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INTELLIGENT WIRELESS COMMUNICATION SYSTEM

Abstract. The subject of the study is models and methods for organizing a semantic communication system to increase the throughput of a wireless communication system. The **goal is to** develop recommendations for the implementation of multiple access with the distribution of information space according to the model. The development is based on artificial intelligence technology, which allows us to extract general and personalized semantic information from the multidimensional semantic space separately, allowing the communication system to move from the traditional transmission of information bits to the transmission of a model. The **task is to** ensure stable and reliable operation of a wireless network with an extended communication channel bandwidth. **Methods** used: methods of analytical modeling and time-position pulse coding. The following **results were** obtained. It is shown that in order to ensure the high quality of the wireless network, it is necessary to expand its bandwidth, which is limited by the physical resource of the radio frequency spectrum. It is proposed to overcome this contradiction by applying the technology of multiple access with distribution over the model. In this case, the information signal is emitted to the base station without a carrier frequency simultaneously in the entire frequency band, provided that the signal level is lower than the noise level. In this case, the method of positional-time coding is used, in which each information bit is encoded by hundreds of ultra-short chip pulses arriving in a certain sequence. In such wireless communication systems, the use of autocorrelation reception of modulated ultra-wideband signals is proposed. At the same time, the best reliability and noise immunity is provided by a wireless network using the time separation of the reference and information signals. **Conclusions.** Semantic communication systems with autocorrelation reception and separate transmission of reference and information signals provide an increase in the bandwidth of a wireless communication system, a high level of structural signal concealment, and reliable transmission of digital information, especially in conditions of interference.

Keywords: Semantic communication; Multiple access technology; Intelligent wireless network; Ultra-wideband signaling technology.

Introduction

The evolution of existing 5G wireless communication technologies and the development of 6G technologies are driven by the need to support new applications with various increased requirements for system performance and capacity. At the same time, modern wireless communications require enhanced security, high reliability and low signal latency. When organizing wireless communication, the physical limitation of the frequency spectrum requires the use of ultra-wideband (UWB) signaling technology, the essence of which is the transmission of low-power coded pulses in a very wide frequency band without a carrier frequency [1, 2]. To transmit information in NSF systems, pulse signals with very short pulse durations are used. Such a signal with a small space-time volume allows transmitting a large amount of information per unit of time, has a high level of noise immunity, and the ability to overcome the phenomena of multipath propagation of radio waves.

The ultra-short duration of the information sequence of the chips is due to the broadband of their spectrum in the radio frequency range (0...10 GHz), which is characterized by the lowest radio signal attenuation.

This makes it possible to use the radio frequency spectrum quite efficiently when operating in a congested frequency range. Thus, the use of NSS signals allows to transmit information at a speed significantly exceeding the speed of traditional communication means with high noise immunity.

However, the broadband of information and reference signals impose significant restrictions on the efficiency of radio frequency spectrum use, especially when organizing multiple access, when system resources must be distributed among different users. Thus, the organization of multiple access requires an increase in the efficiency of radio frequency spectrum use.

The purpose of this work *is to* develop recommendations for the implementation of multiple access with the efficient use of the radio frequency spectrum.

Method of encoding an information signal

In wireless communication channels, the transmission medium is the physical path between the transmitter and the receiver. The most optimal range is between 1 and 10 GHz. This is because frequencies below 1 GHz are subject to significant interference from various industrial electronic devices. At the same time, at frequencies above 10 GHz, there is a large absorption of the useful signal by the transmission medium.

The frequency band of the radiation pulses is determined by the relation $B = WT_s$, where: W is the frequency bandwidth, and T_s is the transmission time of a bit of information. With the expansion of the signal base $B \gg 1$ base, it becomes possible to increase the information transmission rate by reducing the duration of the transmitted signal.

In 1974, Massey J.L. [3] proposed to consider noise immune coding and modulation as a single unit. This ensures higher efficiency and energy gain from coding than the sequential application of noise immune coding and modulation. For example, to transmit information, one information bit is encoded by a sequence of many pulses (chips) per bit, which are shifted in time relative to the reference pulse-chip sequence. Depending on the value of the information bit "0" or "1", the sequence of information pulses-chips is shifted in time by 0.25 of the chip duration forward "zero" or backward "one" (Fig. 1.) [4].

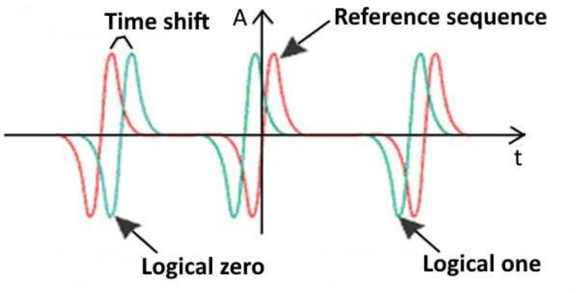

Fig. 1. The method of forming an ensemble of complex NSNS information signal

During encoding, the minimum chip arrival period is determined by the time for the chip energy to dissipate before the next chip in the information sequence arrives. On the other hand, an increase in the number of chips in the information bit sequence allows for an increase in the signal-to-noise ratio at the receiver input during decoding and correlation reception. The accumulation of a certain number of ultra-short pulses encoding each of the information bits in the receiver's correlator makes it possible to significantly increase the signal-to-noise ratio at the receiver's input, providing the ability to transmit information in a wide frequency range well below the white noise level.

Model of information signal ensemble formation

The formation of an ensemble of a complex NSN of an information signal radiated to free space is realized using the model, the scheme of which is shown in Fig. 2. The ultra-wideband signal is formed in the form of a normal random process *n(t)* with a zero mean, uniform spectrum *S(t)* and a frequency band Δf [5].

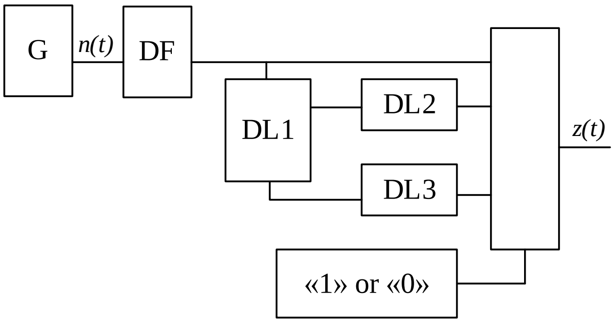

Fig. 2. Model of separate formation of reference and information signals

Fig. 2 shows: G – oscillator, which in self-oscillatory mode generates a sequence of ultrashort pulses- chips; DF – digital bandpass filter, which generates a signal *n(t)*; DL – delay lines, which are shifted by time T_1 or T_0 form information signals according to the flow of binary bits "one" or "zero" from the information source.

The oscillator (G) in self-oscillatory mode generates a sequence of ultra-short pulses-chips with a period of $t_Д$ which is fed to the input of the digital bandpass filter (DF), which generates the signal *n(t)*. From the output of the DF, the ultra-wideband signal *n(t)* is fed to the modulator, where it is divided into information and reference signals. The three-position switch closes the transmitter output directly to the NSF signal generator (G) during the first half of the bit interval.

Thus, during the period of time $T_s/2$ the reference NSS signal is generated. In the middle of the bit interval, the switch is switched to one of two possible positions, depending on the flow of binary bits "one" or "zero" from the information source.

At the same time, the DL1 delay line provides a delay of the signal ***n(t)*** by half a bit interval $T_s/2$ and delay lines DL2 and DL3 are used directly to form a stream of binary bits "one" or "zero". As a result, an information signal is formed, separated in time from the reference signal, which at one interval T_S has the following form:

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

Thus, the transmitter generates and emits a complex signal to free space, which includes an information pulse NSN signal in the form of an encoded pulse sequence and a separate reference pulse sequence of the synchronization signal, which doubles the overload of the radio frequency spectrum when organizing multiple access.

NSF signal generators emit ultrashort duration pulses with ultra-fast rise and fall. The discovery of the effect of voltage recovery and ultra-fast reverse breakdown in high-voltage transients has contributed to the creation of fundamentally new semiconductor devices capable of switching high power in short time intervals, including devices based on a delayed shock-ionization wave and drift devices with sharp recovery. Such generators allow generating ultrashort pulses of nano- and pico-second duration with power up to tens of MW and repetition rate up to tens of MHz, while controlling their temporal position with an accuracy of more than 10 ps. The maximum pulse voltage reaches tens of kilovolts, and pulse currents reach thousands of amperes [6].

As the repetition rate increases, the peak power decreases, but remains much higher than that obtained with any other semiconductor devices. This makes it possible to use the developed oscillators in UWB communication systems (Table 1), and the service life of these devices is extremely high.

Table 1 – **Technical characteristics of NSS generators**

Model	Growth time, ns	Pulse width, ns	Amplitude, V	Repetition rate, MHz
HFPG-1-0.5	< 0,7	< 2	500	2(3)
HFPG-1-2.5	< 0,7	< 2	2500	(2)
HFPG-1-5	< 0,7	< 2	5000	(0,5)
HFPG-5-0.05	< 0,14	< 0,3	50	10(20)
HFPG-7-0.15	< 0,3	< 0,7	150	10(20)
HFPG-7-0.5	< 0,3	< 0,7	500	2
HFPG-7-1	< 0,3	< 0,7	1000	1
HFPG-4-0.5	< 0,1	< 0,5	500	(0,2)
HFPG-4-1-10	< 0,1	< 0,25	1100	0,01
HFPG-4-1-50	< 0,1	< 0,25	1100	0,05

Generators of powerful ultrashort pulses are created using diode avalanche sharpeners as the final stage of a circuit based on drift diodes and transistors with sharp recovery. By connecting them in series, high switching voltages are achieved. [7]. A chain of series-connected drift diodes with a sharp recovery works as a single diode. Its voltage decay time is 50-200 ps, and the maximum allowable voltage is up to 15 kV. The advantages of such circuits are the high rate of voltage rise, which is combined with a high pulse repetition rate and their precise positioning in the time sequence, which undoubtedly makes them the basis for the implementation of the NSW technology in wireless communications.

The useful signal is **extracted** from the noise by correlating the received and reference signals. The correlator convolves the received signal with the reference signal to determine the time shifts of the received pulses relative to the reference. Thus, when receiving a one, the correlation function is equal to +1, and when receiving a zero, it takes the value -1. In all other cases, the correlation function is equal to 0.

At the same time, reliable detection of the information signal is carried out at any small signal-to-noise ratio.

Thus, a wireless network with the use of time separation of the reference and information signals has the best reliability and noise immunity. [8]. However, the constant transmission of the reference signal by users leads to inefficient use of the radio frequency spectrum, especially when organizing multiple access

Multiple access technology

Multiple access (MA) technology seeks to use shared information to eliminate bandwidth losses due to redundant transmissions. Maximizing the throughput of a wireless communication system and minimizing semantic errors during information recovery is based on artificial intelligence (AI) technology, which separately extracts general and personalized semantic information. [9, 10]. AI technology is used to create a knowledge base in both the receiver and the transmitter to ensure high efficiency of semantic information extraction methods and the use of prior knowledge and information about the communication channel.

The semantic communication system creates a new distribution resource, namely the model of information space, which became the basis of a new technology of multiple access. Traditional MD technology takes into account physical resources such as time (TDMA), frequency (FDMA), power and space (SDMA). Thus, building a semantic communication system at the physical level has become an important element in the transmission of semantic information.

The channel capacity, which combines traditional physical resources and the information space of the model [11], is as follows.

$$C = TB\sum_{k=0}^{n} log_2\left(I + \frac{P_k}{\sigma^2} H\Phi_k H^H\right),$$

where T, B, P, H, and Φ are the time domain resource, frequency resource, energy resource, space resource, and information space resource of the model, respectively, I is the identity matrix, and σ^2 is the noise variance.

At the same time, the new CBM technology offers multiple access with model-based distribution. Semantic features extracted from the source information using an AI model allow modeling personal characteristics of the user, which provide a knowledge base for differentiating multi-user semantic information.

In this way, CBM technology sequentially identifies, analyzes, and extracts general and personalized information contained in semantic information extracted from the model from multiple users. Then, the signals containing general information are overlaid and reused. This allows to obtain the CBM effect and increase the transmission channel capacity.

Algorithm of CBM technology implementation

The information in the semantic signals of a certain number of users consists of general and personalized information. In the case of simultaneous transmission of information from several users who initiated the uplink commands, the base station receives and compares it. When requesting a connection, the base station receives general information - the chip reference sequence in the form of a model - which is compared with the existing models in the base station database using AI. If the received model is not available in the database, it is added to the database, and during subsequent signal transmissions from the user, the general information is not transmitted, but is removed from the knowledge base. Continuing the communication session, users send only the synchronization signal and personal semantic information to the base station. After receiving the synchronization signal and personalized information from the users, the base station recovers the primary semantic signals of each user by correlating the received and reference signals. And the reference chip sequence, which is a common information model, is removed from the base station's knowledge base, thus reducing the load on the wireless communication channel by half when organizing multiple access. Thus, the information model created with the help of AI allows modeling the personal characteristics of the user, which provides a knowledge base for differentiating multi-user semantic information.

In addition, the base station simultaneously distributes semantic signals from multiple data sources to multiple users. The signals that carry general information are combined and sent together. At the same time, signals carrying personalized information are transmitted to the user separately. In this way, each user receives his or her own information, which is recovered using a semantic decoder based on the combination of general and personalized information.

The useful signal is extracted from the noise by correlating the received and reference signals. The block diagram of the correlator is shown in Fig. 3.

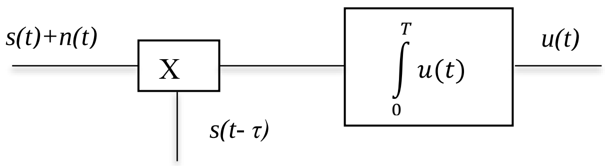

Fig. 3. Schematic diagram of the correlator of NSF signals

The correlator includes a multiplication device, to the other input of which a specially generated reference signal carrying general information is fed [11]. This signal completely repeats the useful signal in form, but lags behind it by a time τ, which allows to distinguish information. Subsequently, the signal that occurs at the output of the multiplication device is integrated, and the integration interval is equal to the duration of the signal $s(t)$.

The correlator performs convolution of the received signal with the reference signal. It is a detector that determines the time shifts of the received pulse signals relative to the reference signals. For example, when receiving a binary one, the correlation function is equal to +1, and when receiving a binary zero, it takes the value -1. In all other cases, the correlation function is zero. The accumulation of a certain number of ultra-short pulses encoding each of the information bits in the receiver's correlator makes it possible to significantly increase the signal-to-noise ratio, providing the ability to transmit information in a wide frequency range well below the white noise level. This makes it possible to meet the requirements for the level of electromagnetic compatibility of wireless mobile communication systems.

The use of ultra-wideband signals in the organization of multiple access requires the use of **special antenna systems** that allow them to be evenly matched to the antenna system in a wide frequency band [12]. For this purpose, an antenna that has the shape of an open slot is usually used, which determines the frequency band during reception/transmission. Moreover, the energy pattern of such an antenna is characterized by a narrow main beam and the practical absence of side lobes. However, the preliminary formation of a Gaussian monocycle entering the antenna system causes difficulties in matching in a wide frequency band. This manifests itself in the form of re-reflection of individual signal components, which distorts the shape of the Gaussian monocycle.

Therefore, the radiation pulse is formed directly in the antenna opening**.**

To do this, the information monopulse signal is split in half. A portion of the signal is sequentially inverted and delayed for a period of time equal to half the duration of the monopulse. Both mono-pulse signals are used to excite two TSA antennas located side by side on a single dielectric base. The electromagnetic fields of both monopulse signals interfere with the equivalent common aperture space of both antennas, creating a bipolar pulse electromagnetic field in it, while eliminating the time gap between the two parts of the radiated field, which is typical for a TSA antenna. Thus, such an antenna in an ultra-wideband communication system is capable of emitting and receiving both an ultra-short unipolar monopulse and a bipolar pulse information signal, which allows to significantly increase (by 3-10 times) the range of propagation of pulsed electromagnetic signals.

Design options for special antenna systems for receiving/transmitting ultra-wideband signals are shown in Fig. 4.

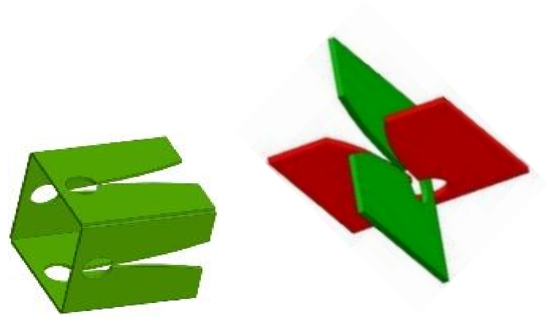

Fig. 4. Design options for special antenna systems

Conclusions

Recommendations for the implementation of multiple access with the distribution of information space according to the model are developed. The development is based on artificial intelligence technology, which allows us to extract general and personalized semantic information from the multidimensional semantic space separately, which allows the communication system to move from the traditional transmission of information bits to the transmission of a model.

It is shown that in order to ensure the high quality of the wireless network, it is necessary to expand its bandwidth, which is limited by the physical resource of the radio frequency spectrum. It is proposed to overcome this contradiction by applying the technology of multiple access with distribution over the model.

In this case, the information signal is emitted to the base station without a carrier frequency simultaneously in the entire frequency band, provided that the signal level is lower than the noise level.

It is shown that semantic communication systems with autocorrelation reception and separate transmission of reference and information signals provide almost a doubling of the wireless communication system capacity, a high level of structural signal concealment, and reliable transmission of digital information, especially in the presence of interference.

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Інтелектуальна безпровідна система зв'язку

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Анотація. Предметом дослідження є моделі і методи організації системи семантичної комунікації для підвищення пропускної здатності безпровідної системи зв'язку. **Мета** – розробка рекомендацій щодо реалізації множинного доступу з розподіленням інформаційного простору за моделлю. В основу розробки покладено технологію штучного інтелекту, завдяки якій із багатовимірного семантичного простору вилучаємо окремо загальну та персоналізовану семантичну інформацію, що дозволяє системі зв'язку перейти від традиційної передачі бітів інформації до передачі моделі. **Задача** – забезпечення усталеної та надійної роботи безпровідної мережі з розширеною смугою пропускання каналу зв'язку. Використані **методи**: методи аналітичного моделювання та часового позиційно-імпульсного кодування. Отримані наступні **результати**. Показано, що для забезпечення високої якості роботи безпровідної мережі слід розширювати її пропускну спроможність, яка обмежена фізичним ресурсом радіочастотного спектру. Запропоновано долати це протиріччя шляхом застосування технології множинного доступу з розподіленням по моделі. При цьому випромінювання інформаційного сигналу до базової станції здійснюють без несучої частоти водночас у всій смузі частот за умов, що рівень сигналу нижче за рівень шуму. При цьому застосовано метод позиційно-часового кодування при якому кожен інформаційний біт кодують сотнями надкоротких імпульсів-чипів, що надходять за визначеною послідовністю. В таких системах безпровідного зв'язку запропоновано застосування автокореляційного прийому модульованих надширокосмугових сигналів. При цьому найкраща надійність і завадостійкість має безпровідна мережа із застосуванням часового розділення опорного та інформаційного сигналів. **Висновки.** Системи семантичної комунікації з автокореляційним прийомом та роздільною передачею опорного та інформаційного сигналів забезпечують розширення пропускної здатності безпровідної системи зв'язку, високий рівень структурної прихованості сигналу, а також надійну передачу цифрової інформації, особливо в умовах дії завад.

Keywords: семантична комунікація; технологія множинного доступу; інтелектуальна безпровідна мережа; технологія надширокосмугових сигналів.