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ORGANIZATION OF A BACK-UP CHANNEL OF COMMUNICATION IN A LOCATION WITH NO CELLULAR COMMUNICATION INFRASTRUCTURE

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Abstract. *In this work, we considered the organization of a backup communication channel with a remote point in emergency situations or in the absence of cellular communication. The maximum distance of information transmission was evaluated using several models of radio wave propagation. The battery life of the device is calculated. A prototype of the device has been developed.*

Keywords: *range of communication, LoRaWAN, Okumura-Hata, propagation of radio waves, communication in emergency conditions, rescue services.*

I. INTRODUCTION

The importance of information transmission as a provision of communication channels in the life of modern society is constantly growing. The development of communication technologies in the context of globalization is of primary importance and is taking place at an undeniably fast pace, growing in geometric progression, but it is mainly commercialized for the mass consumer and is represented by CDMA and GSM communication (Fig. 1) [1].

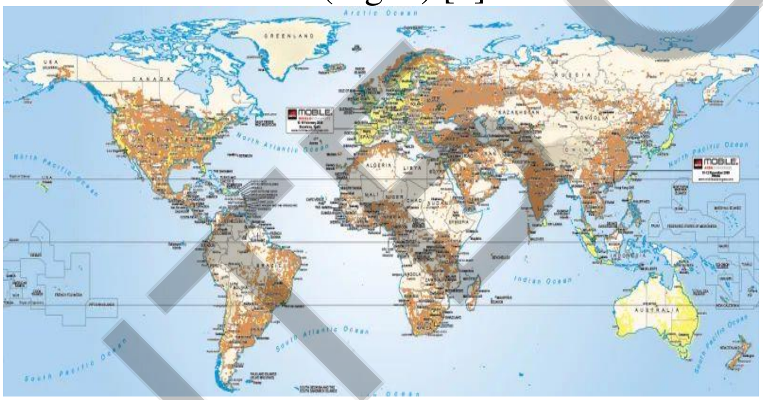

Fig. 1. Coverage of the Global System for Mobile Communications (GSM) in around the world for 2020.

If it is about identifying and saving human lives that are in danger due to force major circumstances - such as a plane crash, a shipwreck, derailment of a tourist group's route, conducting special intelligence operations in the fight against terror and reporting the necessary coordinates, then, unfortunately, the reality is this.

Lack of access to systems satellite and cellular communications due to obvious reasons in these circumstances or the possibility of its tracking (in conditions of rescue of hostages, for example) may cause human casualties. Therefore, it is objectively necessary to solve the problem of backup communication channels.

Even if devices for CDMA or GSM communication are available, there are still many areas on earth without coverage of these networks (Fig. 1.1). In the figure, we can see that even in highly developed countries, 100% is missing coverage of territories with communication. There are still many areas in the world, especially in developing countries, where researchers, tourists, people who have suffered a ship or plane crash, and even the general public, may find themselves without communication, and therefore without help, in the event of force majeure.

Therefore, the development of backup communication channels is still relevant.

II. LITERATURE ANALYSIS

2.1 Existing backup communication systems for searching and rescuing people

At the end of the twentieth century, the COSPAS-SARSAT [2] people search system was developed. In emergency situations on ships and airplanes, a special device notifies about such a situation and the location of personal radio buoys installed on them. Any individual can purchase such a device for $350[3].

The principle of operation of the COSPAS-SARSAT system is that the coordinates of a place in this system are determined not on the ship by satellite signals, but at the shore station (information reception point) by the signals of a radio buoy relayed via a satellite. But even such a convenient rescue system has several drawbacks.

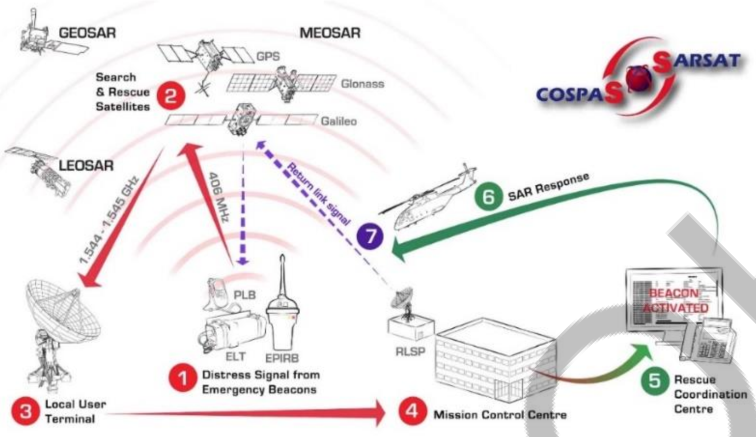

Fig. 2. Principle of system operation COSPAS-SARSAT

Not all countries have joined this alliance. The delay time for the delivery of information can reach up to 1.5 hours in the northern hemisphere and up to 2 hours in the southern hemisphere. There is also no feedback. The error of the system is about 20 km (if no GPS receiver is used), which is quite a lot. The presence of the listed shortcomings forces us to search for new directions for solving the problem of backup communication in an emergency situation for areas with no cellular infrastructure.

2.2 Alternative backup communication systems

To date, there are many systems for organizing communication in hard-to-reach places, all of them are quite different, starting from the fundamental difference and the necessary operating conditions and, of course, the cost of building and using such a system. One of the widely used such systems are radio stations, they enable the transmission of speech information in encrypted or open form over short, medium and sometimes quite long distances, depending on the class.

The most popular technologies used for backup communication can be classified as follows:

4) HF radio station
5) VHF radio station
6) Satellite communication

HF radio stations are transceivers operating at frequencies from 3 to 30 MHz. CV is divided into two subtypes. The first is a range that uses 3 - 25 MHz, which allows you to organize communication over long distances (transcontinental). And the second 25.6–30 MHz "Civilian" range is "Ci-B". The only range in which radio communication equipment can be used by private individuals without restrictions. The high range of communication in flat rural areas and the low cost of subscriber equipment make this range very attractive for various categories of users, from farmers, fishermen and shepherds to large construction, mining and transport organizations. Among the advantages, we can say the low cost of the equipment and the simplified registration procedure, which can be used by ordinary people.

VHF radio stations are stations for two-way transmission of ultra-short radio waves on ships, cars and ships to ensure the safety of work and movement. Unlike HF radio stations, portable VHF radio stations are smaller in size and weight than HF radios, have better autonomy, have a maximum range of about 10 km in open terrain, and a moderate price. The most popular brands of such radio stations are Icom, AOR, Kenwood, Motorola, etc.

Satellite communication is represented by the most common companies Iridium [4], Thuraya[5], Starlink[6] they have advantages - a very large coverage area, but some of them have a large mass (inStarlinkthe terminal weighs 8.5 kg) and volume, often the high price of the device and subscription (subscription fee), not much autonomy around the clock.

The problem of organizing backup communication at a distance of more than 10 km with affordable and compact terminals with high autonomy remains relevant. Longer range communication usually requires a fairly tall transmitter antenna to compensate for the curvature of the Earth and thus provide a line of sight. This is the main idea in this scientific work.

2.3 LoRaWAN trackers

LoRa is a new, spread-spectrum modulation method that allows low-speed data to be sent over long distances with minimal power consumption. LoRaWAN (Long Range wide-area networks) is the most well-known hardware protocol with LoRa, which is designed to manage communication between LPWAN gateways and end devices. More importantly, there are no access fees with this type of wireless technology. Therefore, some researchers [7-9] decided to use LoRaWAN technology to create GPS trackers. The LoRaWAN GPS tracker (GPS-LoRaWAN) is a battery-powered tracking device that uses the GPS satellite positioning service to determine its location and transmits the received coordinates using LoRaWAN radio technology. The intervals between measurements can be freely adjusted to adapt the device to individual needs. The built-in motion sensor detects changes in the movement of the device (if it is picked up or transported in a vehicle). This allows the device to switch between an active mode, in which frequent updates are downloaded during movement phases, and a sleep mode, which conserves battery power by sending only a few messages. Based on the specification [10] and the features of the LoRaWAN technology, we can conclude that it is quite a promising technology for the organization of backup communication in an emergency situation.

III. DEVELOPMENT OF BACKUP COMMUNICATION CHANNEL STRUCTURE BASED ON LORAWAN TECHNOLOGY

3.1 Object of research

The subject of research there is a set of theoretical and applied aspects of the mechanism organization of a backup communication channel with a remote point based on the LoRaWAN system.

User devices in LoRaWAN are divided into three classes:

– class A: after broadcasting, the device waits for a response from the BS, and then turns off the receiver until the next communication session;

– class B: the receiver of the device is turned on according to a predetermined schedule. The BS knows this schedule and therefore can transmit information to the device in accordance with it;

– class C: the receiver is always active, so the BS can transmit information at any time [11].

Strengths of LoRaWAN:

– due to minimal energy consumption for the transfer of small data packets, the energy consumption level of the end device is low;

– compared to other wireless technologies used for telemetry, radio signals travel long distances of 10-15 km in non-line-of-sight conditions and evidence of 766 km in line-of-sight conditions [12];

– in conditions of urban development, when using frequencies of the sub-gigahertz range, LoRaWAN has a high penetration of radio signals;

– no need to obtain frequency licenses and pay for the radio frequency spectrum due to the use of unlicensed frequencies;

– high scalability for large networks;

– relatively small cost.

Weaknesses of LoRaWAN:

– there are risks that the spectrum of the unlicensed frequency range may be noisy;

– the LoRa modulation technology is currently closely supported only by the patent of the Semtech company, which causes the impossibility of its application without this company;

– limiting the maximum signal power [13].

The network based on LoRaWAN consists of terminal devices (End-Device), gateways (Gateway), network servers (Network Server) and application servers (Application Server) (Fig. 3 a). The terminal device sends data to the gateway (Uplink), the gateway forwards it to the network server, and the network server forwards it to the application server as needed.

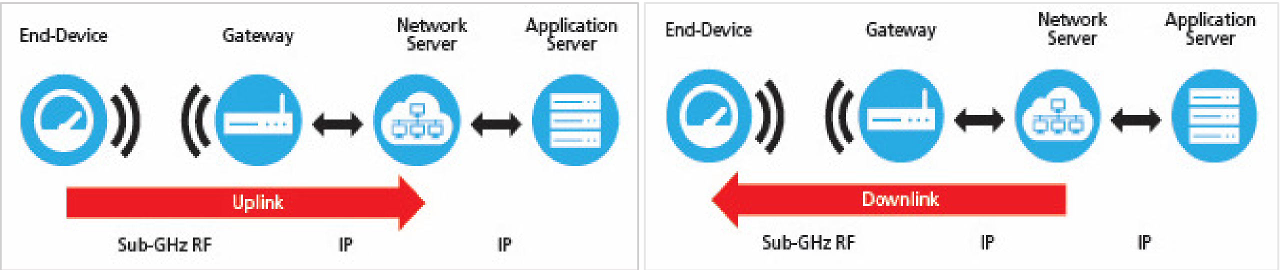

Fig. 3. LoRaWAN transmission: a - Uplink transmission, b - Downlink transmission

In addition, the network server can send messages (for network management or on behalf of the application server) to end devices through the gateway (Downlink) (Fig. 3. b).

Table 1 a contains summarized data for various parameters in the European frequency range.

Table 1. LoRaWAN specification

Parameter	Value
Frequency range, MHz	863-870
Maximum number of channels	35
UL radio signal spectrum width, kHz	125/250
DL radio signal spectrum width, kHz	125
Modulation	LORA, GFSK
Transmission power UL, dBm	2-14 20 (optional)
Transmission power DL, mW	1-25 100 (optional)
Transmission power DL, dBm	14
SF spectrum broadening factor	7-12

Consider the operational communication system, which is built on the basis of the LoRaWAN standard. Their main feature is a long range of communication with a rather small transmitter power, which determines the good autonomy of the device. Since the radio modules have very little power, there is no need for a radio amateur license and there is no need to register modems with national organizations responsible for spectrum managers.

The principle of maximum simplicity and cheapness of the solution is embedded in the concept. The structure of such a system should look as follows: client device of the sender; the LoRaWAN transmitter is equipped with a Bluetooth module for receiving information; base station (BS); recipient's client device.

Let's consider options for the development of events in which it is possible to use the communication system on based the LoRaWAN standard. Figure 4 simulates three situations of searching for a person or a group of people who are lost. They were previously issued with a LoRaWAN mobile transmitter.

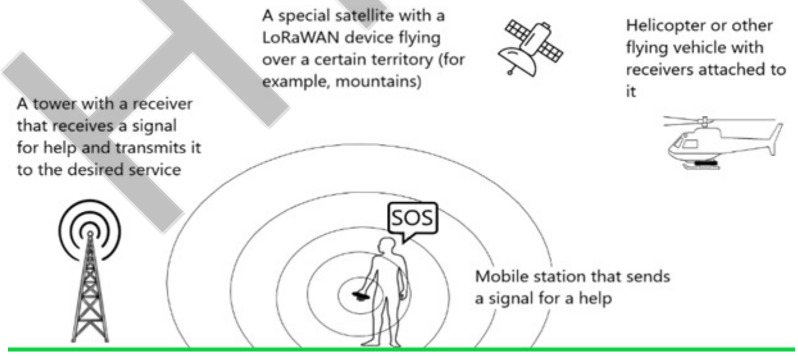

Fig. 4. Schematic view of the coverage organization for mobile transmitter communication

There are three ways to receive SOS signal, each type has its own advantages and disadvantages. The first is to locate ground base stations in a certain area (for example, in mountains or dense forests). The second is to send a helicopter or other aircraft over the likely location of those who are lost.

And the third is to use a satellite or a group of satellites that will constantly monitor the situation over a certain area. Each of these methods has its advantages and disadvantages.

To achieve a better result and a longer range of the alarm message transmission, the transmitter (or transmitter antenna) should be as high as possible relative to the Earth. Due to the light weight and compactness of the device, it can easily be thrown up using a special slingshot, which will be included with the device. An analogue of such a slingshot is usually used for fishing, it is capable of shooting at a distance of up to 400 meters [14], so it can easily raise the device to a height of about 30 meters to transmit information.

Also, to achieve a better result, due to the stability of the height, you can attach the device to quadcopter, and raise to the height necessary for direct visibility conditions. To select the moment at which information needs to be transmitted, the device will be equipped with an accelerometer to monitor the peak flight height of the transceiver in the air.

The typical transmission time of one message, depending on the channel settings, is from 0.1 to 2 s. Accordingly, the transfer speed is quite low - from approximately 100 Bit/s in the most long-range mode (far, but slow) to 20 kBit/s in overclocked mode (fast, but not far). Therefore, unfortunately, at such speeds there can be no transfer of media content, such as images or even more so video. The task of the developed system is simple - to send the shortest possible SMS message with the subscriber's coordinates and receive a response.

3.2 General description of the message transmission process

The system requires the equipment described in Fig. 5, as well as a client device for uploading information to the transmitter. It can act as a smartphone equipped with a Bluetooth module and on which special software is installed.

Message transmission process:

1. The sender is included in the application;
2. Connects to the device using Bluetooth;
3. Selects the required mode of operation (information transfer);
4. Enter a message in the text field;
5. After saving the message, the information is transmitted via Bluetooth to the LoRaWAN module;
6. The device rises into the air to the height required for direct visibility with the help of quadcopter, or on the most possible with the help of a slingshot;
7. In flight, the accelerometer measures the acceleration, and when it drops to a certain value, it transmits a signal to the LoRaWAN module;
8. The LoRaWAN module sends a message to the BS.

Points 1-5 need to be performed only in case of sending a random message. If it is enough to send a standard message, for example, "SOS, Full name (or pseudonym), my coordinates: 49.9808100° 36.2527200°", then for this you need to press a special button on the transceiver itself.

The base station works in reception mode and, after receiving a message, forwards it to the rescue service. A computer, laptop or tablet that has a direct local connection to the base station or to a cloud server via the Internet can act as a client device for the recipient of an alarm message.

3.3 General description of the process of receiving a message

Since most of the time the device is quite low and cannot immediately receive an arbitrary message from the base station, a mechanism is needed to send a delayed message. In order to send messages when the receiver is at a height sufficient for reception, it is necessary to develop an algorithm for the operation of the base station.

As a solution to the above problem, we offer the following synchronization algorithm:

1) The sender (on the BS side) selects the recipient and downloads the information;

2) Information is stored until the BS receives a signal from the device that it is ready to receive data;

3) In the mobile application, the user selects the "Receive message" operating mode;

4) The device rises into the air to the required height;

5) In flight, the accelerometer measures the acceleration, and when it drops to a certain value, it transmits a signal to the LoRaWAN module;

6) The LoRaWAN module sends a 1-bit message to the BS, which signals readiness for reception, and immediately switches to reception mode;

7) After receiving the BS signal, it automatically transmits the saved information after the shortest pre-arranged time;

8) The receiver connects the phone / tablet / laptop via Bluetooth to the device and receives the message.

It should be noted that the procedure described above is for receiving an arbitrary message from the base station (rescue service). To receive the standard message, for example, confirmation of message delivery, it is enough to watch the LED on the transceiver body.

That is, in most cases, the basic functionality of the system remains functional even without a working smartphone.

3.4 Development of the hardware part of the device

Figure 5 shows a functional diagram from which you can understand that we need the same components to build the final device: The LoRaWAN module is equipped with an antenna; The Bluetooth module is equipped with an antenna; The GPS module is equipped with an antenna; accelerometer; battery with a battery charge control module (if necessary). The LoRaWAN module has three main requirements: maximum compactness, the presence of a connector for connecting the battery, and support for the SF 12 parameter to ensure the maximum transmission range. All the above requirements are met by the RAK 3244 BastWAN card.

The communication board RAK 3244 BastWAN - for wireless switching of IoT devices weighs only 6.9 grams, and is built on the RAK4260(H) module.

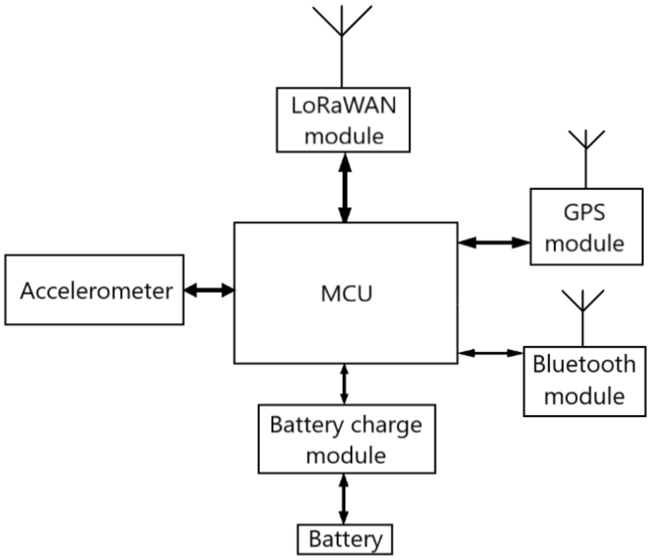

Fig. 5. Functional diagram of the device

The latter includes a Microchip SAML21 32-bit ATSAMR34J18 SiP processor consisting of several cores: ARM Cortex M0+ 48MHz and a LoRa SX127x transceiver. RAK3244 is compatible with the LoRaWAN 1.0.2 specification and supports Point-to-Point communication. LoRa low power consumption and broad communication capabilities make it suitable for many Internet of Things (IoT) applications, such as home automation, sensor and sensor networks, building automation, personal networking applications, and more.

GPS receiver - a radio receiver for determining the geographical coordinates of the current location of the receiver's antenna. GPS Click LEA-6S [15] is suitable for our purposes. Due to its small size, 3 modes of operation and low price. Bluetooth is a standard communication protocol that is primarily designed to be low power with a short range based on low-cost receiver microchips in each device. Since the devices use a radio communication system (broadcasting), they should not be in the direct line of sight of each other [16]. For the prototype of our device, let's stop at Bluetooth version 5.0 on the nRF52810 chip, which is installed on the HOLYIOT-21014 module and which we will consider next.

An accelerometer is a device that provides the ability to measure and analyse linear and angular acceleration. This device is needed with our device to track the peak point during the flight of the beacon and start sending a signal to ensure the maximum coverage area. You can also add an emergency tracking function so that if a person starts moving fast in a certain direction and brakes suddenly with overloads above a critical value, the accelerometer will detect it and activate the transmitter to send SOS signal.

The main requirements for the accelerometer module for the device are maximum energy efficiency, compactness and affordability. One of the possible options that satisfies all of them is the HOLYIOT-21014 module equipped with an LIS2DH12 accelerometer. HOLYIOT-21014 is also equipped with a Bluetooth 5.0 module built on the nRF52810 chip, and despite all this, the dimensions of the entire module are only 25 mm x 25 mm [17].

3.5 Device for increasing the height of the transmitting antenna of a mobile station

The next objective stage of consideration of our topic is the determination of the question of how the mobile station will be launched into the air and transmit information. To solve this problem, it is possible to use a quadcopter or a slingshot as a device for launching a mobile station. Below are the technical characteristics of some of them.

Table 2. Comparative characteristics of quadcopters and slingshots

	Quadcopter	**Slingshots**	
Model	DJI MAVIC 3	Slingshot with coil	SlingFish B
Maximum lifting weight	200 gr	200 gr	250 gr
Price	$4,814.62	$19.86	$20.40
Maximum range	32 km	300 m	250 m
Maximum flight time	45 minutes	-	-
Max. flight height	6000 m	-	-
Dimensions	347.5×283×107.7 mm	16.8x11.2 cm	15.8 11.4
Weight	900 gr	442 gr	215 gr

Let's consider the positive and negative aspects of using these devices in the conditions of a tourist trip or searching for missing people as a result of a plane crash, etc. For quadcopters, the "plus" is a long flight range; the possibility of aerial reconnaissance; and "cons": high cost; lack of possibility of urgent repair; considerable dimensions. When using a slingshot, the advantage is low cost, small dimensions and weight, components are easily replaced and inexpensive. And the disadvantages are the small flight range of the object relative to quadcopters. Based on these results, it can be concluded that in the specified conditions, the slingshot has many more advantages over the quadcopter due to its weight, price and volume.

3.6 Design of the alarm transceiver

After all the necessary components are selected, you can proceed to the housing in which the product will be located.

When designing, it is necessary to take into account the shape of the case, so that when it is launched from a slingshot, the product has minimal aerodynamic resistance and does not interfere with height gain. It should also be taken into account that after such a launch, all internal components must remain intact, that is, the case must be impact-resistant and withstand a fall from a height.

That is, the main requirements for the case are as follows: maximum impact resistance; minimum size; aerodynamic shape.

In addition, if you develop a mechanism for which the product will descend as smoothly as possible after being thrown up, it will provide additional time for the transmission of information and, at a lower speed of fall, will reduce the risk of damage to internal components.

To ensure an aerodynamic shape, we suggest using a cylindrical shape with a cone-shaped antenna. Such a form is able to provide predictability in the air at the moment of gaining altitude and at the moment of falling. It also makes it possible to place the components well inside, so the accelerometer + Bluetooth module can be placed at the base (bottom) of the cylinder, the LoRaWAN radio module and the battery in the middle, and the antenna of the radio module can be removed from the top of the cylinder. Since the antenna can be in the form of a spring (Fig. 6), it can take a shock when it falls on itself and provide cushioning. For additional cushioning, the inside of the antenna can be a soft foam material, such as that used in the soles of modern sneakers.

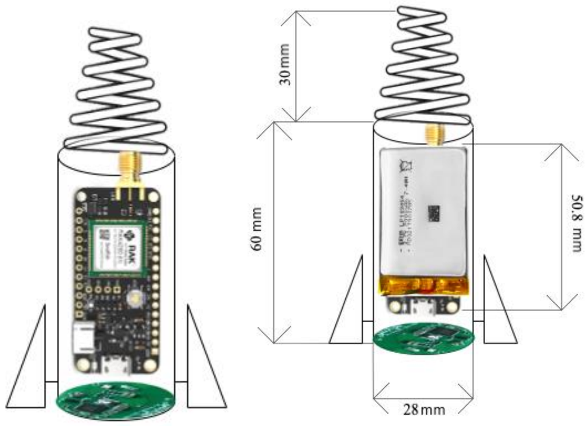

Fig. 6. Placement of components in the case

We offer a simple mechanism with wings that open when falling. At the moment when the product has reached its peak height and free fall begins, the accelerometer reports this, the latch releases the clamped spring, which opens 2 wings at an angle of 45°.

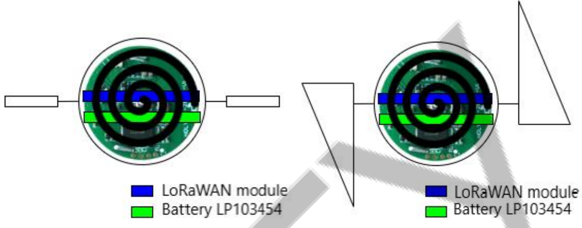

Fig. 7. Top view of the device with closed and open wings

Thanks to this design, the device will start to spin, which will reduce the speed of its fall. The spring is retracted by returning the wings to their initial position.

IV. RESULTS

4.1 Calculation of device autonomy

To choose the optimal power source (battery), it is necessary to calculate the energy consumption of the system and the desired autonomy. The autonomy calculation was performed according to the algorithm shown in Fig. 9.

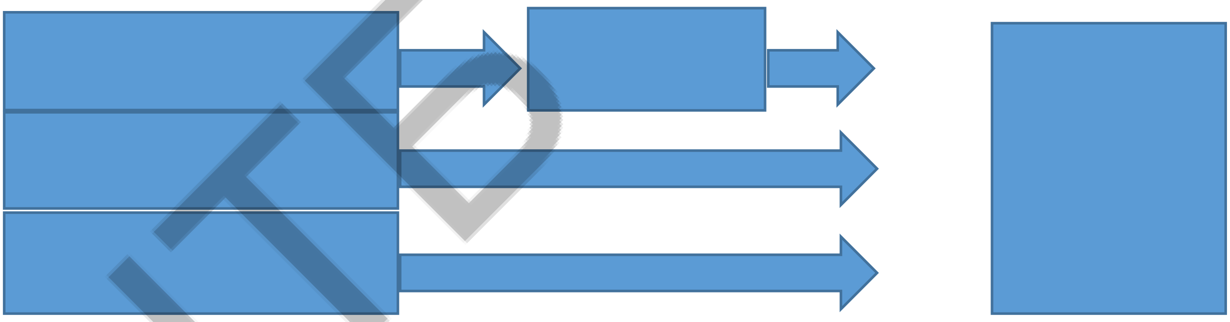

Fig. 9. Algorithm for calculating device autonomy

To perform calculations, you need to consider the energy consumption of all structural elements of our device for different modes (states). The data for the main components of the devices are given in Table 3.

Table 3. Energy consumption of the main structural elements of the device

Regime	**Microcontroller**	**GPS receiver**	**LoRaWAN modem**
Sleep	130 · 10-6	0.3 · 10-6	0.2 · 10-6
Measurement	230 · 10-6	1.5 · 10-6	0.2 · 10-6
Transfer	230 · 10-6	0.3 · 10-6	29 · 10-3
Acceptance	230 · 10-6	0.3 · 10-6	10.8 · 10-3

The results of calculating the autonomy of the device when powered by the LP103454 battery (2000mA) are shown in Fig. 10.

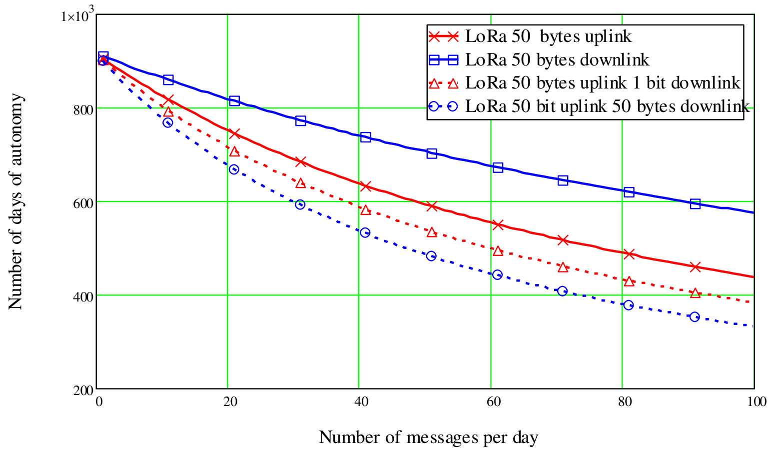

Fig. 10. – Dependence of the number of days of autonomy of the ZP on the number of messages per day

Analyzing this graph, we can say that when using a LiPo battery with a capacity of 2000mA, the autonomy of the device will reach approximately 330 days without recharging, under conditions of transmission and reception of 100 messages per day, each 50 bytes in size.

4.2 Assessment of the maximum range of information transmission

When designing a system that transmits information over a radio channel, the maximum distance between the transmitter and the receiver is one of the most important parameters that will have the greatest impact on the system design process. Selection of the correct communication range allows you to avoid increasing the output power, using repeaters or amplifiers. When creating a radio communication system, you must always strive to ensure the maximum distance. If the communication range is too long, it makes sense to reduce the output power and, as a result, the current consumption.

Choosing the optimal system frequency in the ISM range (0.169...2.4 GHz) is not always obvious. Antenna characteristics and location, regulatory limits on maximum output power, unwanted sources of interference, operating frequency, radio configuration, and propagation attenuation all determine the maximum distance between receiver (Rx) and transmitter (Tx).

Since the information transmission technology has already been chosen, it is necessary to rely on its existing technical characteristics listed in table 3.1.

4.2.1 Conditions of direct visibility

To calculate the maximum, we will use the empirical formula of line of sight LoS[18]:

$$R = 4{,}12 \times \sqrt{(ha + hp)} \tag{4.1}$$

Where *ha*— lift height transmission antennas,

hp — elevation height of the receiving antenna.

In Table 4. assume several communication scenarios when the alarm signal transmitter is on the ground (for example, a person is unconscious), at a height of 1 m and 2 m (in equipment or in the hands of a person), 20 m (the transmitter is thrown up using a slingshot or a compact quadcopter) and for different heights of the receiving antenna (base station), for a ground base station (10m and 30m) and an aerial base station, such as a quadcopter or helicopter (100m and 5000m).

Table 4. The maximum range of information transmission in various conditions

ha/ hp	**10 m**	**30 m**	**100 m**	**5000 m**
0 m	13 km	22 km	41 km	291 km
1 m	13.66 km	22.93 km	41.4 km	291.35 km
2 m	14.2 km	23.30 km	41.6 km	291.38 km
20 m	22.56 km	29.13 km	45.13 km	291.91 km

To clarify the results, we will use the Fries model, which is used to determine the distance d of radio systems in an open environment and free space and can give estimated results for real systems with highly raised antennas:

$$\underset{Friis}{Pr} = Pt * \frac{G_t * G_r * \lambda^2}{(4\pi)^2 * d} \tag{4.2}$$

where*:* $\underset{Friis}{\text{Pr}}$ - signal strength at the receiver input;

Pt - transmitter power;

G_t - the gain of the transmission antenna;

G_r - the gain of the receiving antenna;

λ –wavelength.

The optimal set of parameters of the LoRaWAN protocol is selected to calculate the power at the receiver input and subsequent comparison with the threshold sensitivity, which allows to calculate the range of the communication channel. One of these parameters is SF (spreading factor) - a coefficient to which transmission and reception parameters are tied. SF is a whole number, in the standard it is provided from 12 to 7. The higher the SF, the better the protection against interference in the radio channel and, accordingly, the greater the range, but the lower the speed and, accordingly, the longer the transmission takes on the air. According to the specification [19], the sensitivity of the LoRaWAN receiver, depending on the parameter SF, is in the range from -118 to -136 dBm.

The calculation results are shown in Fig. 11.

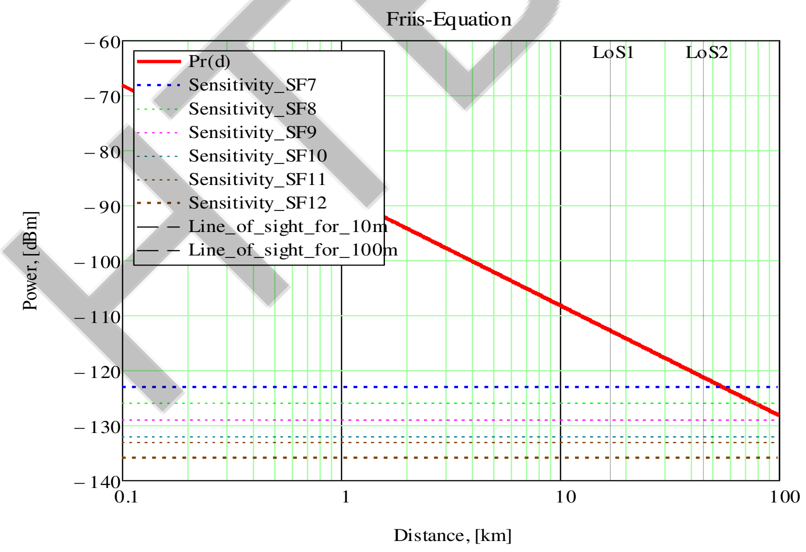

Fig. 11. Dependence of the LoRaWAN radio signal power at the receiver input on the distance to the transmitter (Fries model)

The maximum distance is about 120 km. The known record values for this time, obtained experimentally, are 741 km and 766 km, while the height of the transmitter was 33 km and 25 km, respectively [20]. In that experiment, LoRaWAN modules were launched on a balloon.

4.2.2 LoRaWAN radio signal attenuation in areas with interference

Well-known manufacturers of LPWAN radio modem chips, including the ISM range, such as STMicroelectronics: and Texas Instrument recommend also using a two-beam model to estimate the range of the communication channel [21, 22]. The two-beam model requires a line of sight between the receiver and transmitter antennas. Communication equipment usually operates near the surface of the earth. Therefore, to estimate the range, you also need to take into account the influence of the Earth (simplified form of the formula):

$$P_{2ray}(d) = \left(\frac{\lambda}{4\pi * d}\right)^2 * 4 * \left(\sin\left(\frac{(2 * \pi * h_m * h_b)}{\lambda * d}\right)\right)^2 \tag{4.3}$$

The calculation results are shown in Fig. 4.5.

To compare the results, the line-of-sight (LoS) range, which takes into account the limitation of transmission due to the curvature of the earth's surface for a receiving antenna height of 10 meters and 100 meters (transmitter antenna height of 1 m), was also added to the calculations:

$$\begin{gathered} LoS_1 = 4.12\left(\sqrt{h_b} + \sqrt{h_m}\right) = 4.12\left(\sqrt{1} + \sqrt{10}\right) = 17 \text{ км} \\ LoS_2 = 4.12\left(\sqrt{h_b} + \sqrt{h_m}\right) = 4.12\left(\sqrt{1} + \sqrt{100}\right) = 45 \text{ км} \end{gathered} \tag{4.4}$$

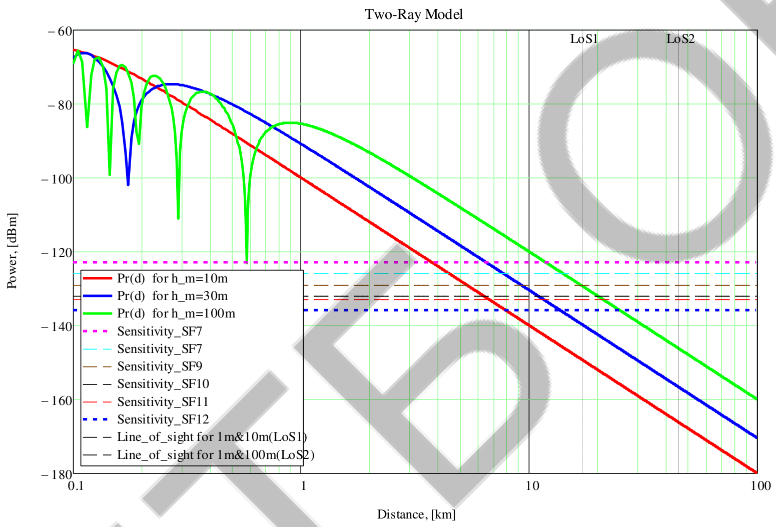

Fig. 12. Dependence of the LoRaWAN radio signal power at the receiver input on the distance to the transmitter (two-beam model)

From Fig. 12 it can be seen that for the selected heights of the antennas (1 m for the transmitting and 10...100 m for the receiving) the influence of wave interference disappears at distances greater than 1 km, so simplified expressions can be used. The maximum distance according to this model was 26 km (SF12, height of receiving antenna 100 m, transmitting antenna 1 m).

Next, the Hata model, which is also called the Okumura-Hata model [23], was chosen for evaluation. This model is used to predict radio wave propagation loss. The essence of the model is to estimate the propagation of radio waves based on the prediction of losses on the way of transmitting information in the propagation medium. The model is based on the use of the three-dimensional SBR (shooting and reflecting beam) algorithm, which is used to determine the paths of rays from the base station to the mobile station in three-dimensional space. Hut's model in the form of a mathematical notation is also based on Okumura's experimental data.

Formulas (4.5–4.7) are used to study the attenuation of the LoRaWAN radio signal in different areas (urban, suburban and rural):

$$L_{urban} = \begin{cases} 65.99+26.16*\log(f_c)+(44.99-6.55*\log(h_b)*\log(d)-13.82*\log(h_b)-(3.2* \\ *\log(11.75*h_m)^2-4.97 \quad if \ \ d \le 20\ km \\ 65.99+26.16*\log(f_c)+(44.99-6.55*\log(h_b)*\log(d)^{b(d)}-13.82*\log(h_b)-(3.2* \\ *\log(11.75*h_m)^2-4.97 \quad if \ \ d \ge 20\ km \end{cases} \tag{4.5}$$

where: f_c - transmission frequency;

h_b–base station antenna height;

h_m - the height of the antenna of the mobile station;

d - distance between base and mobile stations.

$$L_{suburban} = \begin{cases} L_{urban}-2*\left(\log\left(\frac{f_c}{28}\right)^2\right)-5.4 \ \ if \ \ d \le 20\ km \\ L_{urban}-2*\left(\log\left(\frac{f_c}{28}\right)^2\right)-5.4 \ \ if \ \ d \ge 20\ km \end{cases}, \tag{4.6}$$

$$L_{rural} = \begin{cases} L_{suburban}-4.78*(\log(f_c)^2)+18*\log(f_c)\ if \ \ d \le 20\ \ km \\ L_{suburban}-4.78*(\log(f_c)^2)+18*\log(f_c)\ \ if \ \ d \ge 20\ km \end{cases}, \tag{4.7}$$

It should be noted that despite the fact that the Okumura-Hata model is a fairly widespread model for estimating the communication range, including for the LoRaWAN protocol [24], it has some limitations in application, in particular: standard indicators of the height of mobile stations in the Okumura-Hata model from 30 to 200 meters, which significantly reduces the adequacy of calculations for a base station below 30 meters and a mobile station above 200 meters, or requires additional experimental studies [25].

We use formula (4.8) to calculate the power at the receiver input:

$$Pr = ERP - L, \tag{4.8}$$

where ERP is the effective radiation power of the transmitter.

The results of the calculations are presented in Fig.13.

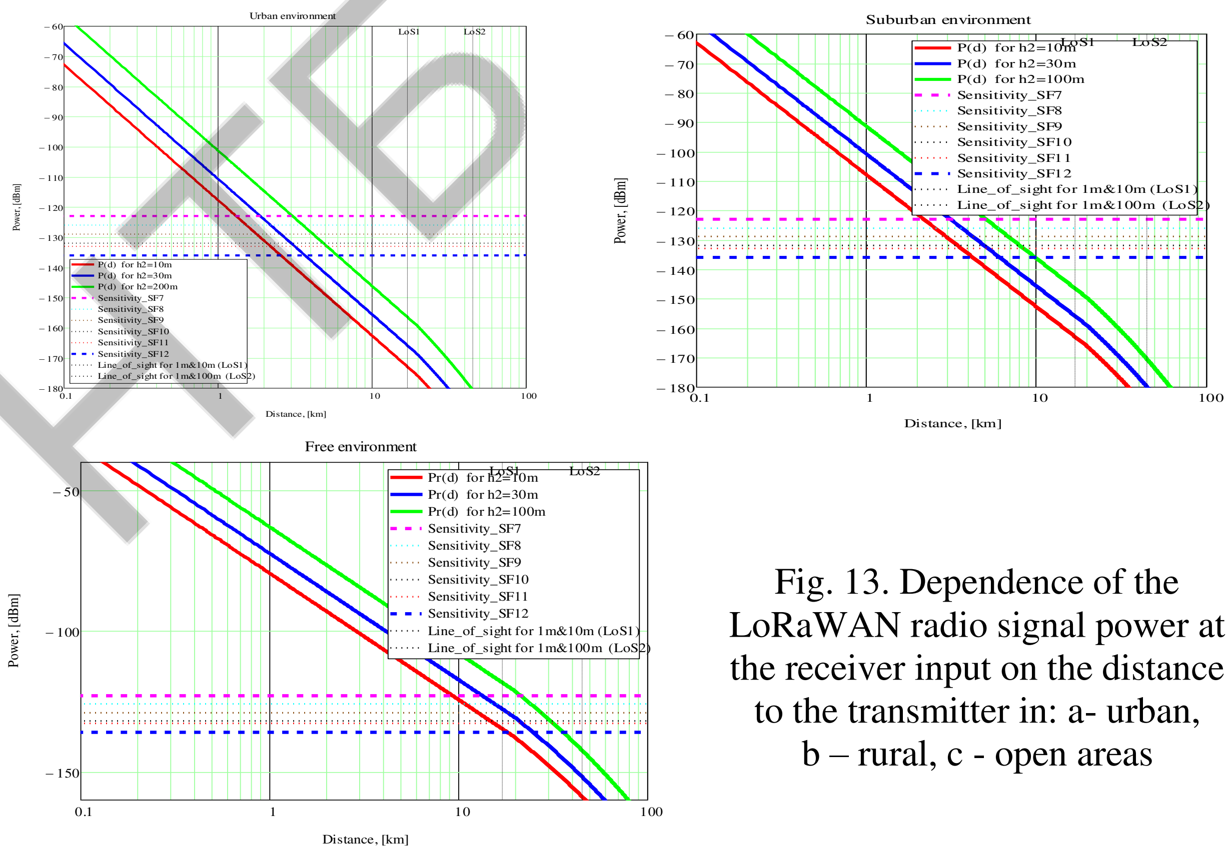

Fig. 13. Dependence of the LoRaWAN radio signal power at the receiver input on the distance to the transmitter in: a- urban, b – rural, c - open areas

It can be seen that when the line-of-sight range threshold is overcome (or near it), the angle of the curve changes, the signal begins to lose power more quickly. The maximum transmission range of the LoRaWAN signal in the open area of the Okumura-Hata model, for the heights of the receiving and transmitting antennas of 100 and 1 m, respectively, is 35 km. As can be seen from Fig. 11 and 13, the signal level at the receiver input calculated according to the Fries formula at a distance of about 5 km coincides with the values calculated according to the Hata-Okumura model for open terrain with relatively low values of the height of the transmitting antennas (1..3m), but the signal level at longer distances. The obtained results allow us to estimate the maximum distance to the ground base station, depending on the conditions and terrain - 30...40 km,

V.CONCLUSIONS

In the scientific work, the system of backup is proposed emergency communicate on built on the basis of LoRaWAN protocol. A detailed analysis of the organization of such a communication system and calculations revealed the strengths and weaknesses of such a system. In conditions of direct visibility and if available quadcopter slingshots, with the help of which the device for transmitting information can be lifted quite high into the air, LoRaWAN shows extremely good results in terms of transmission range.

To date, the following advantages of the developed system can be said:

- due to efficient energy consumption when transmitting small data packets, the energy consumption level of the end device is slightly around 1 year, for the case of transmitting 100 and receiving 100 messages per day;
-the maximum distance to the base station, depending on the conditions and terrain, is up to 300 km;
- to use the system, it is not necessary to obtain a frequency license and pay for the radio frequency spectrum;
- the construction of such a system is relatively cheap, compared to others with such a transmission range, due to the final cost of the device and the base station;
- with a sufficiently developed LoRaWAN infrastructure of base stations, high efficiency of receiving an alarm message by rescue services.

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EFFICIENT AUTOMATIC CONTROL OF THE ENERGY-SAVING PROCESS OF DEALCOHOLYZATION OF WINE IN THE FLOW IN A THERMOELECTRIC HEAT PUMP INSTALLATION
Author: Serhiy Pashkov
Advisor: Aleksandr Mazur
Odesa National University of Technology (Ukraine)………………………………………………. 620

STUDY OF THE OPTIMAL STRATEGY FOR TESTING COMPLEX ML MODELS AND AI APPLICATIONS USING THE MLOPS CONCEPT
Author: Zmiivskyi Volodymyr
Advisor: Kuznetsova Yuliia
National Aerospace University named after N. Ye. Zhukovsky
"Kharkiv Aviation Institute" (Ukraine)……………………………………………………………….. 635

ORGANIZATION OF A BACK-UP CHANNEL OF COMMUNICATION IN A LOCATION WITH NO CELLULAR COMMUNICATION INFRASTRUCTURE
Author: Savenko Stepan
Advisor: Yurii Lykov
Kharkiv National University of Radio Electronics (Ukraine)……………………………………… 650

4. POWER ENGINEERING AND ENERGY EFFICIENCY…………………………………. 666

ENERGY RECOVERY OF A HOUSEHOLD HEATING STOVE
Authors: Andriy Kudrenko, Ksenia Yanovska
Advisors: Maryna Litvinova, Oleksandr Shtanko
Kherson Educational-Scientific Institute of Admiral Makarov
National University of Shipbuilding (Ukraine)……………………………………………………….. 657

DEVELOPMENT OF A METHODOLOGY FOR INCREASING THE
EFFICIENCY OF A WIND TURBINE
Authors: Yevhen Priadko, Ruslan Kravchenko
Advisor: Oleksii Sadovyi
Mykolayiv National Agrarian University (Ukraine)………………………………………………….. 682

IMPLEMENTATION OF AN ENERGY EFFICIENT DRIVING SYSTEM BASED ON THE CONSUMPTION OF ENERGY CARRIERS AS A WAY TO INCREASE ENERGY CONSERVATION IN HIGHER EDUCATION INSTITUTIONS
Author: Oleksii Kuchmar
Advisors: Oleksandr Okushko, Ivan Radko
National University of Life and Environmental Sciences of Ukraine (Ukraine)…………………… 700

MODELS OF REFRIGERATING DEVICES IN THE OPEN MODELING SYSTEM TT-RH
Author: Serhiy Lomovtsev
Advisor: Boris Lomovtsev
Odesa National University of Technology (Ukraine)………………………………………………. 713

INTELLIGENT CONTROL SYSTEM OF GREENHOUSE MICROCLIMATE PARAMETERS
Author: Andrew Ostapenko
Advisor: Svitlana Kyslytsia
National University «Yuriy Kondratyuk Poltava Polytechnic» (Ukraine)………………………….. 736