SERBIAN JOURNAL OF ELECTRICAL ENGINEERING
Vol. 14, No. 3, October 2017, 301-312

UDC: 004.421.6:621.396.67 **DOI: https://doi.org/10.2298/SJEE1703301F**

Adaptive Algorithm Based on Antenna Arrays for Radio Communication Systems

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Abstract: Trends in the modern world increasingly lead to the growing popularity of wireless technologies. This is possible due to the rapid development of mobile communications, the Internet gaining high popularity, using wireless networks at enterprises, offices, buildings, etc. It requires advanced network technologies with high throughput capacity to meet the needs of users. To date, a popular destination is the development of spatial signal processing techniques allowing to increase spatial bandwidth of communication channels. The most popular method is spatial coding MIMO to increase data transmission speed which is carried out due to several spatial streams emitted by several antennas. Another advantage of this technology is the bandwidth increase to be achieved without expanding the specified frequency range. Spatial coding methods are even more attractive due to a limited frequency resource. Currently, there is an increasing use of wireless communications (for example, WiFi and WiMAX) in information transmission networks. One of the main problems of evolving wireless systems is the need to increase bandwidth and improve the quality of service (reducing the error probability). Bandwidth can be increased by expanding the bandwidth or increasing the radiated power. Nevertheless, the application of these methods has some drawbacks, due to the requirements of biological protection and electromagnetic compatibility, the increase of power and the expansion of the frequency band is limited. This problem is especially relevant in mobile (cellular) communication systems and wireless networks operating in difficult signal propagation conditions. One of the most effective ways to solve this problem is to use adaptive antenna arrays with weakly correlated antenna elements. Communication systems using such antennas are called MIMO systems (Multiple Input Multiple Output multiple input - multiple outputs). At the moment, existing MIMO-idea implementations do not always noticeably accelerate traffic at short distances from the access point, but, they are very effective at long distances. The MIMO principle allows reducing the number of errors in radio data interchange (BER) without reducing the transmission rate under conditions of multiple signal re-reflections. The work aims at developing an adaptive space-time signal algorithm for a wireless data transmission system designed to improve the efficiency of this system, as well as to study the efficiency of the algorithm to minimizing the error bit probability and maximizing the channel capacity.

Keywords: MIMO, OFDM, Channel, Adaptation, Channel capacity.

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1 Introduction

Since the frequency resource is limited and has a restriction in application in various areas, for example, in mobile communications, wireless local area networks (Wi-Fi). Also, frequency range allocated for local networks, many different devices can be sources of interference for other devices. Also, the reflection of a useful signal from local objects can be perceived as a hindrance. This leads to the necessity of developing adaptive algorithms to suppress interference sources improving the quality of data transmission.

Adaptive algorithms can be applied in various fields. Sources of interference can be of different nature. For example, it could be a source of deliberate interference to a communication link failure or a source of industrial interference from equipment at factories, etc. Another example is useful components of the interfering signal reach the receiving point after multiple reflections of surrounding objects. These algorithms can be used in communication devices with the base station and a plurality of mobile stations. In this case, the mobile devices share a single propagation medium and one frequency resource, wherein a mobile device of the base station is an active interference to the other device. In this case, the task of the base station is the formation of a corresponding radiation pattern. For this kind of tasks, MIMO technology is also applied and it is called Multi-User MIMO [1].

The use of spatial coding and antenna arrays (AA) on both sides of the communication system is a promising solution that will significantly increase spectral efficiency of the allocated frequency resource. Multipath dispersion except negative impact can be used for data transmission between the transmitter and the receiver, having no straight path.

Methods based on multiplexing transmission of signals using multiple antennas, across space. They can be separated by spatial separation (SDM) or being a form of multiple space division of multiple access (SDMA). These methods can simultaneously transmit different signals to different, transmitting antennas, with the same carrier frequency. These parallel data streams interfere free space but can be reconstructed at the receiver by means of using spatial signal processing algorithms, which usually require antenna arrays to receive, and guarantee adequate efficiency concerning the error rate. The difference between SDM and SDMA is that the latter allows different users to transmit simultaneously to each single antenna, whereas in a spatial division a user transmits simultaneously to multiple antennas. Hybrid schemes may also be proposed. MIMO systems are currently popular due to the lack of frequency resource, and according to the MIMO method, it is possible to increase throughput without spreading the signal spectrum. At the same time, the throughput is increased due to the simultaneous transmission of various data streams through various antenna array elements (AA), and the signals emitted by each of the antenna array elements occupying a single frequency band.

Using MIMO with other popular technologies and modulation methods (OFDM, CDMA, COFDM, etc.) it is possible to increase spectral efficiency significantly, to reduce the bit error and increase the bandwidth. WLAN standards to focus on, are based on IEEE 802.11a [2] and IEEE 802.11g [3]. The main reason of choosing OFDM technology is the basis of these standards its noise immunity to the fading channel. Since OFDM allows to reduce, and in some cases eliminate the effect of fading effect on the signal its application is popular in digital television systems [4]. In essence, the broadband channel having frequency selective fading is divided into a plurality of orthogonal frequency narrow channels with shallow fading (i.e., sub-channels or subcarriers) from which it can be aligned trivially [5, 6]. This principle is combined with coding, providing the communication system with stability of narrowband interference. In addition, it includes the ability to add a proper guard interval between neighboring OFDM symbols to provide an effective mechanism dealing with Inter-Character Interference (ISI) caused by unfavorable multithreaded propagation.

Signals with OFDM are widely used in transmission channels with inter-symbol interference caused by object reflections. The degree of interfering action of inter-symbol interference and the probability of error reception depends on the degree of overlapping of transmitted information symbols. Therefore, to improve the reception quality of signals under such conditions, it is advisable to increase the duration of the symbol T. This can be done by reducing the information transmission rate, which is not always acceptable.

The task of increasing the capacity, as described above, is supposed to be used in MIMO technology for data transmission. This is possible due to the ability to separate various spatial streams from multiple transmit antennas, leading to data rate increase, which depends on the number of antennas of the transmitter. Also, for the cases with many reflecting environment objects, any undesirable stream can be minimized or even annihilated in the receiver, and the stream from the antenna is allocated to the maximum. This separation between the antennas proves the stability of MIMO systems in a medium with a large number of signal propagation paths.

To improve the efficiency of such systems, it is necessary to develop an adaptive algorithm of processing spatio-temporal signals based on antenna arrays, the essence is consisted in continuous formation of an equivalent radiation pattern providing interference suppression on the receiving side [7]. This approach will reduce a possible error in wireless data transmission and send the signal along the path with the greatest power.

2 The Proposed Method

Ideally, if the data rate of MIMO systems grow linearly with the number of transmitter antennas [8]. However, the maximum transmission rate in a given frequency band that can be used in MIMO systems depends on some parameters observed at the receiver, including the average received power of the useful signal, the thermal noise and the noise associated with the system, as well as interference from adjacent channels. Also, the multidimensional statistical mode of the MIMO fading channel is of great significance for the system operation (for example, the effect of spatial fading correlation). Therefore, it is important for the designer of MIMO communication system to have an appropriate MIMO channel modeling design The data of MIMO channel statistics state that radio signals and system parameters will propagate (such as antenna spacing, polarization, antenna element orientation). In a real radio propagation environment, a useful signal can enter the receiving antenna in several ways with different delay, phase and power. This leads to interference of the received signal with its copies, and as a consequence it leads to the distortion of the transmitted information. In this regard, the presence of a mathematical model of a spatial channel is necessary for the possibility of modeling communication systems that are close to the real conditions of radio signals propagation. Many various models differ in implementation complexity. The difficulty consists in a number of parameters of real environment to be taken into account in a particular model. Although the implementation of various models is different, but the result remains the same, it is to obtain the frequency and time characteristics of the channel in the form of impulse response and amplitude-frequency. The impulse response reflects all the paths of a signal arrival with delays and fading, and the frequency features characterizing the channel fading

From the various studies of the channel [9, 10] and many other data given in the literature, it is supposed that the average multi-path power of the transmitted pulse in the environment tends is decreased exponentially for a long period. Also, in general, the amplitudes of the channel coefficient counts are Rayleigh distributions. In this case the communication channel has a Direct Visibility (LOS) or a mirror component, as it can be assumed that the first path is distributed according to Rayleigh-Rice. These features are associated with such characteristics as:

- slow movement of objects and/or transceivers, leading to a slight Doppler shift;
- (in the case of LOS) a component that enters the antenna array completely thus determining from the antenna to the antenna, from the packet to the main packet;
- a large number of reflectors within a usual similar internal environment (leading to the Rayleigh fading);
- a feature of propagation loss, where the longer propagation paths of arriving linearly are later, the energy attenuation is greater.

The simplest is the Rayleigh and Rice channel models. These models allow to imagine an appropriate picture of the signal propagation in a fading channel [11 – 13]. Reflection from objects leads to the appearance of delayed versions of the signal in the receiver, the radio signal is subjected to scattering and attenuation. All these components are combined in the receiver to cause a phenomenon known as fading. Because of this phenomenon, each path acts as a discrete fading path. Typically, the attenuation process is characterized by a Rayleigh distribution if there is no direct visibility between the base station, the mobile station and the Rice distribution of the case with direct visibility between the transmitter and the receiver. There are also complex models, for example based on the 3GPP standard, used in mobile communication systems. This model of the MIMO channel, proposed by the 3GPP consortium (3rd Generation Partnership Project) [14], developed for third-generation mobile communication.

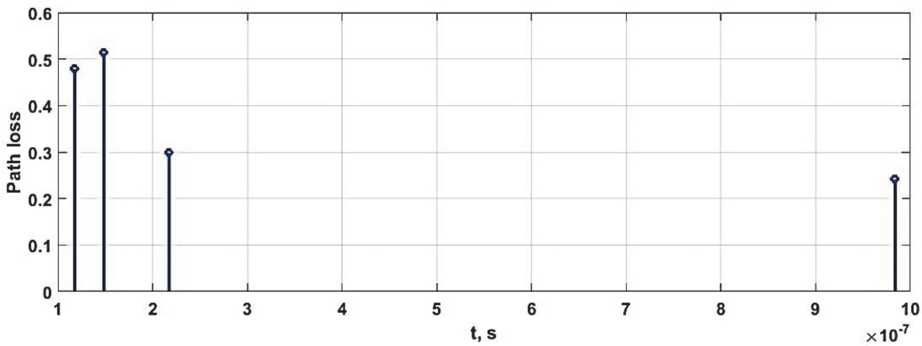

Fig. 1 – *Pulse characteristic of 3GPP data transmission channel.*

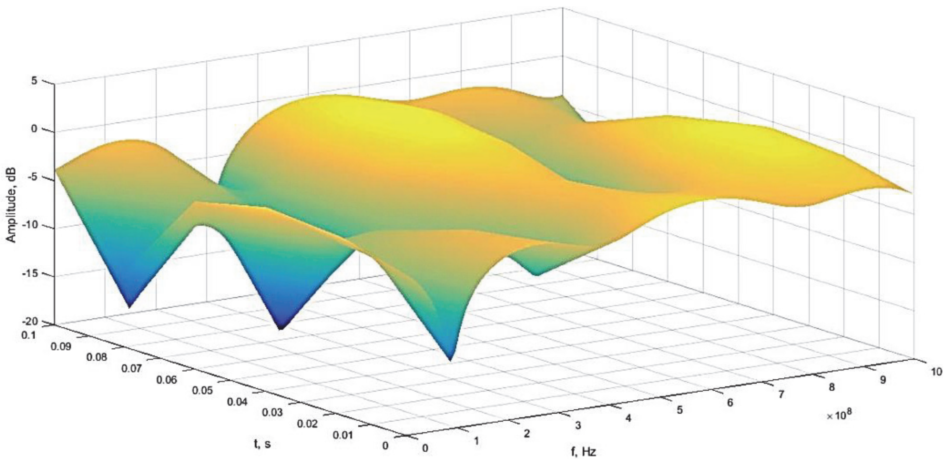

Fig. 2 – *Frequency response of 3GPP data transmission channel.*

And it is a mathematical model of a wireless distribution channel for different scenarios. Figs. 1 and 2 show the impulse and frequency characteristics for such model, respectively.

3 Mathematical Model

Multipath propagation of signals is a problem that can cause fading in communication channel, which is known as a negative factor affecting the quality of radio communication [9, 12]. Nevertheless, the analysis of the results of studies conducted by world scientists shows that the multipath for MIMO-based communication systems may be a favorable factor for wireless communications in some cases. This is due to the absence of sight line between the transmitter, and the receiver while data transmission is carried out by the signal transmission reflected from local objects, for example from buildings. Also using several independent spatial streams, it is possible to increase the throughput of simultaneously transmitting data by using several antennas. At the receiver, the received data symbols are being extracted using various space-time decoding techniques. To ensure effective separation of different data streams, AA elements should be spaced apart by a sufficient distance (usually more than half the carrier wavelength) in order to prevent spatial correlation between the received signals from different antennas. Fig. 3 illustrates the MIMO system.

The figure shows the example when a MIMO system is used for the case with two transmitting antennas, and two receivers. It can be seen from the figure that the receiving antenna gets a mixture of signals from all antennas and the task of the receiver is to separate these signals based on the channel state information.

During the transmission of information on the communication channel from the base station to the mobile station, the characteristics of the channel, and as a consequence, the signal parameters can vary due to the following factors: 1) the presence of the receiver moving relatively to the transmitter, 2) the path of the received signals, 3) the environment (weather conditions, availability of jamming sources).

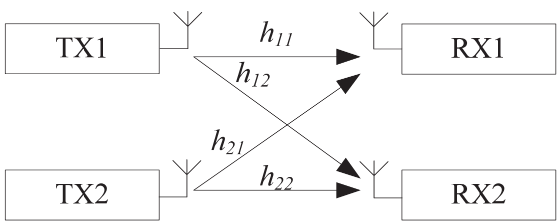

Fig. 3 – *MIMO-system.*

The effect of propagation channel on signal propagation can be characterized by the transfer characteristic

$$\boldsymbol{H}(t,\tau)=\begin{bmatrix} h_{11}(t,\tau) & h_{12}(t,\tau) & h_{13}(t,\tau) & \dots & h_{1N_t}(t,\tau) \\ h_{21}(t,\tau) & h_{22}(t,\tau) & h_{21}(t,\tau) & \dots & h_{2N_t}(t,\tau) \\ h_{31}(t,\tau) & h_{32}(t,\tau) & h_{33}(t,\tau) & \dots & h_{3N_t}(t,\tau) \\ . & . & . & \dots & . \\ h_{N_r1}(t,\tau) & h_{N_r2}(t,\tau) & h_{N_r3}(t,\tau) & \dots & h_{N_rN_t}(t,\tau) \end{bmatrix}. \qquad (1)$$

The lines in formula (1) are the transmission factors from all the transmitting antennas to one of the receivers. The columns show the transmission factors from one of the transmit antennas to all receivers.

In the MIMO system, the received signal can be described as the following expression

$$\boldsymbol{y}=\boldsymbol{Hx}+\boldsymbol{n}\,, \qquad (2)$$

where $\boldsymbol{H}$ is the channel transmission matrix; $\boldsymbol{y}$ is NR×1 is the vector of the received signal; $\boldsymbol{x}$ is NT×1 is the vector of the transmitted signal; $\boldsymbol{n}$ is NR×1 receiver noise vector.

The formulas (1) and (2) ensure the matrix form of the received signal formulas

$$\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_{N_R} \end{bmatrix}=\begin{bmatrix} h_{11} & h_{12} & \cdots & h_{1N_T} \\ h_{21} & h_{22} & & h_{2N_T} \\ \vdots & & \ddots & \vdots \\ h_{N_R1} & h_{N_R2} & \cdots & h_{N_RN_T} \end{bmatrix}\begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_{N_T} \end{bmatrix}+\begin{bmatrix} n_1 \\ n_2 \\ \vdots \\ n_{N_R} \end{bmatrix}.$$

The above written formulas, determine the main task of estimating the received signal is to estimate the channel matrix.

The task of the adaptive algorithm is to generate a radiation pattern having a maximum in the direction of arriving useful signal, and the direction of the interference, a minimum or zero.

Antenna array (AA) receives the signal mixture with interference. With the help of a constant weight vector v, after the elements of the AP, the formation of spaced DLs takes place. Then, the received signals are weighted, by means of the coefficients w, adjusted with the help of an adaptive processor, so that the source of interference is suppressed. After adaptation, there is a space-time treatment.

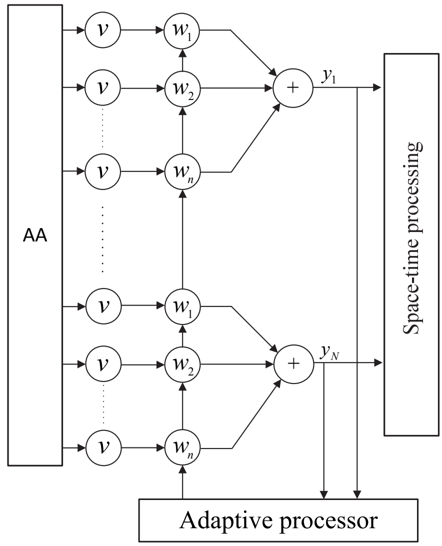

Fig. 4 – *Block diagram of the receiving antenna system and adaptation unit.*

Let's consider how the calculation of the weight coefficients in the adaptive processor is performed in the process of signal reception. To do this it is necessary to calculate the eigenvalues and eigenvectors of the spatial correlation matrix

$$\boldsymbol{R} = E\{\boldsymbol{X}^*(i)\boldsymbol{X}^T(i)\} = \frac{1}{n}\sum_{i=1}^{n}\boldsymbol{X}^*(i)\boldsymbol{X}^T(i),$$

where $\boldsymbol{X}$ is the vector of the received signal; E{·} is the operation of averaging the results; * – is the Complex conjugation operation; $\boldsymbol{X}^T$ – is the transposition of the vector $\boldsymbol{X}$.

In the matrix form, the spatial correlation matrix has the following form

$$\boldsymbol{R} = \begin{pmatrix} \frac{1}{n}\sum x_1^2 & \frac{1}{n}\sum x_1 x_2 & \frac{1}{n}\sum x_1 x_n \\ \frac{1}{n}\sum x_2 x_1 & \frac{1}{n}\sum x_2^2 & \frac{1}{n}\sum x_2 x_n \\ \frac{1}{n}\sum x_3 x_n & \frac{1}{n}\sum x_3 x_2 & \frac{1}{n}\sum x_n^2 \end{pmatrix}.$$

To find the optimal weight vectors for the computed spatial correlation matrix, the approach based on finding the eigenvalues of the matrix $\boldsymbol{R}$(2) is applied. This method is widely used to suppress interference and isolate signals in communication systems using antenna arrays. According to the considered approach, the optimal weight vector is an eigenvector corresponding to the largest eigenvalue of the correlation matrix $\boldsymbol{R}$. Thus, the expansion of the correlation matrix has the following form:

$$\boldsymbol{R} = \boldsymbol{V}\boldsymbol{\Lambda}\boldsymbol{V}^H, \quad (3)$$

where $\boldsymbol{V}$ is the unitary matrix of eigenvectors and $\boldsymbol{\Lambda}$ is the diagonal matrix of the corresponding eigenvalues.

The matrix of eigenvalues has the following form

$$\boldsymbol{\Lambda} = \begin{pmatrix} \lambda_1 & 0 & \cdots & 0 \\ 0 & 0 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \lambda_n \end{pmatrix},$$

where λ denotes the value of the eigenvalues of the spatial correlation matrix.

The matrix of eigenvectors is

$$\boldsymbol{V} = \begin{pmatrix} v_{11} & v_{21} & v_{n1} \\ v_{12} & v_{22} & v_{n2} \\ v_{1n} & v_{2n} & v_{nn} \end{pmatrix},$$

where $\boldsymbol{V}$ is an eigenvector of the matrix $\boldsymbol{R}$.

$$\boldsymbol{X}_W = \boldsymbol{X}^H \boldsymbol{W}_{onm}.$$

As a result, at the output of the adaptive processing unit, we get only a useful signal, free from interference.

3 Experimental Results

As a result of performing the entire procedure of adaptive signal processing, an array must be formed in the receiver, which a decoded information sequence of bits is transmitted through the communication channel. The program implements the method of vertical spatial multiplexing. For testing, the probability of an erroneous signal reception is calculated.

The SNR is a variable, and, there is an error probability for each specific value. Counting the errors number is carried out for the given SNR, comparing the transmitted and received vector of the parcels. In this case, experiment average takes place. Thus, it is possible to obtain the dependence of the error reception probability on the value of a certain parameter. Initial data contains: the number of receiving and transmitting elements, the channel matrix at each time, the vector of radiated parcels.

To evaluate the effectiveness of the developed algorithm, it is necessary to conduct a number of the following studies:

1. Determine the probability of bit error occurrence from the input SNR for a different number of elements in each of the receiving antenna blocks.
2. Estimate the average throughput through the channel, depending on the specified SNR for different signal processing cases.

To obtain the correct dependencies of error from SNR, it is necessary to use averaging over a large number of channel implementations, since most of the parameters of the channel model are randomly assigned, and it is impossible to predict channel behavior from case to case.

The initial data is obtained using the existing SCM spatial channel model, adapted to the task.

Let us analyze the dependence of the bit error probability on the signal-to-noise ratio after applying the adaptive algorithm for various types of digital modulation in the MIMO communication system. Analyzing the probability of a bit error before the adaptation algorithm has no sense since the interference power exceeds the power of the useful signal greatly. As a result, the useful signal is destroyed. Fig. 8 shows the dependence of the probability of an error in the transmitted digital stream on the signal-to-noise ratio in dB.

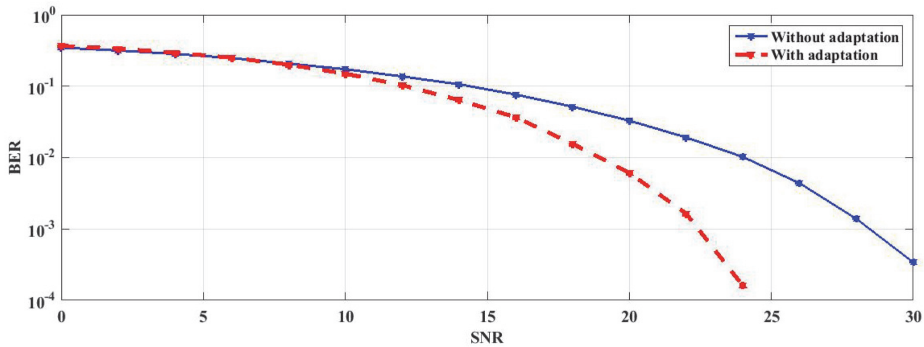

Fig. 8 – *The probability of a bit error depending on the given SNR.*

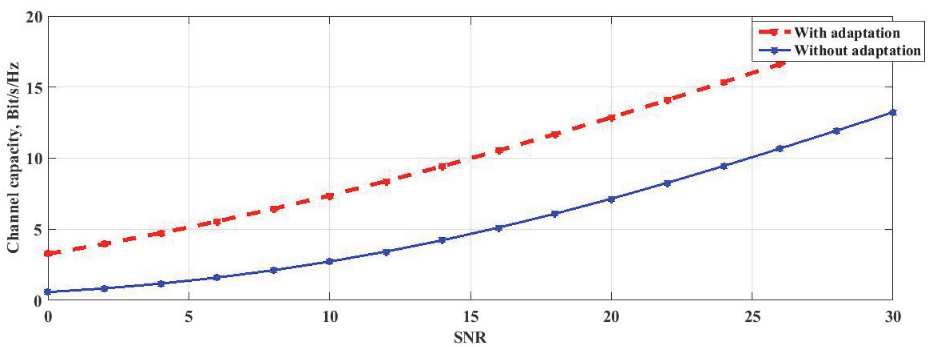

Fig. 9 – *The capacity of the data channel depending on the specified SNR.*

From Figs. 8 and 9 one can judge about the effectiveness of the developed adaptive algorithm. In all cases, the advantage of using adaptation on the receiving side is evident.

4 Conclusion

The article presents a synthesized adaptive algorithm for spatial filtering of signals for a multi-path channel, using output signals from the outputs of the receiving antenna array to eliminate interference sources leading to disruption of the communication system. The algorithm is based on a linear transformation of the received signal, is based on linear algebra methods for calculating the antenna block weights. A block diagram of the communication system is presented using the developed algorithm.

Despite the fact that the MIMO system itself is capable of evaluating the channel characteristics and attempting to suppress interference components, adaptive beam formation is more efficient, especially when it comes to sources of a high radiation power compared to a useful signal. Using antenna arrays from non-direction elements, it becomes possible to apply modern methods of forming digital radiation pattern to isolate the direction of a useful signal arrival, while all other sources will be suppressed.

5 Acknowledgement

The reported study was supported by the Ministry of Education of the Russian Federation, research projects № 8.5591.2017/8.9.

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