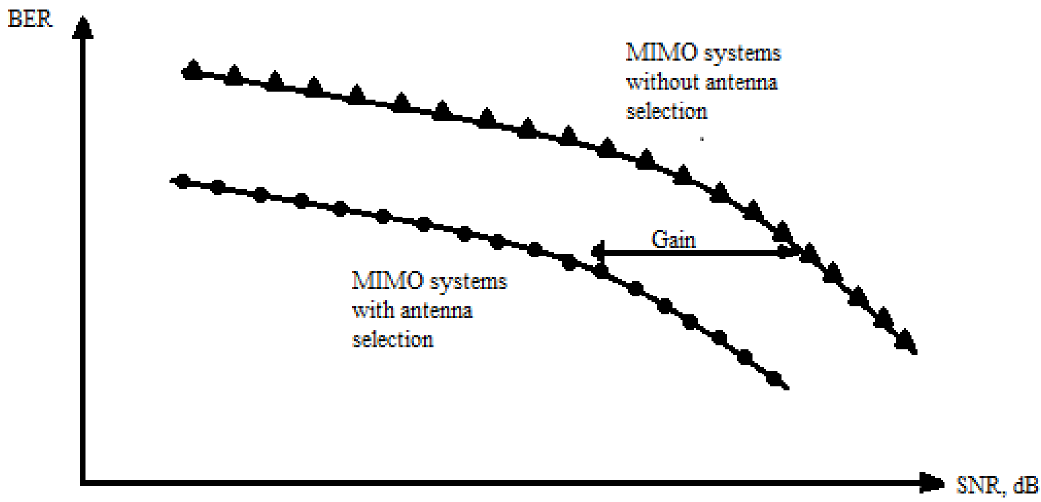

Fig. 2. Expected gain of antenna selection technology

Use of antenna selection technology in MIMO can be described as follows. When the signal is received at the receiving side, the state of the channel is estimated and transmitted using the reverse channel to the transmitting side as a selection feedback. At the transmitting side, on the basis of data received, selection matrix is formed, by which the transmitted signals are multiplied [1], [3], [7]. The mathematical model of the signal at the receiving side can be represented as follows:

$$\boldsymbol{y} = \boldsymbol{HAs} + \mathbf{N} \tag{1}$$

$$\boldsymbol{A} = \begin{pmatrix} a_1 & 0 & \cdots & 0 \\ 0 & a_2 & 0 & 0 \\ \vdots & 0 & \ddots & 0 \\ 0 & 0 & 0 & a_M \end{pmatrix} \tag{2}$$

where **y** – received signals vector of dimension L×1, **s** – vector of transmitted information symbols of dimension M×1, ***H*** – channel matrix (matrix of channel coefficients) of dimension M×L , ***A*** – matrix of antenna selection indexes of M×M dimensions, ***N*** – Gaussian random vector of noise of dimension L×1.

III. Simulation of Radio Communication System with Antenna Selection Technology

To show the noise immunity of MIMO system with antenna selection technology on the transmitting side, let us consider a model with two transmitting antennas and one receiving antenna. As signal quality criteria for determining by which antenna the signal should be transmitted complex coefficients of the channel matrix can be used. After complex coefficients comparison, the antennas transmitting signals with highest SNR will be selected. The results for comparison of noise immunity curve for the case of antenna selection versus the curve for the system with similar configuration without antenna selection, were obtained using computer simulation (Figure 3).

In addition, required number of experiments based on simulation accuracy was estimated. The accuracy of the results obtained in the process of statistical modeling using the example of measuring the probability of an error in obtaining information can be assessed using the well-known Chebyshev inequality:

$$L \geq \frac{1}{4\Delta_p (1-P)} \tag{3}$$

where L – required number of experiments, $\Delta_p = P_{err}^{true} - P_{err}^{est}$ – maximum difference between true value P_{err}^{true} of bit error probability and its estimation P_{err}^{est}, P – probability of inequality $\Delta_p \geq \left| P_{err}^{true} - P_{err}^{est} \right|$.

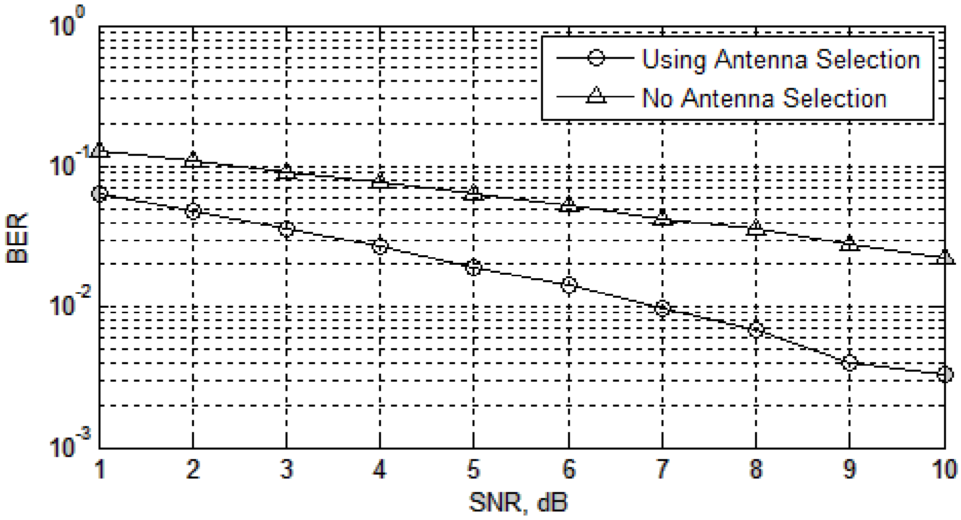

Fig. 3. BER performance curves for MIMO system with configuration 2x1

It can be seen from the Figure 3 that use of antenna selection technology provides significantly better immunity characteristics compared to the system not using this technology. The simulation was carried out in MATLAB for MISO system with 2 transmitting antennas and 1 receiving antenna with a number of experiment equal to 10,000. Algorithm and criteria for antenna selection in this case is described in next section. This number of experiments according to (3) provides level of accuracy equal to 0.0005 for P=0.95. Similarly, antenna selection technology can be applied for systems with a large number of antennas, but to achieve good results, a more careful defining of criteria for antenna selection is required [6].

Next, we illustrate the effectiveness of antenna selection technology using the example of a MIMO system with a large number of antennas in combination with the space-time coding technology (STC) [2].

IV. Joint use of antenna selection technology and STC technology in MIMO systems

First, let us return to the case of a MIMO system with 2 transmitting antennas and 1 receiving antenna. The model of such system when using Alamouti space-time code has the following form [2]:

$$\begin{bmatrix} y_1 & y_2 \end{bmatrix} = \begin{bmatrix} h_1 & h_2 \end{bmatrix} \begin{bmatrix} \tilde{a}_1 & 0 \\ 0 & \tilde{a}_2 \end{bmatrix} \begin{bmatrix} s1 & -s_2{}' \\ s1 & s_1{}' \end{bmatrix} + \begin{bmatrix} n_1 & n_2 \end{bmatrix} \tag{4}$$

where y_1 and y_2 – signals at the input of the receiving antenna, a_1 and a_2 – coefficients for which the normalization condition $|\tilde{a}_1|^2 + |\tilde{a}_2|^2 = 1$ is satisfied.

The model can be written in the equivalent form:

$$\begin{bmatrix} y_1 \\ y_2{}' \end{bmatrix} = \begin{bmatrix} (h_1, \tilde{a}_1) & (h_2, \tilde{a}_2) \\ (h_2, \tilde{a}_2)' & -(h_1, \tilde{a}_1)' \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2{}' \end{bmatrix} \tag{5}$$

In accordance with the antenna selection algorithm you need to select one of the transmit antennas for which the magnitude of the transmission coefficient is greater. Antennas are selected in model (4) using the coefficients $\tilde{a}_1$ and $\tilde{a}_2$, and in model (1) – using matrix **A** of coefficients. Transmission factors should be known at the receiving side, and the number of the selected antenna is transmitted by feedback channel. Thus, for the case of M = 2, L = 1, we have

$$\begin{bmatrix} y_1 \\ y_2{}' \end{bmatrix} = \begin{bmatrix} (h_1, \tilde{a}_1) & (h_2, \tilde{a}_2) \\ (h_2, \tilde{a}_2)' & -(h_1, \tilde{a}_1)' \end{bmatrix}; s = \begin{bmatrix} s_1 & s_2 \end{bmatrix}^T \tag{6}$$

Now consider the case of a MIMO system with M = 4, L = 2 antennas, when we need to select 2 antennas out of 4 at the transmitting side, in which the Double Alamouti scheme is used for coding in space and time. We can do the same by breaking this case into cases when one antenna is chosen from the two. Antenna selection is performed by multiplying by the coefficients $\tilde{a}_1$, $\tilde{a}_2$, $\tilde{a}_3$ and $\tilde{a}_4$. So we get the following:

$$\boldsymbol{H} = \begin{bmatrix} \boldsymbol{H}_{11} & \boldsymbol{H}_{12} \\ \boldsymbol{H}_{21} & \boldsymbol{H}_{22} \end{bmatrix}; \boldsymbol{s} = \begin{bmatrix} s_1 & s_2 & s_3 & s_4 \end{bmatrix}^T \quad (7)$$

$$H_{11} = \begin{bmatrix} (h_{11}, \tilde{a}_1) & (h_{12}, \tilde{a}_2) \\ (h_{12}, \tilde{a}_2)' & -(h_{11}, \tilde{a}_1)' \end{bmatrix}$$

$$H_{12} = \begin{bmatrix} (h_{13}, \tilde{a}_3) & (h_{14}, \tilde{a}_4) \\ (h_{14}, \tilde{a}_4)' & -(h_{13}, \tilde{a}_3)' \end{bmatrix}$$

$$H_{13} = \begin{bmatrix} (h_{21}, \tilde{a}_1) & (h_{22}, \tilde{a}_2) \\ (h_{22}, \tilde{a}_2)' & -(h_{21}, \tilde{a}_1)' \end{bmatrix}$$

$$H_{14} = \begin{bmatrix} (h_{23}, \tilde{a}_3) & (h_{24}, \tilde{a}_4) \\ (h_{24}, \tilde{a}_4)' & -(h_{23}, \tilde{a}_3)' \end{bmatrix}.$$

To test the effectiveness of the proposed algorithm of antenna selection computer simulation was carried out (in MATLAB system) for the case of quadrature phase modulation (QPSK). From Figure 4 it can be seen that 1–1.5 dB energy gain can be obtained for MIMO system with STC.

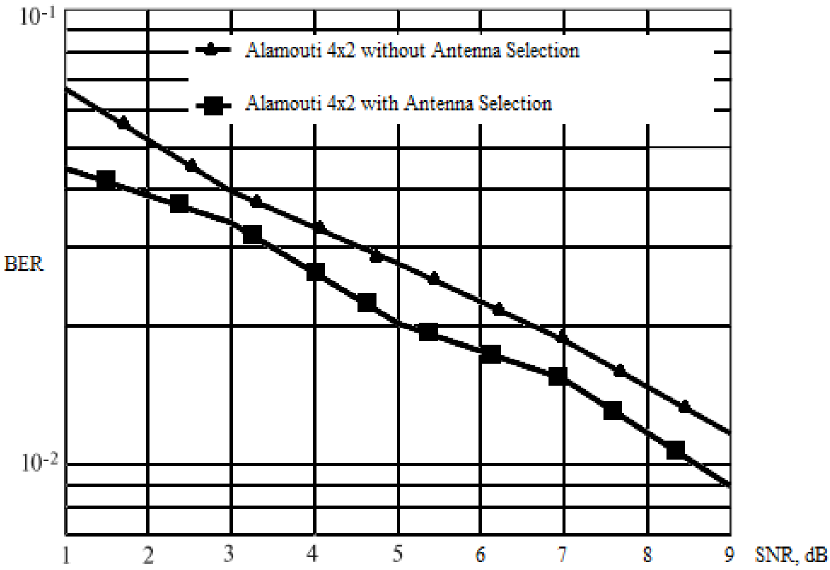

Fig. 4. BER performance curves for MIMO system with joint use of STC and antenna selection technologies

V. CONCLUSION

Antenna selection technology makes possible to reduce the complexity and cost of radio communications equipment, and, under certain conditions, allows one to gain an energy gain. There are several areas of research in this area [2], [7]:

- joint selection of antennas on the transmitting and receiving side,
- selection of antennas with an inaccurately known channel matrix,
- combination of antenna selection with STC technology.

Information about the radio channel is estimated at the receiving side and sent to the transmitting side via the feedback channel, which is a separate area of research. In this case, the high bandwidth of the feedback channel is not required, since not all the information about the transmission coefficients is transmitted, but only some of the coefficients that are calculated on the receiving side. These parameters are used for the redistribution of power between transmitting antennas, so that the energy gain is achieved with minimal complication of the radio communication system. Energy gain is expected to be provided for MIMO systems with a large number of antennas [6], [8], but this will require additional research of selection criteria to apply antenna selection technology with minimal equipment complexity increase.

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