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METHODS AND TOOLS FOR ASSESSING THE LEVEL OF NOISE IMMUNITY OF WIRELESS COMMUNICATION CHANNELS

The **subject** of this article is the process of increasing the noise immunityof wireless channels in the construction or operation of modern digital communication systems (DCS), when the transmission of digital information significantly complicates the presence of interference and distortion in the communication channel. The **aim** is analysis and development of methods for ensuring stable and reliable operation of ultra-wideband wireless communication system in the conditions of interference and distortion of information in wireless communication channels. The **task** is creation and implementation of practical recommendations for improving the level of secrecy and quality of information circulating in the communication channel; development of criteria for quality, information efficiency and noise immunityof DCS wireless communication channels in the conditions of interference of natural and artificial origin. The **methods** used: methods of analytical modeling and the theory of potential noise immunity. The following **results** were obtained. The feasibility of assessing the DCS efficiency by two indicators - energy and frequency efficiency, which are the components that make up the overall integral indicator of informational efficiency was shown. It was proposed to evaluate the DCS efficiency by comparing the indicators of informational efficiency of the inverse and reference systems, using the Shannon limit as an ideal ratio of energy and frequency efficiency. On the basis of the theory of potential noise immunity it was shown that it is possible to operate wireless communication channels in conditions when the level of information signal and noise have the same value. **Conclusions.** It is shown that the use of the technology of supersmooth signals allows to carry out wireless redundant transmission of information with low impromptu capacity. Moreover, the efficiency of digital communication systems significantly increases due to the creation of an ensemble of complex signals through one-time encoding and modulation, which expands its information base, ensuring coverage and energy efficiency in a double symmetric channel. This enables the fullest possible utilization of the channel's Shannon capacity with high integrity of information transfer without a significant increase in the signal-to-noise ratio at the receiver's input. An integral indicator of informational efficiency of the wireless DCS communication channel is provided. It enables real-time integral assessment of link quality and optimal routing in a mobile peer-to-peer network – MANET.

Keywords: Information effectiveness; noise protection; noise immunity; concealment; communication channel.

Introduction

The amount of information is increasing every year, the range of communication is increasing, and the requirements for information quality are becoming higher. Wireless transmission is severely hampered by the presence of obstacles and spoils in the communication channel [1 - 3]. Wireless networks of the next generation are becoming extremely brittle and multifaceted. The use of unmanned aerial vehicle as air base stations of mobile communication makes it possible to support data transmission with high speed for users, in the absence of typical cellular infrastructure [4, 5]. However, the use of these mobile devices, which move in a dynamic space, significantly complicates the problems of mobility, since the relocation to a new location leads to the possible disconnection of the current users. The lack of infrastructure is the main characteristic of mobile peer-to-peer networks - MANET. Therefore, mobile devices that are part of a peer-to-peer network must be able to communicate with one another, acting as routers. They move in space unnecessarily, changing the topology of the network, which requires constant adaptation and reconfiguration of routes, so that the devices will be able to interact with each other. At the same time, a reliable stable connection between devices should be ensured in real time to maintain the appropriate level of service quality and interoperability, reducing delays in data delivery between mobile devices. In view of these requirements, there are methods for controlling the parameters of information and telecommunication networks of critical use [6], re-routing of base stations in mobile communication networks [7], re-routing of data traffic in infocommunication networks [8] and throughput capacity in software-reconfigured networks [9] should be improved to increase reliability of communication and handlers between devices and equipment. Due to the high mobility the information delay increases, wireless communication deteriorates, which causes difficulties in maintaining communication channels of higher quality. Thus, to determine the current optimal topology of the network and quality link channels, an integral indicator of informational efficiency should be developed, which will reduce the time of making an optimal decision. Under these conditions, the problem of increasing noise immunity and efficiency of communication channels becomes one of the most important problems of current wireless communication theory and technology in the construction and operation of modern DCS.

Quality indicators of wireless mobile communication channels

Under conditions of constant growth of demand in communication services and severe limitation of frequency resource there is a need for more efficient use of it. In this case the combination of transmitter, receiver and communication lines creates a communication channel. As the *noise immunity of communication channels* characterizes the ability of the system to ensure the transmission of messages with a given quality under conditions of natural and piecemeal interferences, it also characterizes its ability to resist the means of radio-electronic suppression. Therefore, the noise immunity of communication channels should be considered as the summation of two components – noise immunity and concealment. We understand *the channel concealment* as its energy concealment, including the ability to store the

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fact of information transmission, structural concealment of the signal and the way of its encoding. Since these properties and factors are of an accidental nature, noise immunity and concealment must be defined by the same criteria. When a channel does not have the property of probability or noise immunity, it does not have the property of protection. Thus, noise immunity of a channel is defined by two channel properties – concealment and noise immunity.

The quality of operation of digital communication systems is characterized by a set of indicators, of which the main ones are the accuracy of renewal of messages, noise immunity, speed, throughput capacity, range of operation, the level of electromagnetic coupling and others. The sum of system quality indicators is recorded in the form of a vector:

$$Q = (Q_1, Q_2, ..., Q_n) .$$

The comparison of systems according to these indicators allows to identify the highest quality system, which corresponds to the highest / lowest value of a certain function of partial quality indicators.

$$Q = \varphi(Q_1, Q_2, ..., Q_n) .$$

Thus, the value Q is the efficiency or a generalized indicator of the system's performance, and $\varphi(Q_1, Q_2, ..., Q_n)$ is the objective function of the system. However, such a large set of indicators does not allow us to selectively choose the most efficient variant. Therefore, we should develop a universal integral indicator of binary communication channel quality assessment for its use both at the stage of development and at the stage of DCS operation.

The main structural element of DCS is the communication channel. The maximum efficiency of the channel occurs when the information signal meets the requirements of the communication channel in the best way. Based on the analysis of communication systems [10 – 11], the main indicator of the quality is acceptable to take the authenticity of transmitted information. For this purpose the error coefficient Pe is often used – the probability of error during the transmission of a unit of information:

$$P_e = Q\left(\sqrt{\frac{E}{N_0}}\right),$$

where: $Q(x) = \int_x^{\infty} \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{u^2}{2}\right) du$ is a Gaussian error probability integral.

Another indicator of quality is the signal-to-noise ratio $q_0 = \frac{E_s}{N_0}$, which relates the energy of the signal (bit) E_s to the spectral intensity of the noise N_0 .

When assessing the quality of the transmitted information, the following parameters are often used: P_s – the probability of error and the signal/noise ratio q_0 , which is due to their unambiguous mutual dependence for a particular DCS. The strength of the signal and the bandwidth (signal base) are the main resources that are expended on information transfer. Therefore, it is reasonable to reduce the level of information signal at the input of the receiver to the noise level in order to ensure a smooth and fault-free operation. This determines the appropriate level of reception and noise immunity of wireless communication channels (fig. 1).

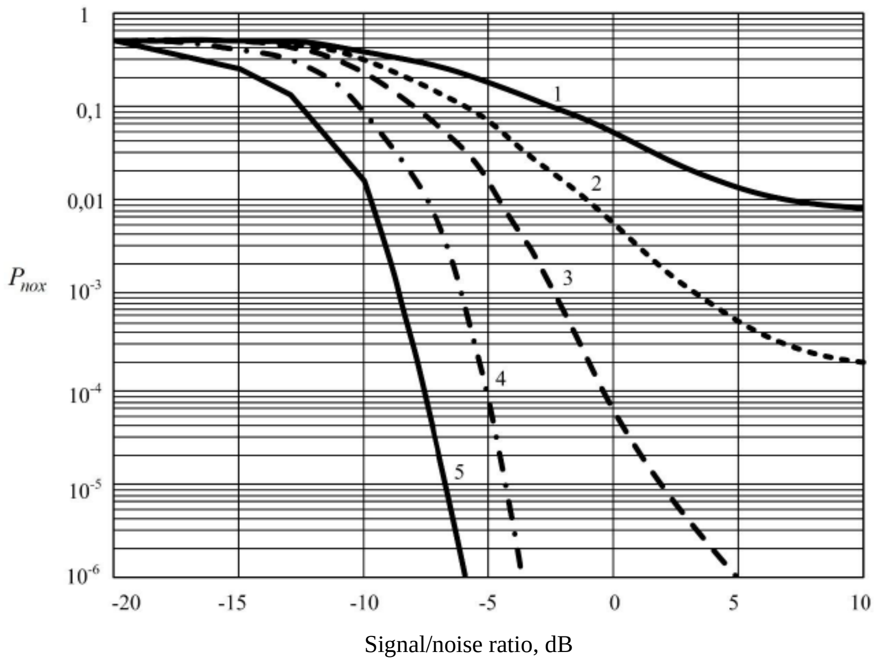

Fig. 1. The dependence of the probability of the error rate P on the signal-to-noise ratio at different signal bases: (1-B=50; 2-B=100; 3-B=200; 4-B=500; 5-B=1000).

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Characteristics analysis has shown that at a high signal base B > 300, when the intensity of the received signals is lower than the level of impairment, information transfer is carried out with a breakeven of less than 10-6, which characterizes its high probability of reliability. For digital double-beam signals the reliability of the received information is increased by 10 - 20 dB at low (-3, ..., - 5 dB) signal/noise ratios by increasing the basis of the information signal [12, 13]. The use of orthogonal functions as channel signals is due to the fact that the separation of these signals is performed without degradation of the signal/noise ratio.

Extension of information base is most effectively realized through creation of complex signal ensemble by means of its one-time coding and modulation [14], which allows the most complete use of the channel's bandwidth with high authenticity of information transmission without a significant increase in signal/noise at the receiver's input

When a complex signal is used, when a bit of information is transmitted during the period T_s by a binary numeric sequence function, its base is defined by the following relationship:

$$B_s = T_s / \tau_s$$

where τ_s is a duration of the elementary symbol (chip) of the numerical sequence.

Thus, increasing the signal base while preserving the speed of information transmission is possible by reducing the duration of the chip τ_s.

At the same time, the wide frequency band and ultra-short duration of the chips make increased demands on the accuracy of synchronization. Information signals and synchronization signals are at the same energy level, and the spectral density of all channels is at the noise level, so the system is significantly degraded by the values of the probability of bit error. Thus, the simultaneous coding, synchronization and modulation of the information bit is carried out, creating a complex signal-code structure. As a result, an ensemble of the complex signal is formed, where the information signal is isolated in time from the reference one bit interval T_s. The transmitter circuit (fig. 2) uses a tripping commutator, which switches the transmitter output directly to the LNS signal generator (G) during the first half of the bit interval. Thus, during the period of time $T_s/2$ the reference LNS signal is formed.

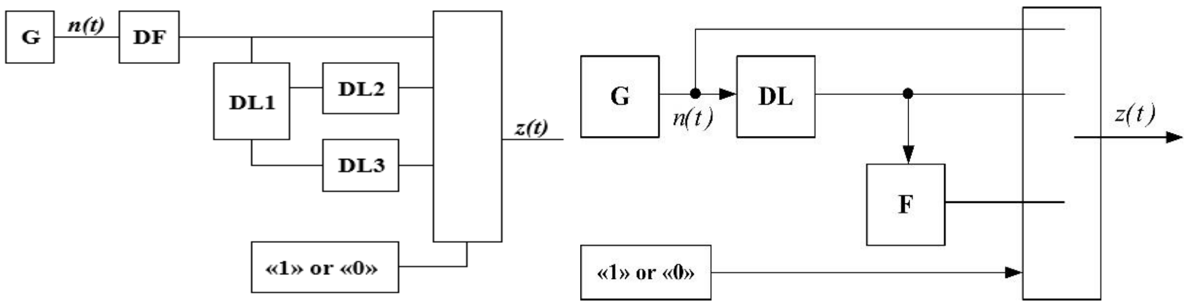

Fig. 2. Scheme of formation an ensemble of complex LNS information signal

In the middle of the bit interval the commutator is switched to one of the two possible positions, depending on the flow of two-way bits "one" or "zero" from the information source. Thus, the delay line DL1 ensures delay of the signal x(t) by half of the bit interval $T_s/2$, and delay lines DL2 and DL3 are backed indirectly to form a stream of double bits "one" or "zero" As a result, an ensemble of complex signals is formed, where the information signal, separated in time from the reference signal, and on one interval T_s has the following form.

$$y(t) = \begin{cases} x(t),\ 0 \le t \le \dfrac{T}{2}; \\ x\left(t - \dfrac{T}{2} - T_0\right),\ \dfrac{T}{2} \le t \le T; \\ x\left(t - \dfrac{T}{2} - T_1\right),\ \dfrac{T}{2} \le t \le T. \end{cases}$$

Thus, the use of LNS communication technology in the timing of the synchronous pulse and information signal allows to ensure that the requirements of noise immunity, security and safety of wireless mobile communication channels at all stages of their development, production and operation are guaranteed.

Due to the creation of complex signal-code structures of information signal by a one-time use of processes of coding and modulation receives a signal that occupies a greater range of frequencies, and has significantly less of its intensity in comparison with the signal that is realized by their successive processes. This allows for higher efficiency and energy gain. Spectrum broadening results in the signal being distributed more evenly and less narrowly in the specified range of the spectrum. Thus, not only increases the noise immunity of information, but also reduces the likelihood of its overexposure due to the absence of a synchronized copy of the broadening signal. Considering that the problem of organization of high-quality mobile communication and protection of information in wireless radio networks is to reduce the level of backward electromagnetic environment, the technology of Ultra-Wide band signals is the most appropriate for its practical use. However, the evaluation of the efficiency of these or other technological solutions when implementing them in DCS requires the use of certain evaluation criteria.

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Method for increasing the energy efficiency of digital communication systems

Concealment of communication channels is characterized by its energetic concealment, the components of which are the processes of forming, coding and modulation of information signal. However, the universal indicator is the base of the information signal, the value of which determines the level of availability of the communication channel.

The main way to increase energy earliness of the communication channel of the digital wireless system is to decrease the signal/noise ratio at the output of the correlation receiver. The dependence of the variability of the hysteresis P on the signal-to-noise ratio at different signal bases (fig. 1) leads to the tendency to the maximum possible reduction of the signal power intensity to the necessity of using the signal at the maximum base. The dependence of the quality of information transmission on the width of the signal spectrum leads to the fact that DCS with complex signals considerably increases the s/n ratio at high demands to the quality of information transmission.

According to V.A. Kotelnikov's potential noise immunity theory [15], the limit for the reduction of the information signal level for all classes of receiver systems without exception is the ratio of the subsurface energy of the signal E to the spectral power density of noise N_0, which is the value:

$$Q = 2E/N_0 = 2q_0 B ,$$

where: $q_0 = \frac{E/T}{N_0 W}$ is the ratio of the average signal power $P_{s0} = E/T$ to the noise power $P_{N0} = N_0 W$ at the receiver input, and $B = WT$ is the signal basis.

In the systems of radio-electronic antidetection when radio contamination of the communication channel is carried out, first of all, the presence of corrupting signal is detected. However, the intelligence receiver practically does not detect the useful signal $q_0 \le 1$ when it is used. This is due to the fact that its square detector further reduces the useful signal that will be identified as interference. The resulting signal/noise value at the output of the receiver detector for a uniform spectral signal strength is determined by the following ratio:

$$\left(\frac{P_s}{P_n}\right)_{out} \approx 55 q_0^2 ,$$

where: P_s is a signal power, P_n is a noise power.

At the same time, the following relationship will take place for the values $q_0 \ge 1$:

$$\left(\frac{P_s}{P_n}\right)_{out} \approx 4,6 q_0 .$$

Thus, at a weak signal in the intelligence receiver there is a suppression of the useful signal by interference, which significantly increases its energy concealment.

Method and criteria for evaluating the noise immunity of the digital communication system

Noise immunity of the discrete communication channel depends on the structure and type of signal and interferences, their intensity, the structure of the channel receiver, type of antennas, etc. However, if the optimal signal reception is performed against the background of the own noise of the receiver, the noise immunity of signal reception of any shape will be the same and will be determined only by the signal energy and spectral noise power, which is brought to the input of the receiver. DCS technical effect determines the amount and quality of transmitted information for a certain period of time or per unit of time, i.e. transmission rate R (bit/s) and the probability of error P in the transmission of discrete messages.

Indicators of energy $\beta = \frac{R_u N_0}{P_s}$ and frequency $\gamma = \frac{R_u}{F_s}$ efficiency, determine the consumption of these resources. In these relations P_s is a signal power, F_s - signal bandwidth, R_u – transmission speed.

Combining these indicators, we get the integral indicator of informational efficiency:

$$\eta = \frac{R_u}{C} ,$$

where C is a communication channel capacity.

It is the most general indicator, which determines the technical efficiency of the system. Graphical dependence for the channel efficiency is presented in coordinates β γ in fig. 2. It is a limit and mirrors the best exchange between β and γ. In coordinates β and γ, each variant of the real system will be matched by the corresponding point on the plane, which is located below the Shannon limit dependence [16]. When comparing it with the ideal system (Shannon's limit) the winnings will be negative. It determines how close the inverse system is to the ideal system.

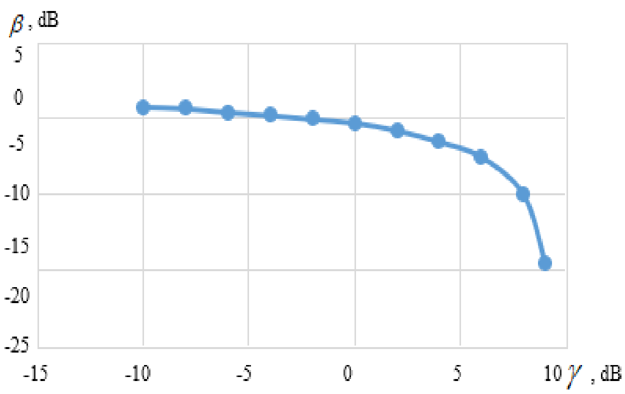

Fig. 3. Shannon's limit

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The coefficients β and γ can be calculated for most real systems in order to compare them. Varying these interrelated characteristics, there is a possibility to estimate the degree of influence of characteristics of real channels and non-ideality of parameters of transmission and reception devices and to determine their optimum correlation

$$\beta = \frac{\gamma}{2^{\gamma} - 1}.$$

Under the condition $\eta = 1$ we obtain the boundary dependence between β and γ (Shannon limit), which means that any radio channel will have poorer characteristics of energy and frequency efficiency.

Channel throughput with additive Gaussian noise (in bps).

$$C = \log\left(P_s / P_n + 1\right). \quad (1)$$

In calculation per character (bits/countdown):

$$C_n = 0,5\log\left(P_s / P_n + 1\right).$$

The channel capacity utilization coefficient (informational efficiency) is entered as a summary indicator of DCS technical efficiency.

$$\eta = \frac{R_u}{C} = 1 - \chi, \quad (2)$$

where: $\chi = \frac{(C - R_u)}{C} = 1 - \eta$ is a redundancy of the channel.

According to (1) and (2)

$$\eta = \gamma \log(\frac{\gamma}{\beta} + 1).$$

We take this function as a target and determine its maximum value. The value η can be close to one, and the error can be arbitrarily small. In real systems, the error always has a finite value and $\eta < 1$. In these cases, β and γ are determined separately and the dependences $\beta = f(\gamma)$ are constructed for $p = const$. It should be noted that in digital binary communication systems, the coefficient γ can vary from 0 to log 2 = 0.3 dB, and the coefficient β from 0 to $\frac{1}{\ln 2}$ = 1.44 dB.

Digital communication systems are divided into two groups. These are systems with high β but low γ efficiency. Digital communication systems belong to this group, which must ensure the best possible use of the signal power at a given accuracy of transmission. In particular, this concerns space and satellite communication systems. The other group includes systems with high γ, but low β – efficiency, which is typical for the systems of conducting communication, when it is necessary to obtain the best possible use of the channel frequency smoothness at a given transmission variability. Sometimes, a compromise solution should be adopted, which allows to obtain simultaneously the values of β and γ of Diagram (fig. 3) to solve this problem. For wireless communication channels the technical effect is conveniently determined by the energy gain:

$$\Delta\beta = \beta / \beta_s \text{ при } \gamma = \gamma_{add}.,$$

where β is an energy efficiency of the selected system;

β_s is an energy efficiency of the basic (reference) system. Thus, the obtained β/γ-diagrams allow turning DCS, which meet the specified requirements, or to optimize for the coefficients of β and γ.

Analysis

Analysis of the problem of ensuring noise immunity and reliability of wireless communication channels has shown that the main method of its solution is to reduce the level of electromagnetic field impromptu. In the case when the speed of information transmission is set (Ru = const), it is possible to operate at a low signal/noise ratio, which is a common problem in a faulty communication system, only by decreasing the frequency and energy efficiency. In this case, according to Shannon's theorem, due to the appropriate coding the quality of transmission of messages can be made as good as desired. On the basis of the theory of potential noise immunity Kotelnikov V.A. shows the possibility of the established and warrantless operation of wireless digital communication system in conditions where the level of information signal and noise have the same value. The possibility of separating the transmitted information signal from the noise by correlation of the received and reference signals is shown.

Conclusions

To increase the energy capacity and noise immunity of the communication channel, it is necessary to use the transmission with the lowest possible quality indicator q_0. In this case, it is advisable to use highly directional antennas with the smallest possible level of lateral pendulums, as well as to use a nose signal with the highest value of the signal base $B \gg 1$, using complex signals.

It is shown that the use of the technology of supersmooth signals allows to carry out wireless redundant transmission of information with low impromptu capacity. Moreover, the efficiency of digital communication systems significantly increases due to the creation of an ensemble of complex signals through one-time encoding and modulation, which expands its information base, ensuring concealment and energy efficiency in a dual symmetric channel. Diffusion in the timing of the synchropulse and information signal within the limits of the duration of the information beat allows you to securely ensure the requirements of noise immunity, prihovanovosti and safety of wireless communication channels at all stages of their design, manufacture and operation at the expense of transmission of information signals with low impromptu power. Using a large base signal makes it possible to ensure smooth and seamless operation of the digital communication system under conditions where the level of information signal is at or below the noise level. The Integral Indicator of Informational Efficiency of Wireless DCS Communication Channel was provided. It enables real-time integral assessment of link quality and optimal routing in a mobile peer-to-peer network - MANET.

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МЕТОДИ І ЗАСОБИ ОЦІНКИ РІВНЯ ЗАВАДОСТІЙКОСТІ БЕЗПРОВІДНИХ КАНАЛІВ ЗВ’ЯЗКУ

Предметом розгляду статті є процеси підвищення завадостійкості безпровідних каналів при побудові чи експлуатації сучасних цифрових систем зв’язку (ЦСЗ), коли передачу цифрової інформації суттєво ускладнює наявність завад та спотворень в каналі зв’язку. **Мета** – аналіз та розробка методів забезпечення усталеної та надійної роботи надширокосмугової системи безпровідного зв’язку в умовах дії завад та спотворень інформації в безпровідних каналах зв’язку. **Задача** – створення та впровадження практичних рекомендації щодо покращення рівня прихованості і якості інформації, яка циркулює в каналі зв’язку; розробка критеріїв якості, інформаційної ефективності та завадостійкості безпровідних каналів зв’язку ЦСЗ в умовах дії завад природного та штучного походження. Використані **методи**: методи аналітичного моделювання та теорії потенційної завадостійкості. Отримані наступні **результати**. Показана доцільність проведення оцінки ефективності ЦСЗ за двома показниками – енергетичної та і частотної ефективності, які є складовими та створюють загальний інтегральний показник інформаційної ефективності. Запропоновано здійснювати оцінку ефективності ЦСЗ шляхом порівняння показників інформаційної ефективності обраної та еталонної систем, використовуючи межу Шеннона як ідеальне співвідношення енергетичної та частотної ефективності. На ґрунті теорії потенціальної завадостійкості показана можливість усталеної та беззавадової роботи безпровідних каналів зв’язку в умовах, коли рівень інформаційного сигналу та шуму мають одне значення. **Висновки.** Показано, що використання технології надширокосмугових сигналів дозволяє здійснити безпровідну приховану передачу інформації з малою потужністю випромінювання. Причому ефективність цифрових систем зв’язку суттєво збільшується за рахунок створення ансамблю складного сигналу шляхом одночасного кодування і модуляції, що розширює його інформаційну базу, забезпечуючи прихованість та енергетичну ефективність у двійковому симетричному каналі. Це дозволяє найбільш повно використовувати шеннонівську пропускну здатність каналу з високою достовірністю передачі інформації без суттєвого підвищення відношення сигнал/шум на вході приймача. Запропоновано інтегральний показник інформаційної ефективності безпровідного каналу зв’язку ЦСЗ. Він дозволяє у режимі реального часу здійснювати інтегральну оцінку якості каналу зв’язку та виконувати оптимальну маршрутизацію в мобільній одноранговій мережі – MANET.

Ключові слова: інформаційна ефективність; завадозахищеність; завадостійкість; прихованість; канал зв’язку.

МЕТОДЫ И СРЕДСТВА ОЦЕНКИ УРОВНЯ ПОМЕХОУСТОЙЧИВОСТИ БЕСПРОВОДНЫХ КАНАЛОВ СВЯЗИ

Предметом рассмотрения статьи являются процессы повышения помехоустойчивости беспроводных каналов при построении или эксплуатации современных цифровых систем связи (ЦСЗ), когда передачу цифровой информации существенно усложняет наличие помех и искажений в канале связи. **Цель** – анализ и разработка методов обеспечения устойчивой и надежной работы сверхширокополосной системы беспроводной связи в условиях помех и искажений информации в беспроводных каналах связи. **Задача** – создание и внедрение практических рекомендаций по улучшению уровня скрытности и качества информации, циркулирующей в канале связи; разработка критериев качества, информационной эффективности и помехоустойчивости беспроводных каналов связи ЦСЗ в условиях действия помех естественного и искусственного происхождения. Используемые **методы**: методы аналитического моделирования и теории потенциальной помехоустойчивости. Получены следующие **результаты**. Показана целесообразность проведения оценки эффективности ЦСЗ по двум показателям – энергетической и частотной эффективности, которые являются составляющими и создают общий интегральный показатель информационной эффективности. Предложено оценку эффективности ЦСЗ путем сравнения показателей информационной эффективности выбранной и эталонной систем, используя границу Шеннона как идеальное соотношение энергетической и частотной эффективности. На основе теории потенциальной помехоустойчивости показана возможность установившейся и беспомеховой работы беспроводных каналов связи в условиях, когда уровень информационного сигнала и шума имеют одно значение. **Выводы.** Показано, что использование технологии сверхширокополосных сигналов позволяет осуществить беспроводную скрытую передачу информации с малой мощностью излучения. Причем эффективность цифровых систем связи существенно увеличивается за счет создания ансамбля сложного сигнала путем одновременного кодирования и модуляции, что расширяет его информационную базу, обеспечивая скрытость и энергетическую эффективность в двоичном симметричном канале. Это позволяет наиболее полно использовать Шенноновскую пропускную способность канала с высокой достоверностью передачи информации без существенного повышения отношения сигнал/шум на входе приемника. Предложен интегральный показатель информационной эффективности беспроводного канала связи ЦОС. Он позволяет в режиме реального времени производить интегральную оценку качества канала связи и выполнять оптимальную маршрутизацию в мобильной одноранговой сети – MANET.

Ключевые слова: информационная эффективность; помехозащищенность; помехоустойчивость; скрытность; канал связи.

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