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MODEL OF IMPACT INTERFERENCES ON RADIOCOMMUNICATION SYSTEMS FOR SPECIAL COMMUNICATIONS

As the analysis of recent events in the East of Ukraine shows, radio communication is the transport basis for the construction of telecommunication networks of special purpose. In view of the above, the subject of study in the article are the special radio communication systems, operating in a complex electronic environment. **The purpose of this article** is to develop a mathematical model for the effects of interference on systems of special radio communication. **The tasks** solved in the course of the study: a formal description of various types of noise that is used to suppress the systems of special radio communication; analytical representation of the probability of a bit error for signals with different types of modulation under the influence of the main types of deliberate disturbances; development of recommendations for increasing the noise immunity of special radio communication systems with different types of signal modulation under the influence of deliberate interference. In the course of the study, the following **methods** were used: signal theory, radiocommunication theory and the theory of potential impedance protection. In the course of the study, analytical dependencies were obtained that allow us to calculate the probability of a bit error in the effect of intentional interruptions for different types of signal modulation. **Conclusions:** the proposed mathematical model should be used in the analytical modeling and evaluation of the performance of broadband radio networks of a special purpose taking into account the combined action of the additive white Gaussian noise and structural impediment, algorithms for the formation and processing of signals at the physical level, as well as the properties of the radio channel.

Keywords: radiocommunication system; radiocommunication; radio-electronic suppression; intentional interference.

Introduction

Radiocommunication is an essential element of management in military systems for various applications, which ensures the continuity of command and control in the most difficult and unpredictable situations. Due to the nature of radio channel, which is channel with free access, the receptor exposed to accidental and intentional interference, which determines the communication quality, which characterized by reliability accepted information. Focus promising means of radio communication in modern multi-service applications and provide customers with a wide range of services with a specified quality determines need to use digital radio communication with digital signals, including on the basis of modern technologies of broadband wireless networks.

Against the background of current events in Ukraine and active military-technical cooperation with NATO information and telecommunications system of the Armed Forces of Ukraine will undergo significant changes. In the armed forces of NATO countries are actively using commercial wireless networking standards as a basis for constructing their own information-telecommunication networks of special purpose. System tactical communication is evolving towards the use of open architecture, introduction of new telecommunication technologies that used in commercial communication systems [1].

Quality radio with digital signals in conditions of interference quantitatively estimates the probability of erroneous reception of symbol (probability of bit error BER). Existing models allow analytical methods to assess the impact of the probability of bit error for a probabilistic-time characteristics of the networks, suggesting that distortions are introduced by the effect of additive white gaussian noise (AWGN). However, the dependence of network characteristics on the ratio of signal and interference at the receiver input for different ways of generating and processing signals as well as statistical properties of the channel remain unexplored. In today's time the influence of bit errors on the performance of broadband communication systems was studied in several papers [2-6], however in these works the dependence of network characteristics on the attitude signal level and interference at the receiver input for different ways of formation and signal processing.

Because of this, there is an actual ***scientific task*** of developing mathematical model to assess the impact of interference on the broadband radio network for special communications to further control mechanisms of interference protection.

Purpose of article is to study the impact of signal levels and noise on the input of the receiver the probability of bit error in a broadband radio networks for special purposes.

Presentation of the main material

Interference background, creation of which involved natural and artificial sources, and the impact thereof on the communication network is difficult to quantify. Interference different species different impact on radio-electronic means for specific purpose with specific types of signals and ways of their processing.

General classification of noise showed on fig. 1. Interference can be AWGN, deliberate and between stations interference, they can be similar to signal and sever us. Between stations interference, as a rule, belong to the class of structural interference, i.e. interference, such as the shape of the useful signal. Between stations interference arise primarily when the violation of the norms of frequency-territorial planning, or in his absence [7]. Despite the diversity of types and parameters of interference in solving scientific and practical problems of functioning of communication networks in accordance with their purpose under certain conditions, the class of the data interference, as a rule, is narrowed depending on the model the actions of the enemy. Given the potential scope, distance, operating frequency, data network will focus on noise (Gaussian) and structural sighting deliberate interference with limited average power, which under optimal duty cycle and radiation are the worst (they must be similar to signal) [8-10].

When exposed to impulse noise with reduced average power and AWGN the probability of error is calculated as follows [8, 9, 11]:

$$BER = p_B \cdot BER_з\left(\frac{h_c^2, h_з^2}{p_B}\right) + \\ +(1-p_B)\cdot BER\left(h_c^2, h_з^2 = 0\right), \quad (1)$$

where p_B – bit error probability in period of radiation, h_c^2 – attitude of energies signal/noise, $h_з^2$ – attitude interference/noise.

First piece on the right side of expression (1) represents the probability of error when exposed to interference during the periods of emission (with probability p_B that depends on the duty cycle) and the second is the probability of error from the conditions of action only AWGN during periods of absence of interference.

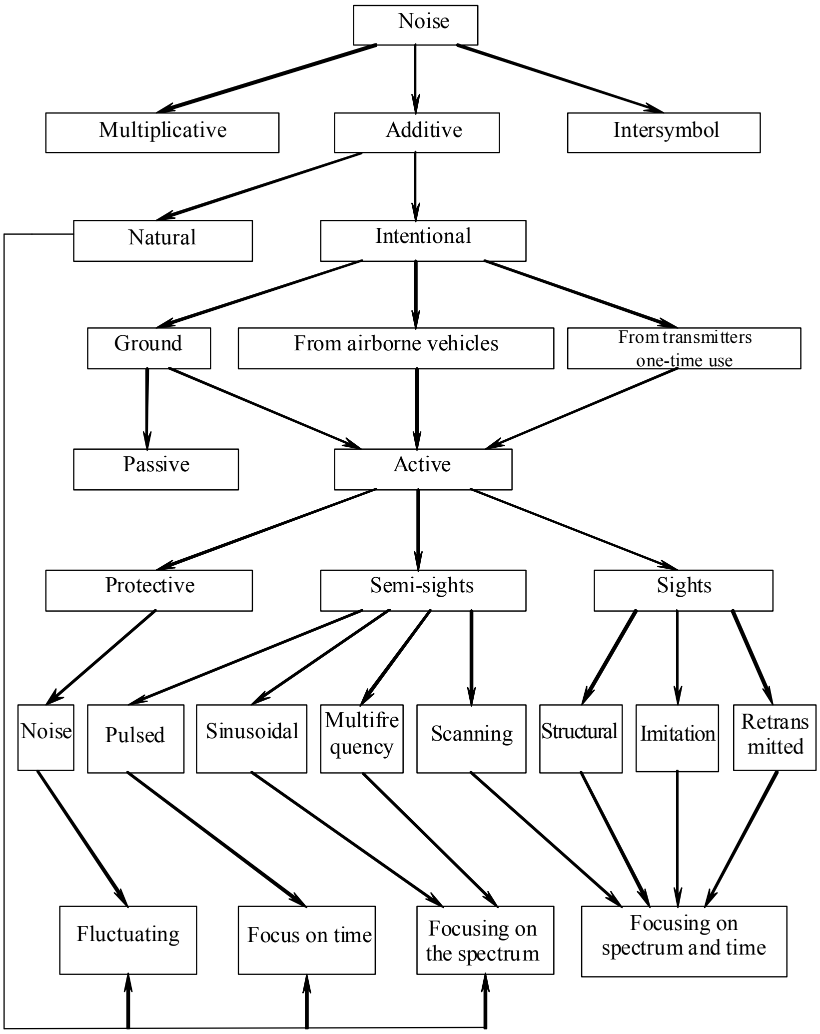

Fig. 1. General classification of noise

You can consider on several options of interaction between signal and interference (intentional or mischance) in terms AWGN, namely: nonfading signal nonfading interference, nonfading signal a dying of a hindrance severalty signal nonfading interference, fading signal – a dying noise. The laws of signal fading and interference can be the same or different. Case nonfading signal and interference correspond to the channel with constant parameters and AWGN that takes place in direct line of sight communication between a fixed location objects. In the presence of signal fading (interference) analytical ratios for the probability of error on a bit perhaps by averaging the error probability in the channel with constant parameters with known probability density values of the coefficient of transmission of the channel ω(μ) μ will be of the form [12-15]:

$$BER = \int_0^\infty P_{\text{error}}\left(h_\mu^2 = \frac{\mu^2}{\overline{\mu^2}}\overline{h^2}\right)\cdot \omega(\mu)\,\mathrm{d}\,\mu, \quad (2)$$

where h_μ^2 – ratio of signal energy to length of the symbol to one-sided power spectral density AWGN (N_o) at particular value of the transmission coefficient of the channel μ; $\overline{h^2}$ – average value of the ratio of signal energy to length of the symbol to one-sided power spectral density AWGN; $\overline{\mu^2}$ – initial moment of the second order random transfer coefficient μ; P_{error} – average value of the probability of occurrence of the error.

For above variants of interaction of the signal and noise expression (2) probability of bit error BER under the impact of intentional or between stations interference and AWGN depending on type of signal and noise is as follows [1]:

a) for fading signals and nonfading interference

$$BER = \\ = \int_0^\infty P_{\text{error}}\left(h_\mu^2 = \frac{\mu_c^2}{\overline{\mu_c^2}}\overline{h_c^2}, h_з^2 = const\right)\cdot \omega(\mu)\,\mathrm{d}\,\mu_c, \quad (3)$$

b) for nonfading signal and fading interference

$$BER = \\ = \int_0^\infty P_{\text{error}}\left(h_n^2 = \frac{\mu_n^2}{\overline{\mu_n^2}}\overline{h_з^2}, h_c^2 = const\right)\cdot \omega(\mu_n)\,\mathrm{d}\,\mu_n, \quad (4)$$

c) for independent fading signal and interference

$$BER = \int_0^\infty \int_0^\infty P_{\text{error}} \begin{pmatrix} h_c^2 = \dfrac{\mu_c^2}{\overline{\mu_c^2}} \overline{h_c^2}, \\ h_з^2 = \dfrac{\mu_n^2}{\overline{\mu_n^2}} \overline{h_з^2} \end{pmatrix} \omega(\mu_c)\omega(\mu_n) \mathrm{d}\,\mu_c\,\mathrm{d}\,\mu_n, \quad (5)$$

where P_{error} (h_c^2, h_n^2) determined by the known relationships for channel with constant parameters, $h_з^2$ – ratio of energy interference on the length of the symbol to the power spectral density N_{o}.

Using general expressions (3) to (5) we can obtain the ratio to calculate the error probability at bit to specific methods of formation and processing of signals, types of interferences and of signal fading or interference.

Let is coherent correlation signal reception binary phase shift keying (BPSK - eng. BPSK — binary phase-shift keying) with a total relevision fading in action nonfading BPSK structural interference that is synchronous in moments of change cycles with the signal and having in General case the pulsed nature of the radiation. Signal selection BPSK in this example substantiates the fact that in a number of IEEE standards 802.11 a, b, g, n uses a Bank of modulation schemes coding, which depending on the state of the channel in the process of communication selected and the adaptive modulation scheme coding, which ensures the required quality of communication. In "bad" channels as times and applies the most interference-free mode – BPSK. The probability density of the transmission coefficient at relevision law of fading look like [6]:

$$\omega(\mu) = \frac{\mu}{\sigma^2} \cdot \exp\left(-\frac{\mu^2}{2\sigma^2}\right), \ \mu > 0, \ \overline{\mu^2} = 2\sigma^2, \quad (6)$$

where σ^2 – dispersion of fading.

We can see that when releasing fading signal and synchronous actions nonfading interference (BPSK-type) with limited average power at arbitrary time interval, average probability of bit error for systems with one carrier is determined by the expression

$$BER = \frac{p_u}{2}\left[1 - \sqrt{\frac{\overline{h_c^2}}{1+\overline{h_c^2}}} \cdot \exp\left(-\frac{h_n^2 / p_u}{1+\overline{h_c^2}}\right)\right] + \frac{1-p_u}{2}\left(1 - \sqrt{\overline{h_c^2} \Big/ \left(1+\overline{h_c^2}\right)}\right). \quad (7)$$

For systems with many carrier (in particular, systems and signals, orthogonal frequency multiplexing) formula (7) will have the following form:

$$BER = p_u \cdot \left(N_з / N_{FFT}\right) \cdot BER_з(h_c^2, h_з^2 / p_u) + (1-p_u)\left(1 - N_з/N_{FFT}\right) \cdot BER(h_c^2, h_з^2 = 0), \quad (8)$$

where

$$BER_з(h_c^2, h_з^2/p_u) = \frac{1}{2}\left[1 - \sqrt{\frac{\overline{h_c^2}}{1+\overline{h_c^2}}} \cdot \exp\left(-\frac{h_з^2/p_u}{1+\overline{h_c^2}}\right)\right], \quad (9)$$

$$BER(h_c^2, h_з^2 = 0) = \frac{1}{2}\left(1 - \sqrt{\frac{\overline{h_c^2}}{1+\overline{h_c^2}}}\right), \quad (10)$$

N_{FFT} – number of carrier OFDM-signal; $N_з$ – number of carrier interference.

In expressions (8)–(10) it should be borne in mind, that h_c^2 and $h_з^2$ is the ratio signal/noise and disturbance-to-noise ratio on each subcarrier of the signal (interference).

Interference coincides with the signal values of the carrier frequency and synchronized with him on the moment of changing the bars.

In the case of general independent releasing fading BPSK signal and synchronous BPSK-interference with reduced average power expression for the error probability in the system with single-carrier turns into this:

$$BER = \frac{p_u}{2} \cdot \left[1 - \frac{\sqrt{\overline{h_c^2} \cdot (1+\overline{h_c^2})}}{1+\overline{h_c^2} + \overline{h_з^2}/p_u}\right] + (1-p_u)\left[1 - \sqrt{\frac{\overline{h_c^2}}{1+\overline{h_c^2}}}\right]. \quad (11)$$

In case of systems with many carrier we have:

$$BER = \frac{p_u}{2} \cdot \frac{N_з}{N_{FFT}}\left[1 - \frac{\sqrt{\overline{h_c^2} \cdot (1+\overline{h_c^2})}}{1+\overline{h_c^2} + \overline{h_з^2}/p_u}\right] + \frac{(1-p_u)}{2}\left(1 - \frac{N_з}{N_{FFT}}\right)\left[1 - \sqrt{\frac{\overline{h_c^2}}{1+\overline{h_c^2}}}\right]. \quad (12)$$

In the case of reception nonfading signal and synchronous pulse interference with relevision fading it can be shown that the error probability in systems with one carrier is determined by the general expression (8), in which

$$BER_з(h_c^2, h_з^2/p_u) = \overline{F}\left(\sqrt{2h_c^2}\right) + 0,5 \times \left\{\sqrt{\frac{\overline{h_з^2}}{\overline{h_з^2} + p_u}} \cdot \exp\left(-\frac{h_c^2 + p_u}{\overline{h_з^2} + p_u}\right) \cdot erf\left(\frac{h_c^2 \cdot \overline{h_з^2}}{\overline{h_з^2} + p_u}\right)\right\},$$

$$BER(h_c^2, h_з^2 = 0) = \overline{F}\left(\sqrt{2h_c^2}\right); \quad (13)$$

$$\overline{F}(x) = \frac{1}{\sqrt{2\pi}} \int_x^\infty e^{-\frac{t^2}{2}} dt.$$

$$erf(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} dt. \quad (14)$$

Consider case when signal and noise do not stand still, that is channel with constant parameters. Average probability of error for coherent correlating reception BPSK in terms of structural disturbances (with BPSK) with continuous radiation in channel with AWGN determined by the ratio [15]

$$P_{error}(h_c^2, h_з^2) = \frac{1}{2} \cdot \left[\overline{F}\left(\sqrt{2h_c^2} + \sqrt{2h_з^2}\right) + \overline{F}\left(\sqrt{2h_c^2} - \sqrt{2h_з^2}\right) \right]. \quad (15)$$

Here, as before, implies that a disturbance synchronous with the signal on when changing cycles and coincides with a signal for high frequency filling.

It is calculated according to formula (15), the value P_{error} (h_c^2, $h_з^2$) used above for substitution in expression (3) to (5) upon receipt of the ratios to determine the probability of error in different options of signal fading and interference.

In case of intermittent interference, the limited average power of the error probability in systems with one carrier with the above terms and conditions determined by the formula (8), in which

$$BER_з(h_c^2, h_з^2/p_u) = \frac{1}{2} \cdot \left[\overline{F}\left(\sqrt{2h_c^2} + 2\sqrt{h_з^2/p_u}\right) + \overline{F}\left(\sqrt{2h_c^2} - 2\sqrt{h_з^2/p_u}\right) \right] \quad (16)$$

$$BER\left(h_c^2, h_з^2 = 0\right) = \overline{F}\left(\sqrt{2h_c^2}\right). \quad (17)$$

As mentioned above, depending on the state of the channel in the IEEE 802.11 x provides an adaptive switching of the modulation schemes and coding. In particular, channels with a low signal/noise interference to improve interference protection used convolution coding with relative code rate R = 1/2 together with the signals BPSK. The probability of error on bit in the channel AWGN under the action of pulsed BPSK-interference with reduced average power for coherent reception BPSK signals with convolution will be encoded with pseudo-random interleaving of the symbols and the use of Viterbi decoder with soft decisions can be calculated using the following additive border-top:

$$BER = \frac{1}{m} \cdot \sum_{k=d}^{\infty} \omega_k(v) \times \left[p_u^k \cdot \overline{F}\left(\sqrt{2 \cdot R \cdot k \cdot h_c^2 \frac{N \cdot p_u}{h_з^2 + N \cdot p_u}} \right) \right] + \left(1 - p_u^k\right) \cdot \overline{F}\left(\sqrt{2 \cdot R \cdot k \cdot h_c^2}\right), \quad (18)$$

where v – length of the code limitations;

d – free length of code;

$R = m/n$ – relative speed of code;

$\{\omega_k(v)\}$ – range of code;

N – base of phase-manipulated broadband signals.

It should be noted that expression (18) is valid under the condition of justice Gaussian approximation of the interference, i.e. when the disturbance Gaussian type, or when the signal is more than 20 in the case of structural disturbance.

In particular, when fading and nonfading hinder the probability of bit error in any relationship, P_c/P_n above 10^{-2}. Application shortage coding significantly reduces the probability of bit error, as shown in the example of a channel with constant parameters when using the soft Viterbi decoder.

Above ratios are true for the general of signal fading and interference. Recognition of the fine multipath structure and statistical properties of the signal (interference) usually carried out using simulation [16-18].

Conclusion from this explosion

Presented in article the model will be used in analytical modeling and performance evaluation of broadband radio networks for special purpose with the joint action AWGN and structural interference, the algorithms of formation and handling signals in the physical layer and the radio channel.

Further research will focus on design methods of control parameters of radio networks for military purposes to enhance the immunity of their functioning in conditions of interference.

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Модель впливу завад на системи спеціального радіозв’язку

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Як свідчить аналіз останніх подій на Сході України, радіозв’язок є транспортною основою для побудови телекомунікаційних мереж спеціального призначення. Зважаючи на сказане, предметом вивчення в статті є системи спеціального радіозв’язку, що функціонують в складній радіоелектронній обстановці. **Метою зазначеної статті** є розробка математичної моделі впливу завад на системи спеціального радіозв’язку. **Завданнями**, що вирішувалися в ході проведеного дослідження були: формалізований опис різних видів завад, що використовуються для подавлення систем спеціального радіозв’язку; аналітичне представлення ймовірності бітової помилки для сигналів з різними видами модуляції при впливі основних видів навмисних завад; розробка рекомендацій щодо підвищення завадозахищеності систем спеціального радіозв’язку з різними видами модуляцій сигналу при впливі навмисних завад. В ході проведеного дослідження використовувалися наступні **методи**: теорія сигналів, теорія радіозв’язку та теорія потенційної завадозахищеності. В ході проведеного дослідження отримані аналітичні залежності, що дозволяють розрахувати ймовірність бітової помилки при впливі навмисних завад для різних видів модуляцій сигналу. **Висновки:** запропоновану математичну модель доцільно використовувати при аналітичному моделюванні і оцінці продуктивності широкосмугових радіомереж спеціального призначення з урахуванням спільної дії адитивного білого гаусівського шуму і структурної завади, алгоритмів формування і обробки сигналів на фізичному рівні, а також властивостей радіоканалу.

Ключові слова: система радіозв'язку; радіозв'язок; радіоелектронне подавлення; навмисні завади.

Модель влияния помех на системы специальной радиосвязи

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Как показывает анализ последних событий на Востоке Украины, радиосвязь является транспортной основой для построения телекоммуникационных сетей специального назначения. Учитывая сказанное, предметом изучения в статье являются системы специальной радиосвязи, которые функционируют в сложной радиоэлектронной обстановке. **Целью данной статьи** является разработка математической модели влияния помех на системы специального радиосвязи. **Задачами**, которые решались в ходе проведенного исследования были: формализованное описание различных видов помех, используемые для подавления систем специального радиосвязи; аналитическое представление вероятности битовой ошибки для сигналов с различными видами модуляции при воздействии основных видов преднамеренных помех; разработка рекомендаций по повышению помехозащищенности систем специальной радиосвязи с различными видами модуляций сигнала при воздействии преднамеренных помех. В ходе проведенного исследования использовались следующие **методы:** теория сигналов, теория радиосвязи и теория потенциальной помехозащищенности. В ходе проведенного исследования получены аналитические зависимости, позволяющие рассчитать вероятность битовой ошибки при воздействии преднамеренных помех для различных видов модуляций сигнала. **Выводы:** предложенную математическую модель целесообразно использовать при аналитическом моделировании и оценке производительности широкополосных радиосетей специального назначения с учетом совместного действия аддитивного белого гаусовского шума и структурной помехи, алгоритмов формирования и обработки сигналов на физическом уровне, а также свойств радиоканалу.

Ключевые слова: система радиосвязи; радиосвязь; радиоэлектронное подавление; преднамеренные помехи.