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TECHNOLOGY ENSURING THE RELIABILITY OF INFORMATION ON THE BASIS OF CONCATENATED CODING

Wireless Data Media (WDM) provide data exchange between subscribers who can perform a single tasks in the conditions of active electronic influence. That is why it is important an indicator that characterizes the effectiveness of such WDM is the ability to ensure a given reliability of information reception in the conditions exposure to interference of various origins, including intentional, which characterized by high power spectral density. Effective the direction of counteraction to disturbances is application in WDM of technologies of expansion signal spectrum and code constructions. The purpose of the research is to increase effectiveness of WDM in the conditions of influence of disturbances through ensuring reliability information through the development of methods based on adaptive coding and their using. To develop technology to ensure the reliability of information in WDM on the basis of adaptation of code constructions methods of the theory of management were used, coding, decision making, adaptive systems, optimization, communication, simulation, noise-tolerant coding theory, information theory. The results of the research permit: to ensure reliability of information of departmental radio communication systems under impact of intentional jamming; to quantify reliability of information of departmental radio communication systems under impact of intentional jamming; to choose control parameters in selecting an operating mode of radio communication equipment; on the basis of the developed results to design components of modem equipment for means of departmental radio communication. The results of the study should be used by industrial and research organizations in order to ensure reliability of adaptive programmed radio stations in conditions of intentional interference.

Keywords: reliability of information transmission, means of departmental radio communication, intentional jamming, concatenated coding, wireless data transmission device, noise, adaptation, decoding algorithms, interference.

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ТЕХНОЛОГІЯ ЗАБЕЗПЕЧЕННЯ ДОСТОВІРНОСТІ ІНФОРМАЦІЇ НА ОСНОВІ КАСКАДНОГО КОДУВАННЯ

Безпроводові засоби передачі даних (БЗПД) забезпечують обмін даними між абонентами, що можуть виконувати єдине завдання в умовах активного радіоелектронного впливу. Тому важливим показником, що характеризує ефективність функціонування таких БЗПД, є здатність забезпечувати задану достовірність прийому інформації в умовах впливу завад різного походження, у тому числі і навмисних, які характеризуються високою спектральною щільністю потужності. Ефективним напрямком протидії завадам є застосування в БЗПД технологій розширення спектра сигналу та кодових конструкцій. Мета дослідження полягає у підвищенні ефективності БЗПД в умовах впливу завад через забезпечення достовірності інформації за рахунок розробки методів на основі адаптивного кодування та їх використання. Для розроблення технології забезпечення достовірності інформації в БЗПД на основі адаптації кодових конструкцій було використано методи теорії управління, кодування, прийняття рішень, адаптивних систем, оптимізації, зв'язку, імітаційного моделювання, теорії завадостійкого кодування, теорії інформації. Результати роботи дозволяють: забезпечувати достовірність інформації систем відомчого радіозв'язку в умовах впливу навмисних завад; кількісно оцінювати достовірність інформації системи відомчого радіозв'язку в умовах впливу навмисних завад; вибирати параметри управління при виборі режиму роботи засобів радіозв'язку; на основі розроблених результатів проектувати компоненти модемного обладнання засобів відомчого радіозв'язку. Результати дослідження доцільно використовувати промисловими й науково-дослідними організаціями з метою забезпечення достовірності адаптивних програмованих радіостанцій, функціонуючих в умовах впливу навмисних завад.

Ключові слова: достовірність передачі інформації, засоби відомчого радіозв'язку, навмисні завади, каскадне кодування, безпроводові засоби передачі даних, завадостійкі коди, адаптація, алгоритми декодування, завади.

Introduction

In modern conditions, the continuous and stable operation of departmental information telecommunications systems (ITS) is impossible without ensuring the reliable operation of general-purpose ITS, which is a transport medium for all types of messages circulating in the management system. The departmental radio communication system is especially relevant in the conditions of ensuring the continuous functioning of departmental ITS. The departmental radio system has the properties of readiness, interoperability, stability, mobility, bandwidth, intelligence protection, noise immunity, reliability, etc. The main trends in the development and modernization of departmental ITS of leading countries are: ensuring their high mobility, survivability, security and capacity; compatibility with public networks of national communication systems, communication systems and networks of other countries; unification and standardization of means and complexes of communication; development of new frequency bands.

Related research

Technology to ensure the accuracy of information in the departmental radio communication system are enough deeply and widely studied in the scientific works of domestic and foreign authors, among whom the most famous are the following scientists: A.G. Zyuko, D.D. Klovsky, M.L. Teplov, L.M. Fink, L.E. Varakin, V.L. Banquet, V.V. Kvashennikov, V.I. Borisov, S.V. Zaitsev, V.V. Casimir, K. Shannon, D. Forney, F.J. McWilliams, K. Barrow,

L. Henzo, A. Goldsmith, M. Valenti, and others. Areas of research related to the implementation of the order of the Decision of the National Security and Defense Council of Ukraine of September 14, 2020 "About National Security Strategy of Ukraine", research work "Information technology to ensure sustainable information in the Internet of Things" (№ 0118U006996).

The following tasks are insufficiently researched and require additional study: creation of new and improvement of existing methods to ensure the reliability of information; development, effective use of computational methods to solve problems of reliability, design, manufacture and operation of new equipment and new technologies; development of effective methods of adaptive noise-tolerant coding to ensure the specified characteristics of the reliability of information in channels with increased noise levels and interference, taking into account unclear decision-making rules.

In systems with parametric adaptation in the case of increasing noise levels and interference to a certain level of ensuring the specified characteristics of the reliability of information becomes impossible, so the question arises of multilevel adaptation, not only parameters but also code structure.

Broadband signal generation method

In modern radio communication systems, one of the methods of generating broadband signals is widely used to ensure the reliability of information transmission - the method of orthogonal frequency division multiplexing (OFDM) in combination with coding technologies and adaptive control systems. However, these systems were developed without taking into account the impact of intentional interference. Therefore, there is a need to address the reliability of departmental radio communication information under the influence of intentional interference by applying adaptive control methods in combination with OFDM system with pseudo-random subcarrier tuning (PRST) and cascading codes, as well as further improvement of scientific and methodological apparatus. It is proved that the task of ensuring the reliability of information is very important for the further development of the departmental radio communication system of Ukraine.

The cascade coding OFDM system consists of transmitting and receiving parts. The transmitting and receiving parts consist of the following elements: Reed-Solomon encoder (decoder), Rademacher code division encoder (decoder), Walsh expansion (narrowing) encoder (decoder), OFDM modulator (demodulator) with pseudo-random sequence generators), adaptation blocks.

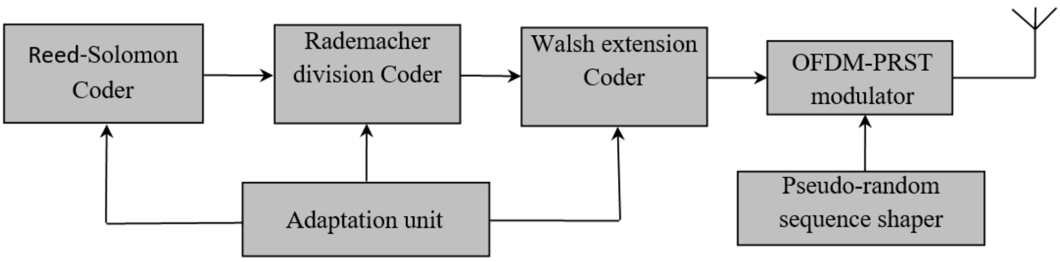

Fig. 1. Block diagram of the transmission architecture of the OFDM system with cascading coding

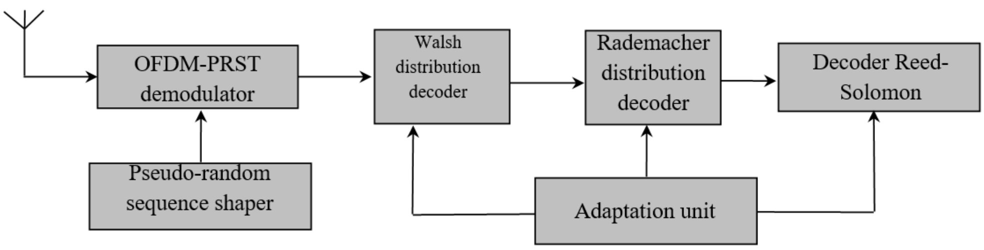

Fig. 2. Block diagram of the reception architecture of the OFDM system with cascading coding

In fig. 1, 2 shows a simplified block diagram of the transmission and reception of a cascading encoding OFDM system, which is the essence of cascade coding information technology to ensure reliability.

For the OFDM-PRST system, the inverse Fourier transform matrix $[W_F^{-1}]_{k,n}$ can be represented by the expression:

$$[W_F^{-1}]_{k,n} = e^{j2\pi n[\Xi]_{k,n}/N}, k, n = \overline{0, (N-1)}. \quad (1)$$

Matrix $[W_F^{-1}]_{k,n}$ allows you to expand the spectrum of the signal by pseudo-random adjustment of the subcarrier frequency of the OFDM signal. In expression (1) the matrix $[\Xi]_{k,n}$ forms a model of subcarrier jumps.

Matrix $[\Xi]_{k,n}$ is obtained as follows:

$$[\Xi]_{k,n} = mod[(f_n + k), (N-1)] = \begin{bmatrix} 0 & 1 & \dots & (N-1) \\ 1 & 2 & \dots & 0 \\ \vdots & \vdots & \vdots & \vdots \\ (N-1) & 0 & \dots & (N-2) \end{bmatrix} \quad (2)$$

To increase the correlation independence between code combinations, we will use Walsh codes. Let $x = [x(0),\ x(1),\ \dots,\ x(N-1)]^T$ – N complex modulated symbols that are transmitted. Then the signal $[X(k),\ k = 0,\ 1,\ \dots,\ N]$, which is transmitted on the k-th subcarrier, $k = 0,\ 1,\ \dots,\ N$, and formed using Walsh codes, will take the form:

$$\begin{bmatrix} X(0) \\ X(1) \\ \vdots \\ X(N-1) \end{bmatrix} = R_N \times \begin{bmatrix} x(0) \\ x(1) \\ \vdots \\ x(N-1) \end{bmatrix}, \quad (3)$$

where R_N – is an Hadamard matrix of size $N \times N$: $R_N = \begin{pmatrix} R_{N/2} & R_{N/2} \\ R_{N/2} & -R_{N/2} \end{pmatrix}$.

Each column and each row of the Hadamard matrix corresponds to a Walsh length code N. Thus, the OFDM signal with PRST and Walsh extension will take the form:

$$\begin{bmatrix} s(0) \\ s(1) \\ \vdots \\ s(N-1) \end{bmatrix} = W_F^{-1} \times \begin{bmatrix} X(0) \\ X(1) \\ \vdots \\ X(N-1) \end{bmatrix} = W_F^{-1} \times R_N \times \begin{bmatrix} x(0) \\ x(1) \\ \vdots \\ x(N-1) \end{bmatrix}. \quad (4)$$

The intentional interference station emits interference in a wide frequency range. The frequency range of the signal depends on the number of subchannels that can be increased to expand it. You can increase the number of subchannels of the signal using the Rademacher encoder. To do this, signals $x = [x(0),\ x(1),\ \dots,\ x(N-1)]^T$ are obtained by adding modul 2 information bits $\{x_j\}$, $j = \overline{1, S}$ with Rademacher codes.

Reed-Solomon codes are used to further increase the reliability of information transmission.

Ensuring the set values of authenticity in the system is by means of the adaptation unit, which, analyzing the state of the channel, decides to change the number of subchannels of the OFDM signal, code combinations of Walsh, Rademacher and Reed-Solomon codes

The average bit error probability of a system with OFDM signals with intra-bit pseudo-random subcarrier tuning can be calculated by the following formula:

$$P_B = \sum_{k=1}^{M} P_{B_k} + \sum_{l=1}^{K} P_{B_l}, \quad (5)$$

where P_{B_k} – the average probability of bit error in the k-th, $k \in \overline{1, M}$, subchannels of the OFDM system under the influence of only white Gaussian noise, P_{B_l} – the average probability of bit error in the l-th, $l \in \overline{1, K}$, a set of subchannels of the OFDM system under the influence of white Gaussian noise and interference, in this case $M + K = L$.

Under the influence of intentional interference is used K_s^g subchannels of the OFDM system for transmitting a single packet of information. If there are no intentional interferences or their level corresponds to the set levels, one subchannel is used to transmit one packet of information.

Spectrum expansion coefficient Ks signal by the PRST method is determined by the expression:

$$K_s^1 = \frac{\Delta F_s}{F_s} = M_f, \quad (6)$$

where ΔFS – the frequency band occupied by the signal, FS – the bandwidth of one frequency channel, Mf – number of frequency channels.

The coefficient of spectrum expansion using codes generated by Rademacher functions is equal to:

$$K_s^2 = N, \quad (7)$$

where N – the number of code elements generated by Rademacher functions.

In the case of combined application of the PRRC method and the spectrum expansion method based on Rademacher codes, the spectrum expansion coefficient in the hybrid scheme is equal to the product of the spectrum expansion coefficients obtained separately for each of the methods:

$$K_s^g = K_s^1 K_s^2 = M_f N. \quad (8)$$

Taking into account the coefficient of expansion of the spectrum expressions for calculating the signal-to-noise ratio + interference when exposed to a satellite (h_{01j}^2) and noise in the part of the strip (h_{02j}^2) accordingly will look like this:

$$h_{01j}^2 = \left(\frac{G_0}{E_b} + \frac{log_2 M \cdot P_j}{K_s^g \cdot P_b}\right)^{-1} = \left(\left(\frac{E_b}{G_0}\right)^{-1} + \left(\frac{K_s^g \cdot P_b}{P_j\, log_2 M}\right)^{-1}\right)^{-1} = \left(\left(h_0^2\right)^{-1} + \left(\frac{q}{log_2 M}\right)^{-1}\right)^{-1}, \quad (9)$$

$$h_{02j}^2 = \left(\frac{G_0}{E_b} + \frac{log_2 M \cdot P_j}{\gamma \cdot K_s^g \cdot P_b}\right)^{-1} = \left(\left(\frac{E_b}{G_0}\right)^{-1} + \left(\frac{\gamma \cdot K_s^g \cdot P_b}{P_j\, log_2 M}\right)^{-1}\right)^{-1} = \left(\left(h_0^2\right)^{-1} + \left(\gamma \cdot \frac{q}{log_2 M}\right)^{-1}\right)^{-1}, \quad (10)$$

where Pb – signal strength, Pj – interference power, $q = \frac{K_s^g \cdot P_b}{P_j}$, $h_0^2 = \frac{E_b}{G_0}$, E_b – bit energy, G_0 – spectral power density of noise, M = 2K – dimension of the signal constellation, γ – part of the frequency band where there is interference.

In the event that the director applies interference in response to the signal-to-noise + interference ratio h_{03j}^2 will look like the following, with the coefficient of expansion of the spectrum K_s^g not taken into account:

$$h_{03j}^2 = \frac{E_b}{G_0 + G_j}, \tag{11}$$

where G_j – spectral power density of intentional interference.

The average probability of bit error when exposed to a wireless network with OFDM signals with PRST (using sets from $l \in \overline{1, K}$ subchannels) will look like this:

$$P_{B1} = (1-\gamma)P_B + \gamma P_{Bj}. \tag{12}$$

Respectively for modulations FM-2 and FM-4:

- FM-2:

$$P_{B1} = (1-\gamma)Q\left(\sqrt{2h_0^2}\right) + \gamma Q\left(\sqrt{2\left(\left(h_0^2\right)^{-1} + (\gamma \cdot q)^{-1}\right)^{-1}}\right), \tag{13}$$

- FM-4:

$$P_{B1} = (1-\gamma)Q\left(\sqrt{2h_0^2}\right) + \gamma Q\left(\sqrt{2\left(\left(h_0^2\right)^{-1} + \left(\gamma \cdot \frac{q}{2}\right)^{-1}\right)^{-1}}\right). \tag{14}$$

The paper obtains similar analytical dependences for calculating the average bit error probability for modulations FM-2, FM-4, FM-8, KAM-16 under the influence of different types of interference.

Let's determine the most effective interference from the point of view of the interference maker, which will provide the maximum value of the bit error probability in the subchannels of a wireless system with OFDM signals with PRST and codes generated by Rademacher functions.

To do this, you must solve the equation $\frac{dP_B}{d\gamma} = 0$ for the case of exposure to noise in part of the strip, a $\frac{dP_B}{dh_j^2}$ – under the influence of interference in response for different types of modulations of signals and codes.

The essence of the proposed method is to adaptively change the parameters of the cascading coding of departmental radio communications depending on the change of the noise situation.

Set: radio modes Φ = {ϕi}, $i = \overline{1, n}$, where ϕ1…ϕn – modes (OFDM, PRST); transmitter and communication channel settings Ψ = {ψi}, $i = \overline{1, m}$, where ψ1…ψm – useful signal power, operating frequency, signal pulse duration, R – code rate, link bandwidth, type of modulation, type of correction code, type of Rademacher and Walsh functions, signal processing method, type of intentional interference, signal-to-noise ratio, signal-to-noise ratio, $H(t)$ – transmission characteristic of the communication channel.

It is necessary: to maximize the value of energy efficiency βE means of departmental radio communication while ensuring the set value of the reliability of information transmission $P_{err} \le P_{\text{err add}}$.

The system of equations for solving the optimization problem has the form:

$$\begin{cases} \beta_E = F_1(N, \rightleftarrows\ M_f,\ M, T_c, k, n,\ h_0^2, h_j^2,\ \gamma) \to max, \\ P_{err} = F_2(N, \rightleftarrows\ M_f,\ M, k, n,\ h_0^2, h_j^2,\ \gamma) \le P_{\text{err add}}, \end{cases} \tag{15}$$

where N – the number of elements of the Rademacher function, M_f – number of frequency channels, M – positionality of signals, Tc – character duration, k – the length of the information combination, n – the length of the code combination, h_0^2 – signal-to-noise ratio, h_j^2 – signal-to-noise ratio, γ – the quarrel parameter.

The method is based on the representation of gold reserves in the form of a controlled system operating on the principle of deviation. The system is controlled on the basis of measuring external influences (characteristics of intentional interference) z, which cause deviations of the system from the specified.

The criterion of optimality is the maximum value of the signal power utilization factor

$$\beta_E = M\{x_{0i} - x_i\}, \tag{16}$$

where x_{0i} – the initial impact applied to the system.

Search for optimal parameters of the working function $\beta_E(w_i)$ carried out by the method of possible directions

$$\beta_{E_{i+1}} = \beta_{E_i} - \alpha_{i+1} c_i, \tag{17}$$

where αi – the magnitude of the step of changing the parameters of the adaptation device, ci – direction of search, which depends on the type and parameters of external influences (intentional interference and selective fading) z, under which the condition is met $\beta_E(w_{i+1}) > \beta_E(w_i)$.

Step size αi is determined such that

$$\beta_E(w_{i+1} - \alpha_i c_i) = \max_{\alpha} \beta_E. \qquad (18)$$

The output data in the communication mode is the current values of the vectors:

- controlled value x (x1 – energy efficiency);
- regulatory impact u (u1 – the length of the information combination, u2 – the length of the code combination, u3 – Rademacher function, u4 – Walsh function);
- interference z (z1 – kind of intentional interference, z2 – the part of the radio bandwidth occupied by the interference, z3 – signal-to-noise ratio, z4 – signal-to- interference ratio).

Communication using the selected mode of signal-code construction is carried out until the probability of erroneous signal reception does not exceed the specified level. ($P_{err} > P_{erradd}$).

Experiments

Using the mathematical package Mathcad and software Borland C ++ Builder, mathematical and simulation modeling was performed and the parameters of Reed-Solomon codes, codes formed using Rademacher and Walsh functions under the influence of different types of interference were selected.

To evaluate the effectiveness of the proposed results, simulations of the OFDM system with cascading coding under the influence of intentional interference on the communication channel were performed.

The study simulated a single-channel OFDM system with PRST, Reed-Solomon codes, and codes generated by Rademacher and Walsh functions. The research was performed by changing the parameters of the Reed-Solomon codes and the codes generated by the Rademacher and Walsh functions.

In Fig. 3 shows the dependences of the average probability of bit error on the ratio P_b/P_j for OFDM system with Reed-Solomon codes, with coding using Rademacher, Walsh and PPPC functions (FM-2 modulation) when exposed to noise interference subchannels in part of the band for different values of code symbol lengths of Reed-Solomon codes n, lengths of information bits k, parameters of Reed-Solomon codes m, t, parameters of PRSTK_s^1 , Rademacher code parameter K_s^2, Walsh code parameter K_s^3, factory parameter γ.

Analysis of fig. 3 shows that the additional use of Walsh codes leads to increased reliability of information transmission and energy gain of coding.

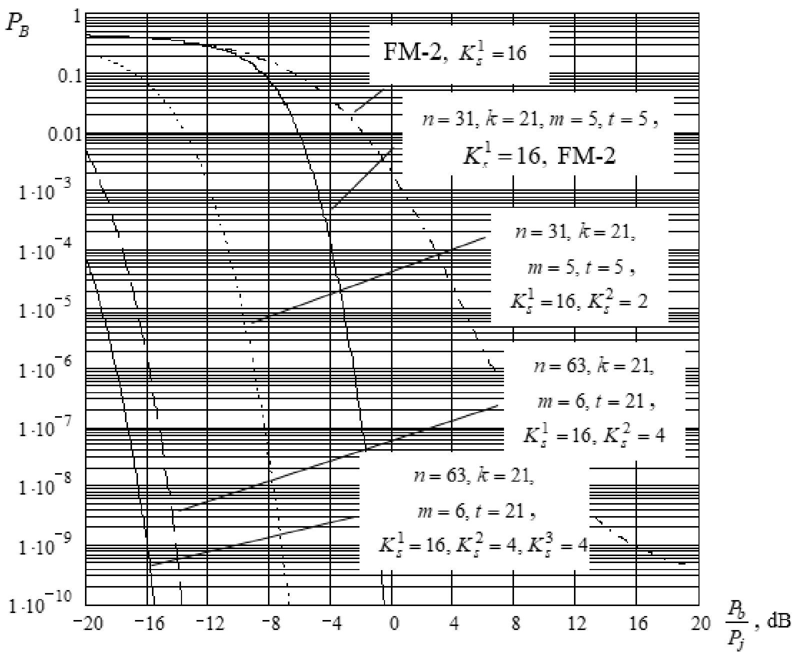

Fig. 3. The dependence of the average probability of bit error on the ratio P_b / P_j for OFDM system with Reed-Solomon codes, coding using Rademacher, Walsh and PPPC functions (FM-2 modulation) when exposed to noise interference subchannels in the part of the band with $\gamma = 0,9$ for different $n, k, K_s^1, K_s^2, K_s^3$

So, applying code values $n = 63,\ k = 21, m = 6,\ t = 21, K_s^1 = 16,\ K_s^2 = 4, K_s^3 = 4$ FM-2 modulation, the energy gain of the coding is 15.5 dB to ensure the reliability of information transmission $P_B = 10^{-5}$ in comparison with the use of modulation of the FM-2, $n = 31,\ k = 21,\ m = 5,\ t = 5$, $K_s^1 = 16$ and 23.5 dB compared to a system that uses FM-2 and PRST modulation with $K_s^1 = 16$ under the influence of noise in the part of the strip with the coefficient of overlap $\gamma = 0{,}9$.

Conclusion

The proposed information technology to ensure the reliability of information in the exchange of data in departmental radio networks through cascading coding, the essence of which is the use of Reed-Solomon codes, codes generated by Rademacher and Walsh functions, OFDM system with pseudo-random tuning for subunit reliability of departmental radio communication systems under the influence of intentional interference. Evaluation of the effectiveness of the developed information technology has shown that it allows to improve the process of forming code structures by introducing additional codes in departmental radio systems, taking into account the impact of intentional interference. Information technology allows to provide the set values of the reliability of information and get an energy gain in ensuring the reliability of 24 dB for the average bit error probability $P_B = 10^{-5}$ under the influence of intentional interference. The adequacy of the simulation model used to confirm the main results has been proved.

A promising direction to ensure the reliability of departmental radio systems in the face of intentional interference may be the use in the structure of departmental radio communications adaptive cascade codes in combination with the system MIMO.

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