Security Improvement Techniques for mobile applications of Industrial Internet of Things

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Abstract
The main aim of this article is to develope recommendations for increasing the throughput, noise immunity and security of discrete messages in communication channels with additive Gaussian noise. Improving the security of mobile applications in Industrial Internet of Things (IIoT) systems is possible with the use of Ultra Wideband Signals (UWS) technology. This technology facilitates the encoding of a bit of information with a series of ultrashort pulses, using position-pulse modulation and flickering polarization of the emitted signal. The use of ultrashort pulses - chips make it possible to provide wireless noise-resistant transmission of discrete information based on ultra-wideband signals with high information capacity. At the same time, the quality of information in wireless mobile communication channels is improved. Increaing penetrating power of the emitting radio signal, increasing volumes and information transfer rates with high noise immunity and almost unlimited number of communication channels are combined with effective protection of information from interception.

Key words:
IIoT; Mobile connection; Noise immunity; Security; Ultra-wideband signals; Flickering polarization

1. Introduction

Industrial objects which use modern IT technologies, with automated enterprise management, require the ensured reliability and security of information circulating both inside the system and outside it. The complexity of organizing the relationships within the system between its individual elements makes it preferable to use wireless communication channels. This is because on the one hand, difficulties arise in ensuring the security of communication channels - both due to a violation of the integrity of information and the possibility of interception. On the other hand, the high density of the placement of system elements in the space of an industrial object degrades the internal electromagnetic environment, contributes to a decreasing quality of communication channels and leads to the disruption of the integrity of information circulating in the system.

The processing of information by individual elements of the system inside an industrial object when it is controlled leads to the appearance of spatial intelligence, which makes the industrial object work as a single organism. Spatial intelligence here refers to the spatial integration of computing elements into a single system [1].

Modern intelligent systems are usually confined to a machine or a separate device. Expanding the benefits of spatial intelligence to an entire industrial object makes it possible to ultimately see the industrial object in its robotic form. Furthermore, its value lies in the coverage of the entire enterprise from workers and equipment on production lines to loading and unloading systems for materials and raw materials. Therefore, underpinning the concept of security implementation of mobile spatial intelligence applications in IIoT systems is the need to place wireless micro-location sensors in the object space. This, together with the corresponding software guarantees the joint efforts of people and machines, while demanding an increase in the speed and volume of information circulation. The result is an increase in the bandwidth of the communication channel and a reduction in the level of noise immunity and security.

The aim of this work is to increase the security, throughput, and noise immunity of distributed multilevel critical IIoT, which is built on the basis of personal and local networks with low energy consumption under the action of natural and intentional electromagnetic interference. Thus, IIoT is a distributed system that operates in real time when exposed to electromagnetic interference with increased security requirements and data transmission delays in wireless communication networks. The technology of ultra-wideband communication is capable of providing the necessary level of security and secrecy of mobile communications. Fundamentally, this translates to the transmission of low-power encoded pulses in a very wide frequency band without a carrier frequency. In addition, the bandwidth of the communication channel determines not the absolute value of the width of the used frequency band, but the ratio between the spectrum of the message, (which determines the speed of information) and the spectrum width of the signal [2].

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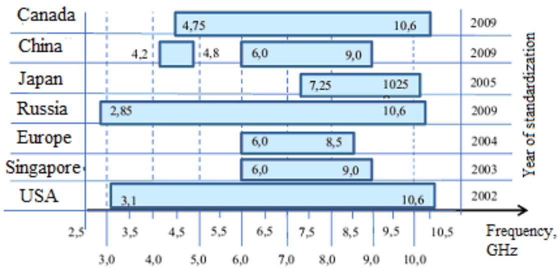

Fig. 1. Frequency bands allocated for ultra-wideband communications

For the organization of ultra-wideband communication, different countries around the world have their own permitted frequency bands [3]. A comparative analysis of the selected frequency bands is shown in Fig. 1. The selection of this specific frequency range (2 ... 11 GHz) is due to the fact that the attenuation of the radio signal in this range is the smallest [4].

2. Features of the influence of signal propagation conditions on wireless quality

For mobile wireless systems, the distribution medium significantly affects the quality of communication, in particular, the possibility of unauthorized access to the communication channel.
Mobile radio communication between moving objects occurs when one or both mobile objects move and occupy one random position relative to the other. Moreover, the parameters of the communication channel change in time - since moving in space leads to a change in the propagation conditions of the signal. A key parameter that affects the solution to the communication channel security problem is the signal to noise ratio (SNR). To resolve the security problem, it is necessary to make a preliminary forecast of the signal intensity at a certain point in space, remote from the transmitter antenna, and taking into account the effects accompanying the propagation of the electromagnetic wave. There is a wide variety of factors causing both deterministic and random attenuation of the signal at the receiver input. Owing to their influence, the received signal is distorted not only by additive noise, but also by the multiplicative noise that occurs when the noise is multiplied with the information signal. Wave propagation in free space assumes that the radiation wave propagates along a single possible path - the line of sight (LOS - line - of sight). In most cases, the mobile communication channel is characterized by the lack of direct visibility between the transmitter and receiver, especially in dense urban areas. As a result of reflections, scattering and diffraction of electromagnetic waves during interaction with different objects in space, multipath propagation occurs. The superposition of these waves leads to a change in the amplitude and phase of the signal, creating a complex electromagnetic environment at the receiving site. The phenomenon of multipath propagation of a signal is inherent in any type of signal, but it becomes particularly dangerous in the case of using broadband signals. This is due to the fact that in the case of interference, individual frequencies either add in phase, - which leads to an increase in the signal level - or, conversely, their addition in antiphase weakens it. In this case, two extreme cases are distinguished. In the first, the maximum delay between different signals does not exceed the duration of one character. Thus, interference occurs within the boundaries of a single symbol. In the other case, when the maximum delay between different signals exceeds the duration of one symbol, intersymbol interference occurs - as a result of the addition of signals representing different symbols. The interference most significantly affects the distortion of the signal, since the amplitude and phase of the signal change for different symbols, making it impossible to restore its original state.
The movement of the subscriber in space also causes a Doppler shift, resulting in the same consequences. The magnitude of the Doppler shift is proportional to the transmission frequency and speed. Even when moving for short distances comparable to the wavelength of the signal, significant changes in its parameters occur. Objects appearing on the direct signal propagation path limit direct visibility and cause dimming and path loss, causing changes in signal parameters over time. Compensating for signal distortion caused by Doppler shift and multipath propagation of radio waves requires complex signal processing at both the receiving and transmitting sides. Thus, the main task of ensuring the safety and noise immunity of wireless mobile systems is to eliminate signal distortion caused by intersymbol interference and multipath propagation of radio waves.

3. Ultra-Broadband Technology

There are a number of technologies that are based on the distribution of parameters such as frequency, time, code and space between individual mobile communications with a minimum of mutual interference and maximum use of the characteristics of the transmission medium. Making an information signal invisible to any consumer (except for those for whom it is intended, and therefore protected) is possible due to the complication of the modulation law and by expanding its spectrum. Such a signal is almost incapable of exerting an undesirable effect on a third-party system operating in the same frequency band. The objective is to use such a gain from signal processing that would guarantee a sufficiently low level of its spectral density Ns relative to the spectral intensity of natural noise No at the receiver input.
Let ΔF is message spectrum width, W – signal width, a T – signal duration. multiplication $B = WT$ is a base of signal.
For broadband systems $W \gg \Delta F$ and $B \gg 1$. [5, 6]. Expanding the frequency band from ΔF to W it becomes

possible to increase the speed of information transfer by reducing the duration of the transmitted signal from the value $T \cong {}^{1}/_{\Delta F}$ to $T_1 \cong {}^{1}/_{W}$, where $T_1 \ll T$. Thus, some redundancy is introduced into the transmitted signal, the value of which determines the coefficient of expansion of the spectrum. $K_f = {}^{W}/_{\Delta F}$. It is the presence of this redundancy that determines properties of ultra-wideband systems such as the ability to overcome the phenomenon of multipath propagation of radio waves as well as the efficient use of the spectrum when working in an overloaded frequency range with the implementation of high noise immunity.

Usually, the lower limit of the ratio of the spectral density of the signal N_s and interference N_o on the receiver input is - 7 dB, which guarantees its normal operation. This level corresponds to the following relation:

$$\frac{N_s}{N_o} \leq 0{,}2. \quad (1)$$

At the same time, the spectral density of the signal N_s is determined by the following relation:

$$N_s = {}^{P}/_{W} = {}^{E}/_{W\,T}, \quad (2)$$

where: P – signal strength;
W – signal width;
E – signal energy;
T – signal duration.

Therefore, taking into account relations (1), (2), the fulfillment of the following inequality becomes the criterion for fulfilling the requirements of noise immunity:

$${}^{E}/_{W\,T N_o} \leq 0{,}2. \quad (3)$$

According to the theory of potential noise immunity [7], the particular characteristics of the properties of information signal depend on the ratio of the doubled signal energy E to noise power spectral densityN_0 and amounts to next formula:

$$Q = {}^{2E}/_{N_0} = 2q_0 B,$$

Where: $q_0 = \frac{E/_T}{N_0 W}$ – average signal power ratio $P_{s0} = {}^{E}/_{T}$ to noise power $P_{N0} = N_0 W$ at the input of the receiver, and $B = WT$ is the signal base

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Now relation (3) will take the following form:

$${}^{q^2}/_{WT} \leq 0{,}4, \quad (4)$$

where the criterion itself is defined in terms of the signal-to-noise ratio at the input of the receiver q ^ 2 and gains from the processing of W T. For example, when the signal-to-noise ratio at the input of any receiver is 20 dB, then WT≥400 is acceptable to provide noise immunity requirements according to performance criteria for noise immunity [8].

Therefore, to ensure the noise immunity requirements of wireless mobile systems, it is most appropriate to use signals with a signal base in the technology of ultra-wideband communication

$$B \geq 400.$$

4. Flickering polarization method

The technology of ultra-wideband communication provides for the use of temporary positional-pulse modulation using ultrashort coding pulses [9]. At the same time, the organization of communication in a system of mobile mobile devices imposes additional restrictions due to the uncertainty in the placement in space and time of the polarization vector of the information signal relative to the axis of the receiving antenna. So, in the case of their orthogonal placement, the level of the received signal will be zero. The greater the direction of the axis of the receiving antenna coincides with the direction of the polarization vector, the greater the current in it will be induced. In this case, the use of rotating polarization of the electric field vector allows eliminating the fading of the harmonic information signal, increasing the signal-to-noise ratio at the input of the receiving antenna. However, the use of ultrashort pulses in the encoded transmission of digital discrete information requires the use of flickering polarization, the essence of which is that each of the ultrashort pulses encoding the information bit is supplied in turn to one or the other antenna, which are arranged orthogonally in the antenna system.

Due to the fact that the emitted ultrashort coded pulses have a very wide frequency band, the requirements for the broadband band of the elements of the block of transmitting and receiving antennas are basic. According to technical characteristics, the most acceptable is the antenna element, which is an antenna with an expanding TSA slot (Tapered Slot Antenna) [10, 11]. The shape of the open slit determines the frequency band in the range 2 - 6.5 GHz., And its energy directivity is characterized by a narrow main beam of the radiation pattern and the absence of side lobes. Due to such technical characteristics, this antenna is the main component of each of the two antenna units, the orthogonal combination of which in turn creates an antenna system (Fig. 2). In this system, the axis of symmetry are located orthogonally, which allows the flickering polarization method to be implemented. This arrangement of both antenna units provides reception of electromagnetic radiation of arbitrary polarization, which is typical for mobile devices.

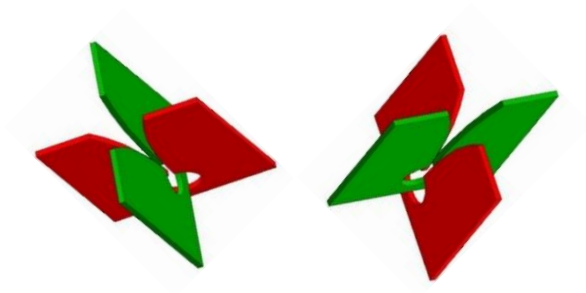

Fig. 2 Antenna system with flickering polarization

Thus, the use of the flickering polarization method in the transmission of digital information can increase the level of noise immunity, security and stealth mobile wireless devices.

5. Analysis

Depending on the mutual placement of the polarization vector of the electromagnetic signal and the receiving antenna of the mobile communication, the level of the induced signal changes in proportion to the directivity function:

- for vertical polarization of the information signal

$$D_v(\psi, \varphi) = \sin\psi \cos\varphi / (1 - \cos\psi \cos\varphi);$$

- for horizontal polarization

$$D_v(\psi, \varphi) = \sin\varphi / (1 - \cos\psi \cos\varphi),$$

where: ψ – elevation;
φ – azimuth angle.

An analysis of the above relations shows that, depending on the type of linear polarization of the information signal, the level of function Dν (ψ, φ) varies from 0 to 2.4. From this it follows that for some combinations of the mutual orientation of the polarization vector and the axis of the antenna, the signal level may be zero. At the same time, the use of the flickering polarization method makes it possible to simultaneously use both types of linear polarization of a signal, including their combination. At the same time, the level of the directivity function Dν (ψ, φ) will vary from 1 to 2.4, which allows more than double its level at the input of the receiving antenna.

6. Conclusion

The using of ultra-wideband signal technology and the flickering polarization method in the communication systems of mobile devices 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, thus providing requirements for increasing the noise immunity and stealth of the communication channel of mobile wireless communication systems. The effectiveness of the application of the developed recommendations is due to the possibility of realizing a potentially high density of communication channels per square meter of the working area. By reducing the level of the information signal relative to white noise in the operating frequency range, simultaneous noise-free operation of both traditional narrow-band communication systems and communication systems that use ultra-wideband signals is carried out. The use of ultra-wideband communication technology, the proposed method of flickering polarization and recommendations makes it possible to guarantee the requirements for noise immunity, stealth and security of wireless mobile communication channels at all stages of their development, manufacture and operation.

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