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METHOD OF EVALUATION OF CHANNEL PARAMETERS WITH TECHNOLOGY MIMO-SEFDM

In this article was developed method of estimating the channel state with using of hybrid information technology, based on a combination of two modern efficient data transmission technologies, namely MIMO technology and SEFDM technology,. This combination allows to increase a significant in the efficiency of using of radio frequency resources and increase the speed of transmission of information. However, to assess the state of the communication channel with using of the specified information technology, it is necessary to develop a method of evaluating channel parameters, because known estimation methods have a high computational complexity. This article is dedicated to the solution of this issue. The article analyzes the basic methods of assessing the state of communication channels that were used to develop the indicated method of assessing the state of the channel using the technology MIMO-SEFDM. In the article were used methods of the theory of signals, the theory of noise immunity coding, the theory of probability, the theory of information, the theory of potential impedance, the theory of matrices, the theory of decision making, the theory of games, the theory of automatic control, methods of mathematical programming and methods of simulation modeling. The method of estimating the status of the channel using the MIMO-SEFDM technology presented in the article allows to reduce the computational complexity, increase the noise immunity, and also increase the efficiency of using the radio frequency resource of perspective radio communication systems. The results obtained in the article can be used in the design and development of special purpose radio systems operating in a complex radio-electronic environment and the shortage of available radio frequency resources.

Keywords: *multiantenna systems, spectral-effective signals, computational complexity, channel characteristics.*

Introduction

The continuous increasing in the amount of information transmitted through the communication channels requires the searching for new technical solutions to provide a given level of bandwidth.

MIMO (Multiple Input Multiple Output-MIMO) technology has long been used successfully in many data transmission systems with different frequency ranges. MIMO technology has proven a significant improvement in impedance and bandwidth [1–3].

Spectral-Efficient Frequency Division Multiplexing (SEFDM) [4–6] is used to increase the efficiency of using radio frequency resource and control fading signals, in conjunction with MIMO technology.

However, SEFDM technology has a relatively large peak-factor of the group signal, making it difficult to use in low-power transmitters with low line paths.

Sharing of MIMO and SEFDM technologies requires the obligatory using of the channel impulse response procedure, even when using relative modulation techniques, such as DPSK-Differential Phase Shift Keying.

Insufficiently precise estimation of the impulse response of the channel results in an unacceptable magnitude of the probability of the bit error rate (BER), that is, the absence of a decrease in BER with an increase in the signal/noise ratio (SNR). This feature significantly significantly reduces the average value of BER in the channel with a large fading dynamics.

A large number of estimation methods for MIMO-OFDM based on various criteria [7–9] are known in which soft or hard decisions, from the output of the demodulator, and from the output of the decoder of the noise immunity code, are used for evaluation of unknown information symbols.

For MIMO-OFDM systems, many methods are proposed to reduce the computational complexity and overcome numerical instability [6; 10–12], at the same time, the number of successive methods of aligning signals in multi-channel channels is quite limited.

Therefore, ***the purpose of the article*** will be to develop a method for evaluating channel parameters with MIMO-SEFDM technology.

Presentation of the main research material

In this work, we will consider the MIMO-SEFDM system consisting of M_t transmit antennas and M_t receiving antennas that use a set of multi-channel channels between the j-th transmitter and the i-th receiver, each of which is described by the pulse characteristic

$$g_{i,j}(t,\tau)=\sum_{k=0}^{K-1}\alpha_k^{(i,j)}(t)\delta\left(\tau-\tau_k^{(i,j)}\right),$$

where K – number of rays, $\alpha_k^{(i,j)}(t)$ – complex amplitudes, which are described by independent narrowband stationary in the broad sense by Gaussian channels, $\tau_k^{(i,j)}$ – delay l-ray from j-th transmitter до i-th reciever, $\delta(\cdot)$ – delta-function Kronker.

Let $y_i=\left[y_i(1),...,y_i(N)\right]^T$ is N-component vector of signals, which received by i-th antenna, which can be written as:

$$y_i^{(j)}=X_j h_{i,j}+w_i, \quad (1)$$

where $X_j=\begin{bmatrix} x_j(k-L+1) & \cdots & x_j(k) \\ x_j(k-L+2) & & x_j(k+1) \\ \vdots & & \vdots \\ x_j(k-L+N) & \cdots & x_j(k+N)\end{bmatrix}$,

where w_i – vector of additive interference offsets, $h_{i,j}$ – L-component vector of momentum characteristic of fading signal, matrix X has dimensionality N×L.

Denote the matrix of all transmitted signals n_T transmitters for N time intervals $X=\left[X_1...,X_{nT}\right]$, and a vector of space-frequency-time (SFT) channels from each j- th transmittor to each i-th reciever

$$h_i=\left[h_{i,1}^T,...,h_{i,nT}^T\right]^T. \quad (2)$$

Gaving a set $y_i, i=1,...,n_R$ vector of received signals and matrix of the exact values of the transmitted signals X (in case of evaluation using a test sequence) or a matrix of estimates of the exact values of the transmitted signals X (in the case of decision-directed estimation, it is necessary to evaluate n_R vectors of the SFT channels and thus reproducing the entire population L channel matrices $H(k), k=0,...L-1$.

As a criterion for estimation, a minimum of least squares (MLS) estimation errors may be selected. $E\left\{\left(h-\hat{h}_{MLS}\right)^H\left(h-\hat{h}_{MLS}\right)\right\}$, then

$$\hat{h}_{i,MLS}=\left[X^H R_{w,w}^{-1}X\right]^{-1}X^H R_{w,w}^{-1}y_i, \quad (3)$$

where $R_{w,w}$ – correlation matrix of readings of additive noise, and if the additive noise is white, then the expression turns into a kind

$$\hat{h}_{i,MLS}=\left[X^H X\right]^{-1}X^H y_i. \quad (4)$$

If as the criterion the minimum medium-quadratic deflection (MMQD) is selected, which minimizes the values of the elements of the main diagonal of the correlation matrix of the error estimation $\Delta h=h-\hat{h}$, [6] then

$$\hat{h}_{i,MMQD}=R_{h,h}\left[XR_{h,h}X^H+\sigma_w^2 I_{n_R}\right]^{-1}y_i, \quad (5)$$

$R_{y,h}=E\left\{yh^H\right\}, R_{y,y}=E\left\{yy^H\right\}$ and $R_{h,h}=E\left\{hh^H\right\}$ – the corresponding mutual and autocorrelation matrices of received signal vectors and SFT pulse characteristics.

Assuming that the additive noise is white, then the expression turns into

$$\hat{h}_{i,MMQD}=R_{h,h}X^H\left[XR_{h_i,h_j}X^H+\sigma_w^2 I_{n_R}\right]^{-1}y_i. \quad (6)$$

This expression includes the correlation matrix to be evaluated and the dispersion of noise.

As elements of the matrix X, both known transmitted information symbols can be used as well as estimates of unknown information. In the first case, the cleanliness of the calculations can be done in advance.

The essence of the proposed method

As can be seen from (4) and (6), the calculation of MLS and MMQD estimates requires the return of matrices of a rather large size. In addition, as shown in [12], with increasing the size of these matrices, their number of condition increases, which further reduces the accuracy of calculations.

To overcome these particularities, we will use an approach based on the reduction of rank R_{h_i,h_j}. As R_{h_i,h_j} is a hermitian matrix, then for it, it is fair to decompose its own vectors and eigenvalues (eigenvalue decomposition – EVD)

$$R_{h_i,h_j}=U_i\Lambda_i U_i^H, \quad (7)$$

where $U_i=\left[u_1^{(i)},...,u_N^{(i)}\right]$ – unitary matrix of proper vectors $u_m^{(i)}$, corresponding to their own values $\lambda_m^{(i)}$, so $\Lambda_i=\mathrm{diag}\left\{\lambda_1^{(i)},...,\lambda_N^{(i)}\right\}$ – diagonal matrix of eigenvalues. Own values are placed in order not to increase their values.

On the basis of (7) can be obtained χ-rank approximation R_{h_i,h_j}:

$$R_{h_i,h_j}^{(\chi)}=U_i\Lambda_i^{(\chi)}U_i^H, \quad (8)$$

where $\Lambda_i=\mathrm{diag}\left\{\lambda_1^{(i)},...,\lambda_\chi^{(i)},0,...,0\right\}$.

Let's denote $U_i^{(\chi)}=\left[u_1^{(i)},...,u_\chi^{(i)}\right]$ – matrix of proper vectors corresponding to the first one χ own value in (8).

Using discrete Karhunen-Loeve transformation estimated vector h_i can be approximated as:

$$h_i \approx \sum_{m=1}^{\chi} \tilde{h}_{i,m} u_m^{(i)}, \quad (9)$$

where $\tilde{h}_{i,m}$ – new unknown values to be evaluated that determine h_i and represent the eigenvalues of the reference correlation function. As is known, this approximation is indicated h_i has the smallest number of terms, with given representation accuracy. If χ equal to the rank of the correlation matrix R_{h_i,h_j}, then the expression (9) is exact.

Let's denote $\tilde{X} = \left[X_1 U_1^{(\chi)}, ..., X_{n_T} U_{n_T}^{(\chi)} \right]$. Taking into account the entered designation and (4) the expression (1) can be written in the form $y_i = \tilde{X}\tilde{h}_i + w_i$, substantially reduces the dimension of the vector of the evaluated parameters (χ instead L). MLS and MMQD evaluation $\tilde{h}_i$ respectively, will be calculated using formulas similar to (4) and (6) with the trivial replacement of the symbols.

However, matrices subject to inversion have considerably smaller dimensions than in (4) and (5), therefore, according to [10], should be better conditioned. Final scores h_i can be obtained can be obtained using (9).

However, the score R_{h_i,h_j} and calculating its EVD additional requires significant computing costs. We suggest variants of computational cost, on the basis of the approaches proposed in [8], the essence of which is the use of fast and fast methods of iterative calculation of fast and fast methods of iterative calculation of EVD calculation of correlation matrix (7) by successive orthogonal iterations, representing a special case Bauer double iterations for the calculation of linear invariant subspaces and singular matrices.

May $Q(n-1)$ is a unitary dimensional matrix $N \times \chi$. Execute QR factorization of the matrix product

$$R_{h_i,h_j} Q(n-1) \xrightarrow{QR} Q(n) R(n). \quad (10)$$

As shown in [6], under recursive calculations (10) $Q(n)$ is reduced to the matrix of eigenvectors $U_i^{(\chi)}$, so $R(n)$ is reduced to a diagonal matrix of eigenvalues $\Lambda_i^{(\chi)}$ correlation matrix $R_{h_i,h_j}^{(\chi)}$. QR decomposition performed during recursion (10) can be done in any way, but in this case, it is expedient to use the modified Gram-Schmidt algorithm [5].

After n iteration recieve:

$$\hat{R}_{h_i,h_j}^{(\chi)}(n) = Q(n-1) R(n) Q^H(n).$$

Let the changes R_{h_i,h_j} in time due to the unsteadiness of the transmission channel it is calculated for the help of the expositionally weighted averaging with the factor of oblivion α (forgetting factor)

$$R_{h_i,h_j}(n) = \alpha R_{h_i,h_j}(n-1) + (1-\alpha)\hat{h}_i \hat{h}_i^H. \quad (11)$$

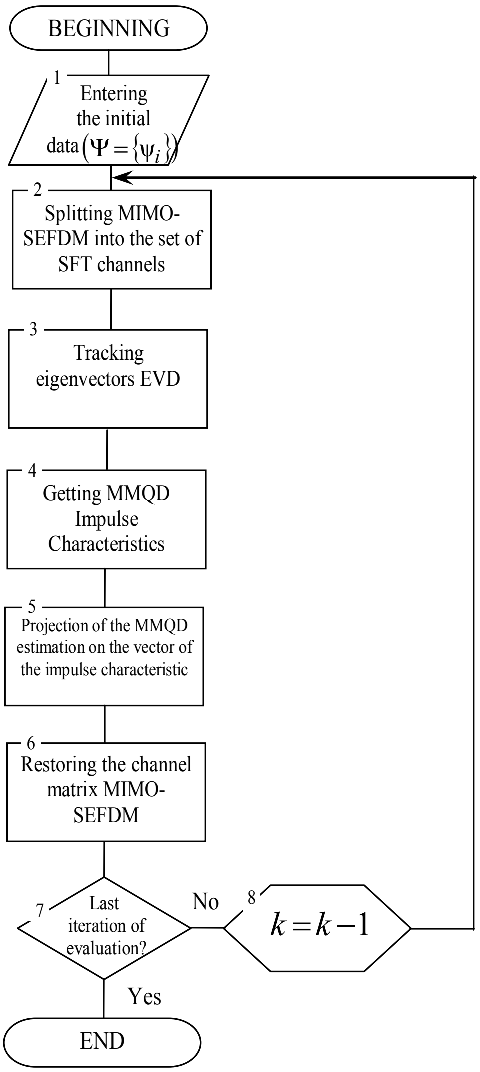

Fig. 1. The algorithm for implementing the proposed method

If during the execution of the iterations (10) on each p-step is upgrading R_{h_i,h_j} according to (11), we will track changes in time χ-rank approximation R_{h_i,h_j} (the value is determined by the dimension of the matrix $Q_{N \times \chi}$). Then MLS and MMQD $\hat{h}_i$, which can be converted into estimates of the reduced rank by projection into the domain of the subspace of the principal vectors (dominant eigenvectors):

$$\hat{h}_i^{(\chi)} = U_i \hat{h}_i. \quad (12)$$

The greatest computational complexity of the algorithm is the procedure of QR expansion in (10) and the calculation of the inverse matrix.

The simulation was carried out for the MIMO-SEFDM channel, which is described by the Kronecker model.

Each subchannel is described by the Waterons model [3–4]: two rays of equal power with independent relay fading for each. The energy spectrum of fading has a Gaussian form:

$$G(f) = \frac{1}{\sqrt{2\pi f_d}} \exp\left\{-\frac{f^2}{2f_d^2}\right\},$$

f_d – the magnitude of Doppler scattering, all statistical characteristics of all subchannels are considered the same [7; 11].

Correlation of subchannels is described $R_{R_x}^{1/2}$ and $R_{T_x}^{1/2}$ was made only at the expense of the mutual influence of antenna elements. Investigated MIMO-SEFDM channels with the configuration: 16×32, 32×64, 64×128, which was transmitted (1) randomly uncorrected but timely known receiver 64 PSK characters.

Noise is always considered white Gaussian (3) with the same dispersion σ_w^2. The time sampling was carried out at symbolic speed. The take-off time always coincided with the correlation peak of the first beam.

In fig. 2 shows that the accuracy curves of the estimation, depending on the value of Doppler scattering for different values of relative delay of the rays. As can be seen from the figure, the magnitude of Doppler scattering up to 4 Hz practically does not affect the accuracy of the estimation.

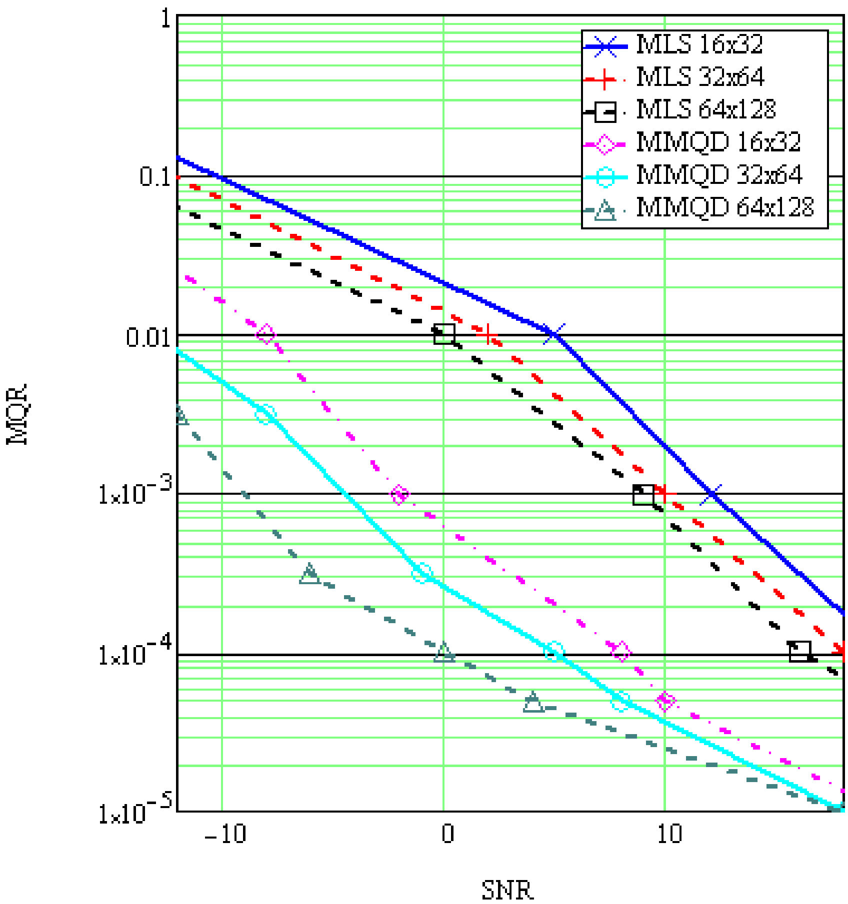

Fig. 2. Dependence of the medium-quadratic error (MQR) on the estimation of the elements of the channel matrix depending on the value of the SNR for the proposed MMQD of the MLS evaluation options

It is clear that MMQD provides a prominent advantage, which justifies the increasing computing complexity. The gain from using the filter based on its own values depends on the ratio of the length of the symbol and the magnitude of the delay between the rays. With a delay of multiple symbol duration, the winnings are minimal. The maximum gain is observed with a delay of 1-2 characters. Which, obviously, explains the dispersal of the energy of physical rays by components of the equivalent low-frequency impulse response of the channel. The dependence of the accuracy of the estimation on the number of transmitting and receiving antennas corresponds to the expected.

Conclusion

Thus, the method of estimating the channel parameters with the MIMO-SEFDM technology was proposed in the work, consisting of:

I) decompositions of MIMO-SEFDM channels into the set of inhomocomponent channels;

II) estimation of impulse characteristics of each SFT channel, by:

a) time tracking of the required number of eigenvectors of EVD decomposition of the correlation function of the impulse response performed over a large period of time;

b) frequent taking of MMQD estimates of the current values of the impulse response using the obtained correlation function of the impulse response obtained during the above-mentioned procedure of monitoring the evaluation of the lowered rank;

c) the projection of the received MMQD estimates for the domain of the subspace of the main eigenvectors of the correlation function of the impulse response;

III) restoring the channel matrix of the frequency-selective MIMO-SEFDM channel along the pulse characterization of the SFT channels.

The results of the simulation are confirmed by the performance and good characteristics of the proposed method.

The direction of further research should be considered development of a method for managing the parameters of MIMO-SEFDM systems.

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МЕТОД ОЦІНКИ ПАРАМЕТРІВ КАНАЛУ З ВИКОРИСТАННЯМ ТЕХНОЛОГІЇ MIMO-SEFDM

О.Г. Жук, А.В. Шишацький, Є.М. Прокопенко, Р.М. Животовський

В зазначеній статті проведено розробку методу оцінки стану каналу з використанням гібридної інформаційної технології, що заснована на поєднанні двох сучасних ефективних технологій передачі даних, а саме технології MIMO та технології SEFDM. Зазначене поєднання дозволяє отримати значне підвищення ефективності використання радіочастотного ресурсу та збільшити швидкість передачі інформації. Проте для оцінки стану каналу зв'язку з використанням зазначеної інформаційної технології необхідно провести розробку методу оцінки параметрів каналу, оскільки відомі методи оцінки мають високу обчислювальну складність. Вирішенню зазначеного питанню присвячена зазначена стаття. В статті проведений аналіз основних методів оцінки стану каналів зв'язку, що були використанні для розробки зазначеного методу оцінки стану каналу з використанням технології MIMO-SEFDM. В статті застосовані методи теорії сигналів, теорії завадостійкого кодування, теорії імовірності, теорії інформації, теорії потенційної завадостійкості, теорії матриць, теорії прийняття рішень, теорії ігор, теорії автоматичного управління, методи математичного програмування та методи імітаційного моделювання. Представлений в статті метод оцінки стану каналу з використанням технології MIMO-SEFDM дозволяє зменшити обчислювальну складність, підвищити завадозахищеність, а також підвищити ефективність використання радіочастотного ресурсу перспективних систем радіозв'язку. Отримані в статті результати можуть бути використані під час розробки та проектування систем радіозв'язку спеціального призначення, що функціонують в складній радіоелектронній обстановці та дефіциті наявного радіочастотного ресурсу.

Ключові слова: *багатоантенні системи, спектрально-ефективні сигнали, обчислювальна складність, канальні характеристики.*

МЕТОД ОЦЕНКИ ПАРАМЕТРОВ КАНАЛА С ИСПОЛЬЗОВАНИЕМ ТЕХНОЛОГИИ MIMO-SEFDM

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В указанной статье проведена разработка метода оценки состояния канала с использованием гибридной информационной технологии, основанной на сочетании двух современных эффективных технологий передачи данных, а именно технологии MIMO и технологии SEFDM. Указанное сочетание позволяет получить значительное повышение эффективности использования радиочастотного ресурса и увеличить скорость передачи информации. Однако для оценки состояния канала связи с использованием указанной информационной технологии необходимо провести разработку метода оценки параметров канала, поскольку известные методы оценки имеют высокую вычислительную сложность. Решению указанного вопроса посвящена данная статья. В статье проведен анализ основных методов оценки состояния каналов связи, которые были использованы для разработки данного метода оценки состояния канала с использованием технологии MIMO-SEFDM. В статье применены методы теории сигналов, теории помехоустойчивого кодирования, теории вероятности, теории информации, теории потенциальной помехоустойчивости, теории матриц, теории принятия решений, теории игр, теории автоматического управления, методы математического программирования и методы имитационного моделирования. Представленный в статье метод оценки состояния канала с использованием технологии MIMO-SEFDM позволяет уменьшить вычислительную сложность, увеличить помехозащищенность, а также увеличить эффективность использования радиочастотного ресурса перспективных систем радиосвязи. Полученные в статье результаты могут быть использованы при разработке и проектировании систем радиосвязи специального назначения, функционирующих в сложной радиоэлектронной обстановке и дефиците имеющегося радиочастотного ресурса.

Ключевые слова: *многоантенные системы, спектрально-эффективные сигналы, вычислительная сложность, канальные характеристики.*