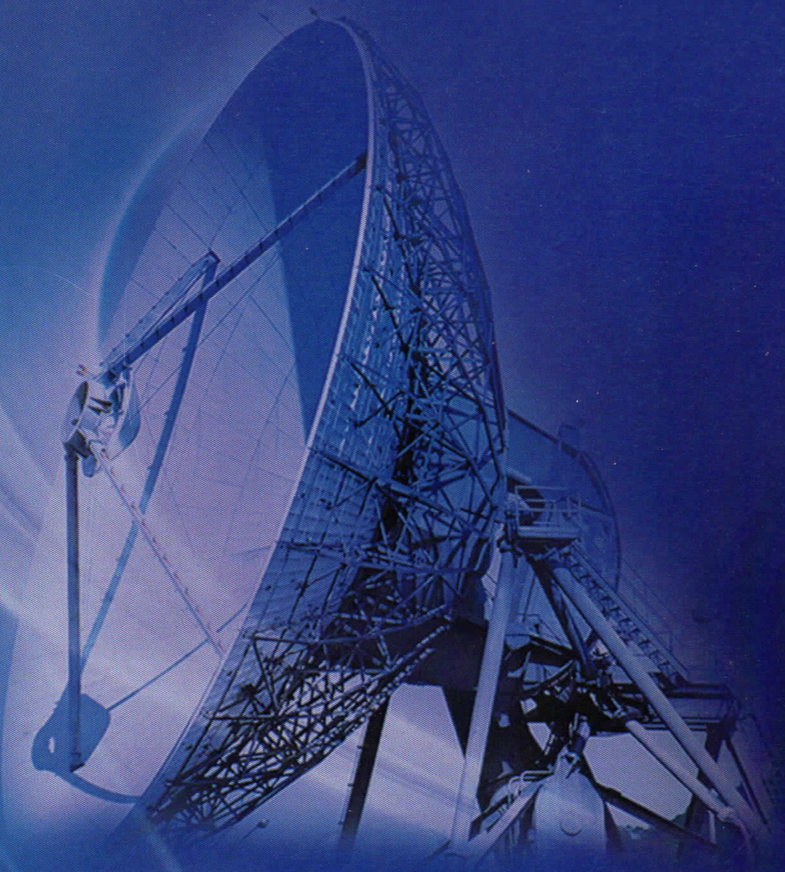

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CONTENS
(VOLUME 2)

ion of Signals from a LoRa System Under Interference Conditions

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paper examines the factors that affect the in devices using modern LoRa technology between devices that are part of the in an interference environment. Features a long range of information exchange in similar technologies, which is achieved spreading spectrum, the transmission of in *short packages and suppression of multipath propagation. The article notes the contribution of each to the quality of reception and studies the reception of messages at the LoRa technology in a city with the* ificant interference that created by means of cellular munication and Wi-Fi devices.

Keywords—LoRa technology; signal processing; detection; terference; chirp decomposition

I. Introduction

LoRa is a new technology, recommended for use on the ternet of things to create devices with low power consumption [1]. The main purpose of devices that support this technology is to transfer a small amount of information to distances exceeding the capabilities of traditional wireless technologies, such as Wi-Fi and LTE.

A typical application of technology is a reasonable house, a smart city, management of supplies (supply) and agricultural needs. The use of intelligent sensors allows to reduce maintenance costs or common expenses in managing households, as well as improve the quality of life of city residents, reduce downtime in transport management or effectively use natural resources. Household monitoring of domestic animals, the collection of water, gas, and electricity consumption meters, transfer of water, gas, electricity meters, evaluation of smoke detectors and garbage cans are using in everyday life.

The end devices form the "star" network architecture. Network security is providing by double encryption. Low power consumption is achieving by a short information transfer time in a relatively large time interval, most of which the end device is in a "sleep" mode. Transmission can be carried out in synchronous and asynchronous modes, in the latter case, an acknowledgment is used. From the end node of the network, the encrypted information is transmitted through the gateway (hub) to the network server and then to the application server.

The basis of LoRa technology is modulation with spreading and variations of linear frequency 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 technology was carried out in [2]. In [3], studies were made of the feasibility 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 presenting 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 presenting 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 presenting in [6]. The project of a system for tracking urban transport in real time is presenting 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 proposing 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 made 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

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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 country 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

$$y(t) = A(t)\cos(2\pi f_0 t + \pi\mu t^2) \qquad (1)$$

In the expression (1), $A(t)$ is the signal amplitude, $A = 0$ if $|t| > \tau/2$, where τ is the packet duration, and t is the time; f_0 is the initial frequency of the radiation, μ 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

$$s(t) = y(t) + n(t) + w(t), \qquad (2)$$

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 u interference conditions using signals with spread spect is determining by the processing gain

$$G_p = \frac{W_{ss}}{W_{\min}},$$

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

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

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

Then the processing gain for LoRa of the system the form

$$G_p = \frac{2^{S_f}}{S_f R_c}.$$

Taken into account the values $S_f = 7 \ldots 12$, $R_c = 1$ [12], the processing gain can vary from 3 to 585. La values of this coefficient should be taken for l transmission distances. It should be noted that this ef 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 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 bi bit error rate (BER), N is the number of bits in the pac 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 pac N, we need to decrease the value of the bit error p_e follows from expression (7).

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

$$p_e = 0.5 erfc\left(\sqrt{\frac{E_b}{N_0}}\right), \qquad ($$

SK modulation

$$p_e = 0.5erfc\left(\sqrt{\frac{E_b}{2N_0}}\right), \quad (9)$$

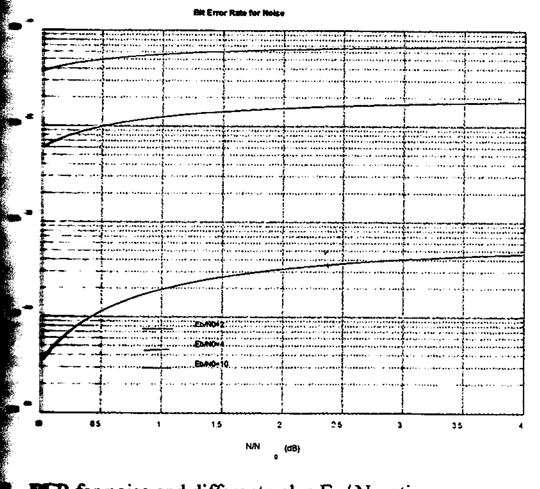
OK modulation

$$p_e = 0.5erfc\left(\sqrt{\frac{E_b}{4N_0}}\right). \quad (9)$$

equations (8) – (10), E_b is the energy of the bit, N_0 is ectral density of white noise, and

$$erfc(x) = \frac{2}{\sqrt{\pi}}\int_{x}^{\infty} e^{-t^2}\,dt. \quad (10)$$

ven that the E_b / N_0 ratio is equivalent to the signal-se ratio, the expressions confirm a physically obvious ship, when an increase in the E_b / N_0 ratio leads to a on in errors in the transmission of the data packet accordingly increases with increasing noise in the el (Fig. 1). Calculation of curves in Fig. 1 made for K modulation.



. BER for noise and different value E_b / N_0 ratio

s we can see from Fig. 1, an increase in the ratio of , by a factor of 5 leads to a decrease in the probability it error by 1000 times. A similar situation occurs in irp modulation.

ltipath Propagation

his phenomenon is associated with the reflection of a beams from surrounding objects, such as stationary res, elevations of terrain, trees, etc., which can also presented by interference signals. The effect of ath manifests itself in the effect of fading of the l or leads to a shift in the frequency of the main l, which is equivalent to the introduction of the ler additive into the main signal.

his also leads to a deterioration in the reception ty of the transmitted information due to the shift of the itted signal relative to the filter bandwidth. A similar ion in radar is solving by introducing a Doppler ive into the frequency of the heterodyne of the ency converter or by the deviation of the frequency of 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 β into a four of parameters $\beta = (t_s, f_s, \sigma_T, c)$, which denote the signal energy concentration relative to the time $t_s \in R$, the frequency $f_s \in R$, the spread of the pulse spreading σ_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_{γ_n} (atoms) from the dictionary D, i.e.

$$y(t) \approx \hat{y}_N(t) = \sum_{n=1}^{N} a_n g_{\gamma_n}, \quad (11)$$

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 ε, i.e.

$$e_N = |y(t) - \hat{y}_N| \le \varepsilon, \quad (12)$$

where ε 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.

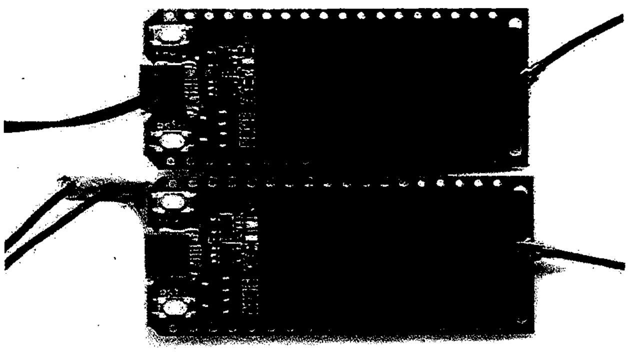


Fig. 2. Board in examination

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, Rc 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

Sources of interference	*F, MHz*	*Power, W*	*Impact*
CDMA	800-900	2-60	strong
LTE	900-2400	2-60	middle
Wi-Fi	2400	0,1	weak
Other	400-5000	<0,01	weak

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.

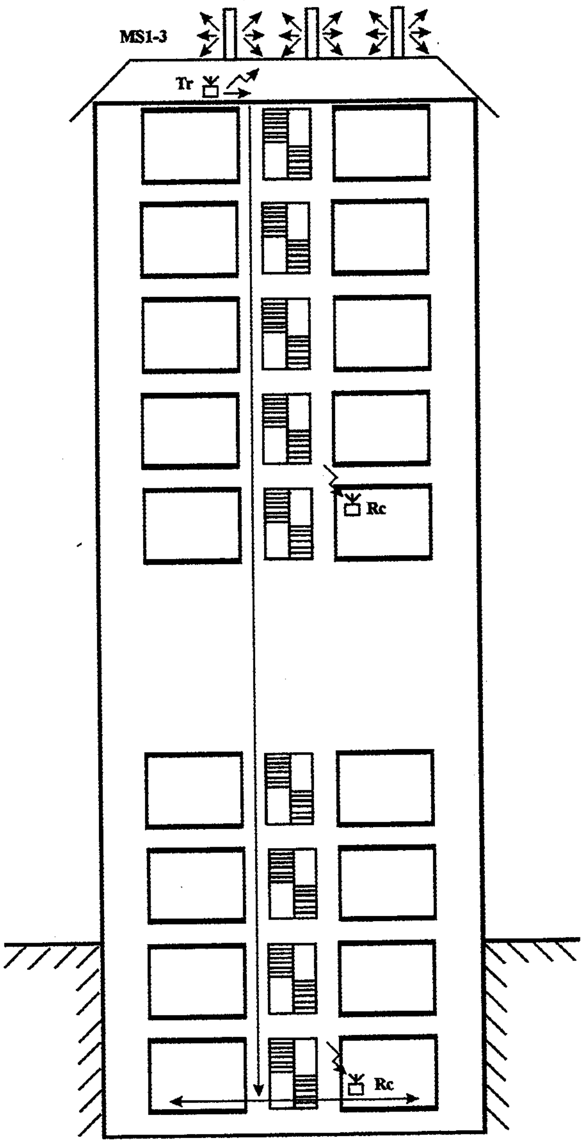


Fig. 3. Scheme of experiment

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

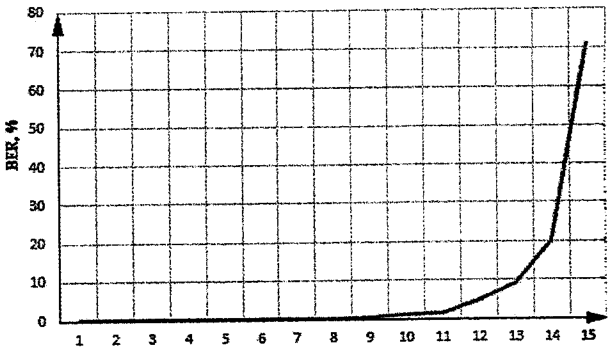
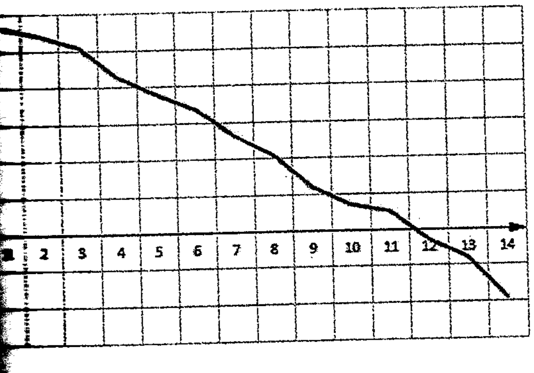


Fig. 4. Change BER in dependence on the number of the floor



...ge: SNR in dependence on the number of the floor

...nd that the message was received on all floors ...e basement within 2 *m* of the stairwell when the ...was 8-10 *m* from the stairs, the connection was

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 dispersion 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 proposed. The proposed methodology recommended for use in assessing the parameters of similar systems. Our future research is planning to focus on studying the effective technique of chirp decomposition of the received signal.

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