The Order of Formation of Information Signals in IIoT

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Abstract
In this article we propose using mathematical models of signals in wireless communication systems with autocorrelation reception of modulated ultra-wideband signals. For the transmission of information content, the method of positional-time coding is used, in which each information bit is encoded by hundreds of ultra-short pulses that arrive within a certain sequence. Comparative analysis has shown that the best noise immunity of the systems considered in this paper is the communication system, which uses the time separation of the reference and information signals.

Keywords
IIoT, security, mobile communication, noise immunity, ultra-wideband signals.

I. INTRODUCTION

The Industrial Internet of Things (IIoT) it is a system of integrated computer networks and industrial facilities connected to them with built-in sensors and software for data collection and exchange, with the possibility of remote monitoring and control in automated mode, without human intervention. This system requires providing it with a large number of high-quality communication channels that have a high specific density of their location in space. At the same time, the main indicator of the quality of a wireless ultra-wideband channel is the signal-to-interference ratio at the input of the correlation receiver. The complexity of organizing connection within the IIoT system between its individual elements gives an advantage for the use of wireless communication. In turn, this causes difficulties in ensuring a certain level of noise immunity of communication channels, which is due to the high density of system elements located in the space of an industrial facility IIoT. Their simultaneous operation worsens the internal electromagnetic environment, contributes to a decrease in the quality of communication channels and the speed of transmission of information circulating in the System [1, 2, 16 - 20].

II. WAYS TO IMPROVE THE QUALITY OF WIRELESS COMMUNICATION AND THEIR ANALYSIS

The most effective way to increase the level of noise immunity and speed of information transmission in IIoT is to introduce frequency redundancy, which is inherent in signals with an ultra-wide frequency band. The application of such communication systems is based on the concept of ultra-wideband pulse signals with short duration [3-7, 15]. By increasing the frequency band of the signal, the stability of the communication channel to interference from neighboring channels increases, which makes it possible for a large number of communication channels to work simultaneously in the same frequency range. Due to the low spectral density of the radiation signal during message transmission, a high level of its energy secrecy and information protection is provided, also exceeding the capabilities of conventional wide-band systems in terms of information transmission speed and noise immunity. Therefore, the use of ultra-wideband signals is a priority in solving the problem of improving the information capabilities of communication in the IIoT system.

The aim of the work is to increase the security, bandwidth and noise immunity of distributed IIoT, which are built on the basis of personal and local area networks with low energy consumption under the influence of natural and artificial interference. Thus, IIoT is a distributed system that operates in real time under the influence of electromagnetic interference with increased requirements for security and speed of information transmission in wireless communication networks.

III. OVERVIEW OF THE COMMUNICATION CHANNEL QUALITY CRITERIA

The difference between ultra-wideband pulse signals communication systems and traditional narrow-band ones is the absence of a carrier frequency.

According to the theory of potential noise immunity [8], the characteristic of an information signal depend on the ratio of the double energy of the signal E to the spectral density of the noise power N_0 and is the value of:

$$Q = 2E/N_o = 2q_oB \qquad (1)$$

where: $q_o = (E/T)/N_oW$ – ratio of average signal strength $P_{s0} = E/T$ to the noise power $P_{N0} = N_0W$ at the receiver input, $B = WT$ is the baseband signal.

This criterion of noise immunity of multi-channel wireless access systems is extremely achievable for all classes of receiving systems without exception. At the same time, the possibility of further increasing the potential noise immunity of receiving devices was justified by D. Slepyan in his theorem [9], the application of which is valid only in cases where the width of the signal spectrum is greater than the width of the noise spectrum.

Ultra-wideband pulse signals systems use these signals with very short pulse duration to transmit information. Such a signal, which has a small space-time volume, allows transmitting a large amount of information per unit of time. To transmit one bit of information to a narrow-band system, it takes from 10 to 50 periods of carrier oscillation. At the same time, the ultra-wideband pulse signals communication system uses only one oscillation to transmit one bit of information. Obviously, the use of ultra-wideband pulse signals allows us to transmit information at a speed significantly higher than the speed of traditional means of communication.

In digital wireless communication, the channel quality criterion is the signal – to – noise ratio E_s/N_0 (SNR signal – to – noise ratio), which relates the average signal power S to the average noise power N. Moreover, E_s is the energy of the information bit, which is the signal power S multiplied by the transmission time of the bit T_s, and N_0 – is the spectral power of noise, which determines the noise power N divided by the bandwidth W. It should also be noted that the bit transfer time T_s, and its transfer rate R_s, are mutually inverse $T_s, = 1/R_s$.

The efficiency of a digital communication system determines the dependence of the probability of occurrence of a false bit P_s on the signal-to-interference ratio, which is also a standard measure of the noise immunity of digital communication systems [4],

$$E_s/N_0 = ST_s,/(N/W) = (S/N)(W/R) = (S/N)B \qquad (2)$$

where: $B = WT_s$ is the baseband signal.

Analysis of this ratio shows that the main parameter that allows you to ensure high communication quality and appropriate performance and noise immunity is the baseband signal B.

With the expansion of the B>>1 baseband signal, it becomes possible to increase the speed of information transmission by reducing the duration of the transmitted signal. Thus, some redundancy is introduced into the transmitted signal, the value of which is determined by the coefficient of expansion of the spectrum. It is the presence of this redundancy that determines such properties of ultra-wideband signal systems as the ability to overcome the phenomena of multipath propagation of radio waves and the effective use of the spectrum when operating in an overloaded frequency range.

However, under the influence of natural and artificial interference, redundancy leads to an increase in the probability of interference in the working frequency band, distorting information signals in the wireless communication channel.

IV. METHOD OF GENERATING INFORMATION SIGNALS

Information signals are generated by using ultra-wideband signals with a low spectral power density. Ultra-wideband pulse signals $n(t)$ is divided into two parts, of which one is used as a reference signal. The rest of the signal $n(t)$ is delayed for the time T_1 when the character «1» arrives or for the time T_0 when the character «0» arrives. The delay and reference signals are intended for mutual interference in the transmitter. In the transmitter adder, the reference signal $n(t)$ is compiled with ultra-wideband pulse signal, which is delayed for the time T_1 or T_0 depending on the receipt of the binary character «1» or «0»

$$Z_{1,0}(t) = n(t) + n(t - T_{1,0}) \qquad (3)$$

The power spectrum of the total signal is calculated for the time of receipt t_a of each of information symbol in the form:

$$\widetilde{S_z}(f) = 2\widetilde{S_n}(f)\,(1 + \cos(2\pi f T_{1,0})) \qquad (4)$$

where $\widetilde{S_n}(f)$ – estimation of the signal strength spectrum $n(t)$ during the analysis of t_a.

Folding of completely incoherent signals occurs when the relative delay T_1 or T_0 of the reference and delayed signals significantly exceeds the coherence time $\tau_c \approx 1/(\Delta f)$ of ultra-wideband signal $n(t)$:

$$T_{1,0} \gg \tau_c \quad \text{or} \quad T_{1,0}\Delta f \gg 1 \qquad (5)$$

Thus, the wireless line receives ultra-wideband signals with periodic code modulation of the spectrum in accordance with the flow of binary information symbols.

Optimal coherent reception of ultra-wideband signals consists in measuring the function of mutual correlation with the reference signal during the receipt of one

information bit. Measurement of the mutual correlation function for delayed ultra-wideband signals is carried out in the frequency domain by double spectral processing, performing their spectral compression.

The determination of the correlation function, taking into account the ratio (4) for the spectrum of received signals, is usually assigned to a high-speed digital Fourier processor. Applying the inverse Fourier transform from the power spectrum (4) allows us to calculate the autocorrelation function of the received ultra-wideband signal:

$$\widetilde{R_z}(\tau)=4\pi\int_0^\infty \widetilde{S_z}(f)cos(2\pi f\tau)df=$$
$$2[\widetilde{R_n}(\tau)+Rn(\tau-T_{1,0})+\widetilde{R_n}(\tau+T_{1,0})$$

where: $\widetilde{R_z}(\tau)$ - autocorrelation function of ultra-wideband signal.

The calculated autocorrelation function has an information peak on the delay time depending on the current character «1» or «0». The decision on the presence of one of the binary characters is made by shifting the information peak for the autocorrelation function by time T_1 or T_0. In this way, reliable recovery of the transmitted information is performed.

The wide frequency band and ultra-short pulse duration place increased demands on synchronization accuracy. In these ultra-wideband signal systems, a reference sequence of signals is used as a synchronization signal. 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 affected by the deterioration of the bit error probability values. At the same time, the use of ultra-wideband signal technology in mobile device communication systems makes it possible to increase the signal-to-noise ratio at the receiver input, which makes it possible to reduce the level of electromagnetic radiation and thus meet the requirements for increasing the level of noise immunity and stealth of the channel of mobile wireless communication systems.

Pulse receivers use a correlator that convolutes the input signal that is close in shape to the reference one. The correlator receives synchro pulses and pulses with different time intervals between them, which correspond to separate time intervals of the reference code sequence. If any interval coincides, the correlator generates a maximum, the position of which in time or a change in its polarity provides information about the type of transmitted binary signal. However, in this case, the synchronization system only works at large values of the signal-to-noise ratio at the receiver input.

During the formation of the ultra-wideband signal of an information signal in the transmitter and its decoding in the receiver due to interference of the reference and noise signals, intra-system interference occurs. Moreover, their

influence increases and leads to an increase in the level of bit error with an increase in the information transfer rate under conditions of a decrease in the bit transfer time T_s [10, 13].

Usually, in existing wireless channels of ultra-wideband signal communication systems, both reference and information signals are transmitted simultaneously, which create intra-system interference for each other.
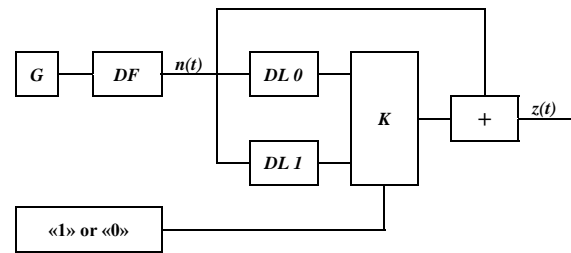

Fig. 1. Scheme of simultaneous formation of reference and information signals.

Fig.1 indicates: G-generator, which in self - oscillating mode generates a sequence of ultrashort pulses from chips; DF - digital bandpass filter, which generates a signal $n(t)$; DL - delay lines that shift 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 reference signal is continuously transmitted by the transmitter through the power adder. The signal $Z_{1,0}(t)=n(t)+n(t-T_{1,0})$ as the sum of the reference and information signals, has a secondary maximum of the autocorrelation function, the position of which in time is an information parameter of the signal.

The communication system with opposite ultra-wideband signals has higher noise immunity. The transmitter has only one delay line (Fig. 2). In this case, the information is encoded not by changing the position of the secondary maximum of the autocorrelation function over time, but by changing the polarity of this maximum.
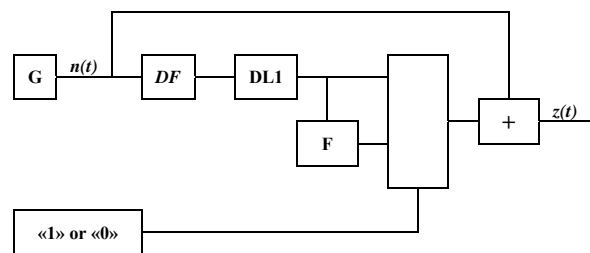

Fig. 2. Scheme of information generation by opposite ultra-wideband signal.

Compared to the previous scheme, the second DL delay line has been replaced with a wide-band phase shifter F, which provides a fixed phase shift in the operating frequency band. Since the delay between the

reference and information signals is constant, and the change in the sign of the autocorrelation function is inherent in the structure of the signal itself, the receiver circuit is significantly simplified [14]. However, the presence of a wide-band phase shifter with a fixed phase shift makes its implementation difficult, which is due to the need to coordinate the technical characteristics of the phase shifter F in a wide frequency band.

The method of time separation of reference and information signals with the corresponding implementation scheme is shown in Fig. 3.
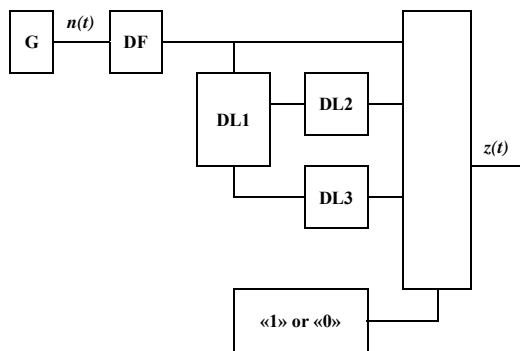

Fig. 3. Scheme of separate formation of reference and information signals.

Unlike the existing ones (Fig. 1, 2), a three-position switch is used in the transmitter circuit. During the first half of the bit interval, the switch closes the transmitter output directly to the ultra-wideband signal generator (G). Thus, during the time period $T_s/2$ forms a reference ultra-wideband signal. In the middle of the bit interval, the switch is changed to one of two possible positions, depending on the flow of binary bits "one" or "zero" from the information source. In this case, the delay line DL1 provides a delay of the signal x(t) by half of the bit interval $T_s/2$, the delay lines DL2 and DL3 are directly used to form a stream of binary bits "one" or "zero". As a result, an information signal is generated that is separated in time from the reference signal, which has the following form on one T_s interval.

$$y(t) = \begin{cases} x(t), 0 \le t \le \dfrac{T}{2}; \\ x\left(t - \dfrac{T}{2} - T_0\right), & \dfrac{T}{2} \le t \le T; \\ x\left(t - \dfrac{T}{2} - T_1\right), & \dfrac{T}{2} \le t \le T; \end{cases} \qquad (6)$$

At the same time, it should be noted that systems with ultra-wideband signals that use reference signal transmission and their autocorrelation reception provide a high level of structural stealth of the signal.

V.   CONCLUSIONS

The transmitter generates and emits a complex signal into free space, the signal of which includes an information pulse ultra-wideband signal in the form of an encoded sequence of pulses and a separate pulse sync signal. Due to the fact that synchronization conditions are maintained continuously during the communication session and not at discrete points, which is typical for known pulse systems, high-quality synchronization is also maintained during mutual movements of mobile objects. Reducing the synchronization time of radio communication system signals with pulsed ultra-wideband signals and improving its quality significantly increases the efficiency of using high bandwidth when working with a large number of users, especially when working with mobile objects. At the same time, the stability of communication channels to the influence of interference from neighboring channels increases, providing such main advantages of ultra-wideband signals communication systems as:
- increased noise immunity;
- Ability to provide code separation of channels;
- Low level of spectral density;
- Energy and information security of communications;
- Increased throughput.

The use of the method of generating an ultra-wideband signal with stable synchronization makes it possible to effectively realize the potential high density of communication channels per square meter of the working area. By reducing the level of the information signal relative to the level of white noise in the operating frequency range, both traditional narrow-band communication systems and communication systems that use ultra-wideband signals are simultaneously trouble-free. The use of ultra-wideband signals communication technology with time distribution of the sync pulse and information signal allows us to guarantee the requirements for noise immunity, secrecy and security of wireless mobile communication channels at all stages of their development, manufacture and operation.

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