Information systems research

UDC 621.391 doi: 10.20998/2522-9052.2018.4.12

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ANALYSIS OF THE PROPERTIES OF NON-ORTHOGONAL METHODS OF SIGNAL PROCESSING IN MIMO SYSTEMS

Conflicts of the last decades (the Chechen war (Russian Federation), armed confrontation in the countries of the Middle East and North Africa, anti-terrorist operation in the territory of Donetsk and Lugansk regions (Operation of the United Nations)) go beyond the existing (traditional) forms and methods of warfare, conducted on the background of information and psychological operations and the active using of electronic emitters. One of the directions of increasing the noise immunity of radio communication devices is using of multi-antenna radio communication systems. They are complex technical systems. There are many approaches to increasing the impedance of multi-antenna systems, but the authors of this article limited themselves to considering only the methods of signal processing, namely, non-orthogonal spatial-temporal codes. During the research, the authors used the basic provisions of the theory of communication, the theory of antennas, the theory of noise protection and signal-code structures. In the course of the research, it was found that non-orthogonal methods of spatial-temporal signal processing have more spectral efficiency than orthogonal ones, with an equal number of transmitting antennas, but they lose in energy efficiency the orthogonal methods of space-time signal processing. Using of non-orthogonal codes leads to the increasing the number of computational operations in the receiver of the radio communication device. All this results in further research on the development of the spatial-temporal signal coding method in multi-antenna radio-communication systems with high energy and spectral efficiency, and it is necessary, that the proposed method has an acceptable computational complexity.

Keywords: signal-interfering environment; information transfer speed; bit error probability; spatial-temporal processing; MIMO system; parallel channels.

Introduction

Conflicts of the last decades (the Chechen war (Russian Federation), armed confrontation in the countries of the Middle East and North Africa, anti-terrorist operation in the territory of Donetsk and Lugansk regions (Operation of the United Nations)) go beyond the existing (traditional) forms and methods of warfare, conducted on the background of information and psychological operations and the active use of electronic emitters. Therefore, the provision of sustainable communication is one of the priority directions of scientific research. One of the directions to increase the noise immunity of radio communication devices is using of the multi-antenna radio communication systems. MIMO (Multiple Input Multiple Output) technologies have been found to be practical in many modern telecommunication systems, in particular, wireless LANs of the IEEE 802.11n standard, as well as WIMAX and LTE mobile wireless networks, and others [1-5].

The essence of MIMO technology is similar to the method of spaced reception, when several uncorrelated copies of the signal created on the receiving side due to the diversity of antennas in space, in polarization, in the distribution of signals at the frequency or in time. Spatial multiplexing was implemented in MIMO radio systems: the data stream on the transmission was split into two or more sub-streams, each of which was transmitted and received using various antennas [1-6, 10-12].

The transmission of signals in the MIMO system results in inter-symbol interference (ISI) on the receiving side and may cause errors in the receiver output. In order to compensate for these distortions, channel alignment or evaluation of its impulse response must be performed, which will allow the most faithfully recovered symbols.

The authors of this article in the previous research have established [13] that it is most expedient to use non-orthogonal processing methods to increase the frequency effectiveness of multi-antenna systems.

The purpose of this article is to analyze the properties of non-orthogonal methods of signal processing in the MIMO system.

Presentation of main material research

Let's formalize the work of the MIMO system. In general, the structure of the MIMO system has in its composition M_t transmitters (transmit antennas) and M_r receivers (receiving antennas) (Fig. 1). Transmitted signals after the influence of the relay fading and white Gaussian noise (WGN) in the radio channel, arrive at the M_r receiving tracks [1-10].

Consider the MIMO system $M_t \times M_r$, depicted in Fig. 1. High-speed data flow was divided into M_t independent sequences at $1/M_t$, which was then transmitted simultaneously from several antennas, respectively, using only $1/M_t$ of their primary band.

The data flow converter at the transmitter end of the communication line converts the serial stream into parallel, and at the receiving terminal, it performs the inverse transformation.

In such a system, signals on the transmitting side were emitted simultaneously and in the same band of frequencies through the M_t transmit antennas. The transmitted signals, after the effect of the fading of the signal and the additive white Gaussian noise, arrive in the M_r of the receiving paths. Each additive tract receives an additive mixture of transmitted signals.

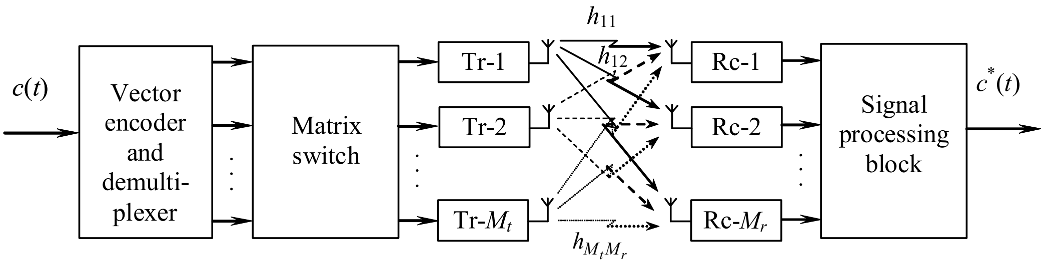

Fig. 1. The block diagram of the MIMO system

You can increase the bandwidth of communication channels by using non-orthogonal spatial-temporal codes.

The symbolic speed with non-orthogonal encoding can reach values corresponding to the number of transmitting antennas M_t, that is K_t, time intervals can be transmitted from a block $L_b = K_t \cdot M$ of information symbols.

This condition corresponds to the coding scheme V-BLAST (Vertical Bell Labs Layered Space Time). For the V-BLAST, the following generating matrix is used

$$(a_i) \quad (1)$$

where a_i - information symbols.

For the WiMax systems with two transmitting antennas of the IEEE 802.16e standard, that is recommended not to orthogonal code, the so-called code “C”, the symbolic speed of which also coincides with the number of transmitting antennas:

$$\frac{1}{\sqrt{1+r^2}} \cdot \begin{vmatrix} \alpha_1 + jr\alpha_4 & r\alpha_2 + \alpha_3 \\ \alpha_2 - r\alpha_3 & jr\alpha_1 + \alpha_4 \end{vmatrix}, \quad (2)$$

where $r = \left(\sqrt{5}-1\right)/2$.

Fig. 2 shows the maximum likelihood demodulation characteristics for systems with 4 transmitting and receiving antennas using the V-BLAST code and the “C” code in the case of QAM-16 (Quadrature Amplitude Modulation).

Code "C" allows better protection of the system than the V-BLAST code. At the same time, the cost of increasing energy efficiency is the complication of the signal processing procedure on the receiving side.

Another example of a non-orthogonal code is the double-code of Alamouti, which generates a matrix, which can be represented as

$$\begin{vmatrix} \alpha_1 & -\alpha_2' \\ \alpha_2 & \alpha_1' \\ \alpha_3 & -\alpha_4' \\ \alpha_4 & \alpha_3 \end{vmatrix}. \quad (3)$$

The specified pair consists of two blocks, each of which is a matrix of Alamouti for two pairs of information symbols α_1, α_2 and α_3, α_4. The specified code is used in systems with 4 transmitting antennas.

Fig. 3 shows the maximum likelihood demodulation characteristics for systems with 4 transmitting and 4 receiving antennas using V-BLAST and the Alamouti dual code while using QAM-16.

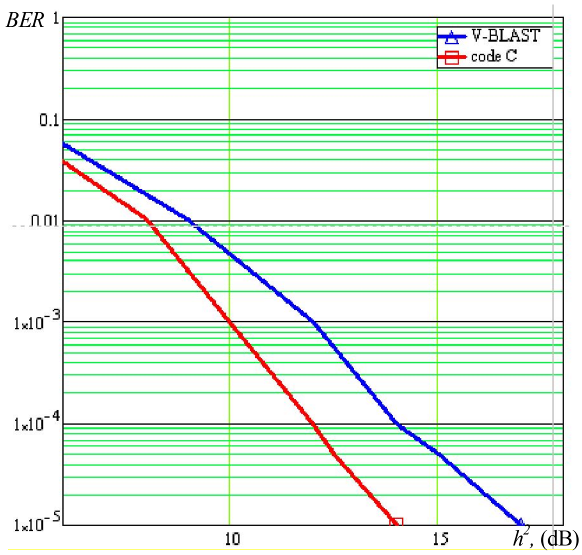

Fig. 2. Dependence on the probability of a bit error from the signal/noise ratio for the BLAST code and the “C”

From the above graph, it can be seen, that demodulation of the code V-BLAST with a symbolic rate of 4 requires a signal-to-noise ratio of more than 5 dB while demodulating the double code of Alamouti. Increasing the spectral efficiency in the MIMO system was achieved by using the spatial-temporal code with a higher symbolic speed for a given number of transmitting and receiving antennas leads to the increase in the energy efficiency of the MIMO system.

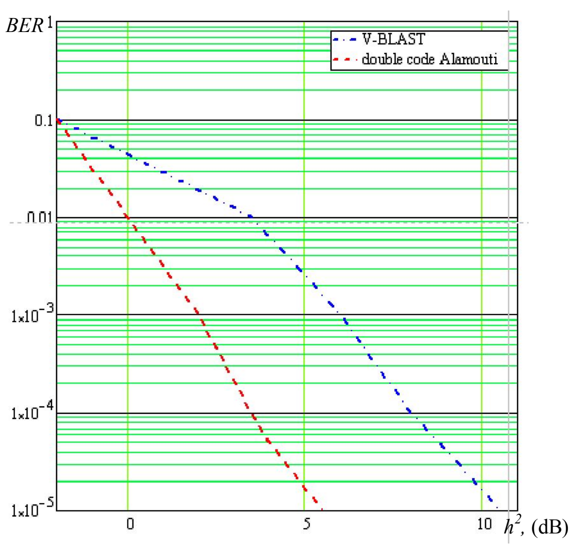

Fig. 3. Dependence on the probability of false reception from the signal/noise ratio for the double code of Alamouti and V-BLAST

In the case of orthogonal spatial-temporal codes, the procedure for calculating the transmitted symbols that are optimal for the criterion of maximum likelihood with linear computational complexity, that is, the number of arithmetic operations is directly proportional to the number of transmit antennas, is implemented on the receiving side. In non-orthogonal coding, the maximum likelihood algorithm is complicated.

In general, the process of demodulation in systems with spatial-temporal coding mathematically reduces to the solution of the equation

$$\mathbf{Z} = \mathbf{HA} + \mathbf{B}, \tag{4}$$

where **Z** is the vector, each component of which z_i, $i = \overline{1,V}$ is the countdown of the complex output at the i-th input of the demodulator STC; **A** is the vector, whose component is a_j, $j = \overline{1,S}$ is a complex information symbol belonging to the set $\{a^{(1)}, \ldots, a^{(K)}\}$ is transmitted, **K** is the multiplicity of quadrature amplitude modulation, QAM (Quadrature Amplitude Modulation); **H** is a matrix, each element of which h_{ij} is a complex transmission coefficient of the path of propagation of the signal emitted by the j -th antenna and taken by the i -th antenna; **B** is a vector, every component of which b_i is counting the complex Gaussian noise at the i-th input of the STC demodulator, having a zero mean and a dispersion of $2\sigma^2$.

However, in the expression (4) is a random component in the form of Gaussian noise, then traditional methods for solving linear equations can lead to errors.

Different methods can be used to compute estimates of transmitted symbols: Zero Forcing, Successive Interference Cancellation (SIC), Maximum Likelihood Method (MLM), and Spherical Method Decoding (SMD) and so on.

Consider the spatial-temporal codes, that is used in the standards of wireless communication.

In IEEE 802.16, IEEE 802.11 standards governing the radio interface for broadband radio access systems, it is recommended to use orthogonal and non-orthogonal spatial-temporal codes.

Tables 1 and 2 show the basic codes of spatial and temporal signal processing for broadband radio access systems.

As it can be seen from tables 1 and 2, most spatial-temporal codes are non-orthogonal.

Table 1 – **IEEE 802.16 spatial-temporal codes**

Formation matrix	Number of antennas	Code speed	Code class
$\begin{vmatrix} \alpha_1 & -\alpha_2' \\ \alpha_2 & \alpha_1' \end{vmatrix}$	2	1	Orthogonal
$\begin{vmatrix} \alpha_1 \\ \alpha_2 \end{vmatrix}$	2	2	Non-orthogonal
$\begin{vmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \end{vmatrix}$	3	3	Non-orthogonal
$\begin{vmatrix} \alpha_1 & -\alpha_2' & 0 & 0 \\ \alpha_2 & \alpha_1' & 0 & 0 \\ 0 & 0 & \alpha_3 & -\alpha_4' \\ 0 & 0 & \alpha_4 & \alpha_3' \end{vmatrix}$	4	1	Orthogonal
$\begin{vmatrix} \alpha_1 & -\alpha_2' & \alpha_5 & -\alpha_7' \\ \alpha_2 & \alpha_1' & \alpha_6 & -\alpha_8' \\ \alpha_3 & -\alpha_4' & \alpha_7 & \alpha_5' \\ \alpha_4 & \alpha_3' & \alpha_8 & \alpha_6' \end{vmatrix}$	4	2	Non-orthogonal
$\begin{vmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \alpha_4 \end{vmatrix}$	4	4	Non-orthogonal

Table 2 – **IEEE 802.11 spatial-temporal codes**

Formation matrix	Number of antennas	Code speed	Code class
$\begin{vmatrix} \alpha_1 & \alpha_2 \\ -\alpha_2' & \alpha_1' \end{vmatrix}$	2	1	Orthogonal
$\begin{vmatrix} \alpha_1 & \alpha_2 \\ -\alpha_2' & \alpha_1' \\ \alpha_3 & \alpha_4 \end{vmatrix}$	3	2	Non-orthogonal
$\begin{vmatrix} \alpha_1 & \alpha_2 \\ -\alpha_2' & \alpha_1' \\ \alpha_3 & \alpha_4 \\ -\alpha_4' & \alpha_3' \end{vmatrix}$	4	2	Non-orthogonal
$\begin{vmatrix} \alpha_1 & \alpha_2 \\ -\alpha_2' & \alpha_1' \\ \alpha_3 & \alpha_4 \\ \alpha_5 & \alpha_6 \end{vmatrix}$	4	3	Non-orthogonal

Conclusions

In this article, the authors analyzed the parameters of non-orthogonal spatial-temporal codes, that are used for signal processing in MIMO systems.

Thus, having conducted a comparative analysis of orthogonal and non-orthogonal codes, it should be noted, that the cost of increasing spectral efficiency in systems with non-orthogonal spatial-temporal coding is the complication of processing procedures on the receiving side, as there is no algorithm that is optimal for the criterion of maximum likelihood and with linear computational complexity.

Since non-orthogonal codes have not always provided sufficient diversity of transmitted signals, this led to the decreasing the energy efficiency of MIMO channels.

Consequently, an urgent scientific problem arises, which was solved in further studies by the authors, which consists of developing spatial-temporal signal processing methods with acceptable computational complexity and high energy and spectral efficiency.

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Received (Надійшла) 14.08.2018
Accepted for publication (Прийнята до друку) 03.10.2018

Аналіз властивостей неортогональних методів обробки сигналів в системах MIMO

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Конфлікти останніх десятиліть (Чеченська війна (Російська Федерація), збройні протистояння в країнах Близького Сходу та Північної Африки, Антитерористична операція на території Донецької та Луганської областей (Операція Об'єднаних Сил)) виходять за рамки існуючих (традиційних) форм та способів ведення бойових дій, проводяться на фоні інформаційно-психологічних операцій та активного використання засобів радіоелектронного подавлення. Одним з напрямків підвищення завадозахищеності засобів радіозв'язку є використання багатоантенних систем радіозв'язку. Вони є складними технічними системами. Існує багато підходів до підвищення завадозахищеності багатоантенних систем, проте автори зазначеної статті обмежилися розглядом лише методів обробки сигналів, а саме не ортогональних просторово-часових кодів. В ході дослідження авторами були використані базові положення теорії зв'язку, теорії антен, теорії завадо-захищеності та сигнально-кодових конструкцій. В ході проведеного дослідження встановлено, що не ортогональні методи просторово-часової обробки сигналів мають більше спектральну ефективність у порівнянні з ортогональними, при рівній кількості передавальних антен, проте вони програють в енергетичній ефективності ортогональним методам просторово-часової обробки сигналів. Використання не ортогональних кодів призводить до збільшення кількості обчислювальних операцій в приймачі засобу радіозв'язку. Все це обумовлює подальше проведення досліджень з розробки методу просторово-часового кодування сигналів в багатоантенних системах радіозв'язку з високою енергетичною та спектральною ефективністю, при цьому необхідно, щоб запропонований метод мав прийнятну обчислювальну складність.

Ключові слова: сигнально-завадова обстановка; швидкість передачі інформації; ймовірність бітової помилки; просторово-часова обробка; система MIMO; паралельні канали.

Анализ свойств неортогональных методов обработки сигналов в системах MIMO

Р. Н. Животовский, А. С. Момит

Конфликты последних десятилетий (Чеченская война (Российская Федерация), вооруженные противостояния в странах Ближнего Востока и Северной Африки, Антитеррористическая операция на территории Донецкой та Луганской областей (Операция Объединенных Сил)) выходят за рамки существующих (традиционных) форм та способов ведение боевых действий, проводятся на фоне информационно-психологических операций та активного использование средств радиоэлектронного подавления. Одним из направлений повышения помехозащищённости средств радиосвязи есть использования многоантенных систем радиосвязи. Они являются сложными техническими системами. Существует много подходов к повышению помехозащищённости многоантенных систем, тем не менее авторы указанной статьи ограничились рассмотрением лишь методов обработки сигналов, а именно неортогональных пространственно-временных кодов. В ходе исследования авторами были использованные базовые положения теории связи, теории антенн, теории помеха защищенности и сигнально-кодовых конструкций. В ходе проведенного исследования установлено, что не ортогональные методы пространственно-временной обработки сигналов имеют большую спектральную эффективность в сравнении с ортогональными, при равном количестве передающих антенн, также они проигрывают в энергетической эффективности ортогональным методам пространственно-временной обработки сигналов. Использование неортогональных кодов приводит к увеличению количества вычислительных операций в приемнике средства радиосвязи. Все это обуславливает дальнейшее проведение исследований по разработке метода пространственно-временного кодирования сигналов в многоантенных системах радиосвязи с высокой энергетической и спектральной эффективности, при этом необходимо, чтобы предложенный метод имел приемлемую вычислительную сложность.

Ключевые слова: сигнально-помеховая обстановка; скорость передачи информации; вероятность битовой ошибки; пространственно-временная обработка; система MIMO, параллельные каналы.