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The paper examines the factors that affect the operation of devices using modern LoRa technology. The interference environment features a large range of information exchange in similar technologies, which is achieved through modulation with integrated forward error correction. The advantages of this technology are the better sensitivity of the receiving device, the high resistance to channel noise and the insensitivity to frequency shifts of quartz resonators.

The technology is in the stage of experimental studies of its potential in various industrial applications. A general analysis of the effectiveness and sustainability of LoRa was carried out in [2]. In [3], studies were made of the possibility of using LoRa technology in the distribution and monitoring of electricity in one industrial zone. Some results of using this technology on the vine farm are presented in [4]. Here it is supposed to collect data from sensors and transfer it to a cloud server. In [5], an experimental estimate of the probability of reception of a signal is presented depending on the power of the radiated signal, which can be described by the Nakagami distribution. The probabilistic model for the estimation of congestion and its reliability is presented in [6]. The project of a system for tracking urban transport in real time is presented in [7].

Asynchronous protocol for the receive-transmit cycle by each sensor node, based on the measurement of three indicators, is proposed in [8]. As indicators, it is proposed to use residual energy, node load, and network congestion rate. According to the protocol, the sensor node selects a duty cycle with a minimum connection interval. The obtained results show the advantages of the proposed protocol in the life of the batteries and the speed of delivery of the packets.

In [9] the factors influencing the performance of the protocol are analyzing, namely: Time on Air (ToA), bit rate and propagation factor (SF). The obtained results make it possible to establish for the LoRa system the dependence of the SF parameter on the transmission time of the communication packet and the connection of the bandwidth of the communication channel with the ToA.
parameter. In [10], the limiting possibilities of LoRaWAN are describing based on examples of application usage.

In papers [11, 12], we performed an estimation of the computer network parameters in conditions of overload by information packages and an estimate of the frequency of an unknown signal using a single adaptation algorithm. In this paper, we consider the evaluation of the reception of signals in the LoRa system under interference conditions.

II. PROBLEM STATEMENT

We consider a messaging system between end-point users and a server that processes user information and responds to their requests. Communication between users and the server is carrying out over a radio channel in the sub-gigahertz ISM radio range. Each device uses its own range of radio frequencies. The most popular in Europe are the bands 863 – 868 MHz, in the USA 902 – 928 MHz, in Asia 779 – 787 MHz. The transmitted packet consists of a preamble, a header, and useful information, the volume of which ranges from 51 to 256 bits, depending on the spreading factor. The data transfer rate also varies from 22 bps to 27 kb/s, depending on the range and bandwidth and according to spreading factor.

The main radiated signal is a linear frequency modulated pulse signal, which is currently the standard in the field of wireless short-range communication systems (IEEE 802.15.4a). The signal obtained at the output of the dispersion ultrasonic delay line, it has a form

\[ y(t) = A(t) \cos(2\pi f_0 t + \pi \mu t^2) \]  

(1)

In the expression (1), \( A(t) \) is the signal amplitude, \( A = 0 \) if \( |t| > \tau / 2 \), where \( \tau \) is the packet duration, and \( t \) is the time; \( f_0 \) is the initial frequency of the radiation, \( \mu \) is the parameter that determines the rate of change of the frequency in time. A useful signal has a binary form if it has a logical "1" that corresponds to a frequency increase and \( \mu > 0 \) in this case and another case if logical "0" that it is responses a frequency decrease and \( \mu < 0 \). By type of the system organization and signals, we assume that it corresponds to the LoRa system.

Reception of signals is carrying out under interference conditions of various types, for example, interference from external or nearby radiators is possible. The signal at the input of the receiving device looks like as follow

\[ s(t) = y(t) + n(t) + w(t), \]  

(2)

where \( n(t) \) is the additive white noise with zero mean, \( w(t) \) is the interference due to the reflection.

Our goal is to consider the problem of effective signal processing of the LoRa system under conditions of natural interference and multipath reflections.

III. EFFICIENCY EVALUATION

To assess the efficiency of the receiving device of the technology in question, the spectrum expansion, errors in the transmission of data packets, and multipath in the propagation of radio waves were studying in this section.

A. Spectrum spreading effect

As is known [13], the efficiency of the system under interference conditions using signals with spread spectrum is determined by the processing gain

\[ G_p = \frac{W_{ss}}{W_{min}}, \]

where \( W_{ss} \) is the bandwidth of the wideband signal spectrum, associated with the chip's shortest signal, \( W_{min} \) is the bandwidth determined by the rate. The higher the \( G_p \) coefficient, the more difficult it is to create an interference.

Let the bandwidth of the signal spectrum \( W_{ss} \) be set for the LoRa system and equal some value, and the rate in accordance with the [14] is determined by the expansion factor \( S_f \), the code rate \( R_c \), and the signal spectrum \( W_{ss} \), written by the expression

\[ W_{min} = \frac{S_f \cdot R_c}{(2^{S_f} / W_{ss})}. \]

Then the processing gain for LoRa of the system takes the form

\[ G_p = \frac{2^{S_f}}{S_f R_c}. \]

Taken into account the values \( S_f = 7 ... 12, R_c = 1/5 \) [12], the processing gain can vary from 3 to 585. Large values of this coefficient should be taken for large transmission distances. It should be noted that this effect does not affect the quality of communication.

B. Packet error rate

An effective measure of the quality of the received packet in an interfering noise environment is the probability of a transmission error of the data packet, which can be expressed by the relation

\[ P_p = 1 - (1 - p_e)^N, \]

where \( p_e \) is the bit error probability of the information bit, \( p_e \) is the bit error rate (BER), and \( N \) is the number of bits in the packet. Assuming \( p_e \) small, we get

\[ P_p \approx p_e N. \]

To reduce the errors in the transmission of information packets if they have equal length of the packets \( N \), we need to decrease the value of the bit error \( p_e \) follows from expression (7).

There are known [14] relations for estimating BER when representing the transmission channel by the additive Gaussian white noise model. Therefore, the BER of binary phase-shift keying (BPSK) modulation is

\[ p_e = 0.5 \text{erfc} \left( \sqrt{\frac{E_b}{N_0}} \right). \]
the transmitted signal, which makes it possible to level out the deviation of the frequency of the received signal with respect to the central passband of the receiving filter. Thus, the hardware implementation of the receiving part is complicated to improve the processing quality of such signals.

IV. INTERFERENCE PROCESSING

The natural way to increase the signal-to-noise ratio at the output of the receiver is to perform consistent filtering. However, multipath reflections present a serious problem in cellular communications, radio navigation, and satellite communications and in LoRa technology. Exceeding the threshold noise-signal outputs, the receiving device from the action. To improve the reception quality at the input of the matched filter, an interference protection is included. Unfortunately, the known technique of overcoming narrow-band interference is of little use in this case.

An effective technology for chirp signals is the chirplet decomposition, by which one can detect and remove interference in the joint time-frequency plane. The chirplet decomposition [15] assumes the decomposition of the signal \( \beta \) into a four of parameters \( \beta = (t_0, f_0, \sigma_t, c) \), which denote the signal energy concentration relative to the time \( t \in R \), the frequency \( f \in R \), the spread of the pulse spreading \( \sigma_t \), and the rate of change of frequency in signal \( c \).

As the basis of interference removal, the matching pursuit algorithm is used. The essence of the algorithm is to find the best matching of the projections of multidimensional data to some interval of the possible atom in the dictionary \( D \). In this case, the desired signal \( y(t) \) is approximated by the weighted sum of a finite set of functions \( g_{\gamma_n} \) (atoms) from the dictionary \( D \), i.e.

\[
y(t) \approx \hat{y}_N(t) = \sum_{n=1}^{N} a_n g_{\gamma_n},
\]

where \( a_n \) is the weight factor for the atom \( g_{\gamma_n} \in D \), number \( N \) is the number of atoms. Atoms from the dictionary chosen so to minimize the error of approximation. This is an iterative process, which ends when the approximation error \( e_N \) decreases to a predetermined value \( \varepsilon \), i.e.

\[
e_N = | y(t) - \hat{y}_N | \leq \varepsilon,
\]

where \( \varepsilon \) is a sufficiently small number.

Since the reflections of \( w(t) \) represent weakly correlated samples, their contribution to the output of the protection system decreases, and the samples of the main signal are strongly correlated and therefore go further to the output of the suppression system and then to the main filtering in the receiving path.

V. EXPERIMENTAL RESULTS

To investigate LoRa systems, a number of experiments carried out to simulate interference conditions by receiving transmitter signal in a densely populated city, where cellular communication was widely used and Wi-Fi devices used.
The signal transmitted using the "point-to-point", "point-to-gateway" scheme with further processing on the cloud server. In the experiment, a LoRa system transceiver used based on the SX1276 chip to transmit a short message at a frequency of 868 MHz. In the experiment, the message "hello" used (Fig. 2); the volume of the transmitted packet was 60 bytes. The output power of the emitted signal did not exceed 20 mW.

![Board in examination](image)

The receiver installed on the 11th floor of a panel reinforced concrete building that located in the downtown of Kyiv. The building has several Wi-Fi networks deployed on the roof installed mobile antennas of several operators. The indicator of the receiver monitored the quality of the message. During the experiment, the transmitter moved from the 11th floor to the first and further to the basement, which is lower than the first one on two floors. The scheme of experiments shown in Fig. 3. The scheme uses the abbreviation MS is the antenna designation of the base stations of mobile operators, Tr is the transmitting set, Re is the receiving set.

The transmitting antennas of mobile operators and Wi-Fi routers that located near the building create jamming with reception. The signals of these devices create an interfering background, which is taken for "white" noise n(t). Crosstalk w(t) is created by multiple re-reflection raying from the interior of the building from the reinforced concrete structures. On each floor of the building, the level of signal and noise is fixed and the quality of the message is controlled. The panoramic receiver selected as the benchmark additionally documents the measurement results. A preliminary analysis of the interference situation presented in the Table I.

**TABLE I. INTERFERENCE SITUATION ANALYSIS**

<table>
<thead>
<tr>
<th>Sources of interference</th>
<th>F, MHz</th>
<th>Power, W</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDMA</td>
<td>800-900</td>
<td>2.60</td>
<td>strong</td>
</tr>
<tr>
<td>LTE</td>
<td>900-2400</td>
<td>2.60</td>
<td>middle</td>
</tr>
<tr>
<td>Wi-Fi</td>
<td>2400</td>
<td>0.1</td>
<td>weak</td>
</tr>
<tr>
<td>Other</td>
<td>400-5000</td>
<td>&lt;0.01</td>
<td>weak</td>
</tr>
</tbody>
</table>

The operation of the transmitter in the "point-gateway" mode is functionally the same as the "point-to-point" mode. The only difference took place in the processing of data that conducted on a remote server, so the results got with a slight delay (a few tens of seconds) in relation to the point-to-point mode. In both cases of measurements, an additional communication channel used, implemented using a mobile phone.

![Scheme of experiment](image)

In Fig. 4, 5 shows the results of measuring the number of erroneous bits and the signal-to-noise ratio.

![Change BER in dependence on the number of the floor](image)
VI. CONCLUSION

The paper deals with the system for transmitting short messages over long distances by LoRa technology. A special feature of the system is the use of chirp signals generated by the passage of a sinusoidal signal through a dispersive ultrasonic delay line (chirp modulation). Due to non-directional reception, the system is subject to interference, the effect of which is equivalent to the Doppler shift. In addition, situations are possible where the level of the interfering signal exceeds the permissible level, which leads to the loss of the useful signal. To protect against this kind of interference, chirp applies the decomposition of four useful signal components together with the matching pursuit algorithm. The study of this technology in the conditions of neighboring sources showed satisfactory results. A technique for estimating the parameters of a device in a city was proposed. The proposed methodology recommends for use in assessing the parameters of similar systems. Our future research is focusing on studying the effective technique of signal decomposition of the received signal.

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