Development of Distributed Multi-Segment Wireless Networks for Determining External Situations

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Abstract

The object of the research is the development of a distributed multi-segment wireless network of the IEEE 802.11 and ZigBee standards at 2.4 GHz, which in this study is proposed to be used to establish the fact of fire. The main areas of application are conducting observations for detecting fires, conducting chemical and radiation reconnaissance of objects and territories. Also, it is equally important to monitor objects that are in continuous production, in particular in areas with no line of sight. Where the use of video or infrared systems for detecting emergency situations is not possible for two reasons:

- these systems require more frequent maintenance, therefore, their installation when deploying continuous production, where there will be no access later, will cause great inconvenience during maintenance;
- Mechanical obstacles, like trees or shrubs, are insurmountable obstacles to the optical or infrared beam compared to the radio signal.

The sensors can be made both on a flexible basis, for example, for a more reliable fixing on a tree, or on a solid one. Such sensors can be placed even from an airplane in places where it is problematic to place them by ground methods. Placing video or infrared systems for detecting emergency situations in this way is impossible. They require high-quality installation work and are placed only from the ground. They require more frequent maintenance than wireless sensors in a distributed network. This, in turn, greatly complicates the maintenance of such systems in hard-to-reach places of the natural landscape. Also, the components of distributed wireless networks are much cheaper. One of the most problematic places is such phenomena as scattering and absorption during the passage of radio waves through a forest, as well as other objects of the natural landscape.\In the course of the study, methods were developed for measuring distance by means of multi-segment distributed wireless networks using an algorithm for bypassing sensors in indirect visibility zones in order to localize the fire point. Determined not only the dependence of the radio signal power with increasing distance, but also on the density of trees in the forest, which affects the accuracy of localization of the fire source. It has been found that the drop in signal power between open and mixed areas is almost a third, with the same indicators of increase in distance. Corrections for these indicators are introduced into the system, which ensures a decrease in the error in determining the coordinates of the fire source. Thanks to this, it is possible to operate a distributed network in order to measure the distance and angle between objects in the radius of which a fire has occurred, in areas with no line of sight. This ensures sufficient accuracy (error $\delta \approx 2$ m), which is impossible when using traditional measuring instruments. It is shown that the influence of the flame on the signal power leads to a drop in power (- 1 dBm). This change does not reduce the accuracy of determining the position of the fire, but makes it possible to determine that this is a flame.

Keywords [1]

Emergency, signal, radio waves, open space, flame, IEEE 802.11, ZigBee.

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1. Introduction

The question of studying the propagation of radio signals in ordinary areas is of great scientific and technical interest, especially recently. Significant relevance of these works came with the improvement of wireless network technology of the IEEE 802.11 standard, which uses the frequencies of 2.4 and 5 GHz. The reason for this is that forest fires have serious consequences for the environment and the economy, both in Ukraine and around the world.

The use of distributed multi-segment networks of the IEEE 802.11 standard provides advantages in prompt transmission for the exchange of necessary information between emergency services, their location relative to the point of occurrence of an emergency situation. This has a significant impact on the radio, both in the open and in the average (forest area). Radio waves, propagating through trees, are distorted due to scattering and absorption. Due to the fact that the signal power decreases, this method of propagation was effective only at short distances. But when using distributed networks (more than 2 devices in a segment) and connecting the required number of segments, it is possible to deploy a network of up to tens of kilometers.

Delays in locating an object that is part of a fire detection system cause incorrect data to appear on the computer network for emergency detection. This shortcoming, in turn, can lead to, for example, late detection of the source of ignition. Such effects are most likely in environments where there is a significant amount of radio emission. Among the many standards of computer networks are those whose data transmission system is based on the use of wireless communication channels. Such systems are used as means of signal propagation of computer networks for emergency detection (wireless sensor networks).

The relevance of this work is that in the process of deploying wireless computer networks to detect emergencies, the ability of the system to work in a mixed area is essential. One of the ways to solve this problem is to improve the existing methods of "bypassing" the sensors that make up the system.

Delays in sending packets, as well as errors in sending them, are also a significant disadvantage of existing wireless computer networks. This is also the cause of radio overload and significantly increases the occurrence of errors in the localization of coordinates, within which there was an emergency situation, such as fire.

But the most urgent task to be solved in this work is to identify signs based on changes in a number of parameters that characterize the occurrence of an emergency situation (fire). Also, these features make it possible to distinguish fire and smoke from other natural and man-made phenomena.

2. Analysis of literature sources and problem statement

Article [1] is devoted to the use of the Internet to control the measuring head, but the processing and adjustment of the obtained indicators via the Internet remained unresolved. Instead, in [2] the research of the issues of development of analog means of adjustment of measuring equipment is considered, but it does not investigate the issue of determining the position of the object. However, the work [3] is devoted to the elimination of localization errors by means of systems for finding the coordinates of the object, but for this purpose a cable communication is used.

This shortcoming has been eliminated in [4], which is devoted to a general overview of various protocols of wireless networks, but only for the purpose of analyzing their bottlenecks, without giving methods for their elimination. This issue is addressed in [5], which are devoted to positioning algorithms that can bring positive changes in the process of localization of objects, but they are not able to identify signal transmission media.

Another area of solving this range of problems includes works [6], which are devoted to current issues of integration of sensor networks and methods of their improvement. A separate area should include works [7], which are devoted to methods of determining the position used by satellite navigation systems. An equally important area related to the long life of equipment is the work [8, 9] on energy-saving technologies for computer networks to detect emergencies. As a confirmation of the need for more charge is the work [11], which states that the signal level in the open is higher than in the forest.

An option to overcome the above shortcomings may be work [12]. It presented the results of experimental studies of the influence of species and structural properties of forest vegetation on the peculiarities of the propagation of electromagnetic waves in the meter range.

However, wireless computer networks do not work in the meter range. Therefore, the results of experiments are described in [13], which show a significant difference in the change of the spectra of pulse signals during propagation in different types of forest vegetation.

This issue is largely addressed in [14], which shows experimental data on the attenuation of radio waves by the crowns of individual trees. No less relevant is the work [15], which reviewed electrodynamic models and methods of analysis of radio wave propagation in forests at different frequencies and distances.

This approach, with a greater focus on the specifics of forest vegetation, is presented in [16, 17]. In these works, as well as in works [18-23] the data on weakening of power of radio waves at simulation of a forest fire, and also in laboratory conditions are given, thus metal salts were poured on a burner flame, emitting burning of leaves in the forest containing meadow.

All this suggests that this study is appropriate. It discusses models and methods for deploying distributed multi-segment wireless computer networks to measure distance and angle between objects. These models and methods are adapted to areas of no direct vision, which allows determining the position at which the emergency occurred (fire.) Also described an experiment, the results of which reflect the effect of flame and smoke on signal strength, which will identify them among others types of interference.

3. The purpose and objectives of the study of the effect of flame on signal strength

The purpose of the study is to develop a distributed multi-segment wireless network with the improvement of existing technological solutions to identify emergency situations (sources of fire) in the forest area, which is an area of lack of direct visibility,

To achieve this goal it is necessary:

1. To propose a method of measuring the distance between the objects of wireless computer (sensor) networks, in order to calculate the position of the emergency situation (ignition sources);
2. to offer the equation of distribution of an error of calculation of position of objects of wireless computer (sensor) networks (δ_n), for the purpose of introduction of adjustments in process of localization of a site of ignition;
3. to investigate the algorithm of "bypassing" the devices of distributed wireless computer (sensor) networks, which allows to measure the distance to objects in areas of no direct visibility, which is almost impossible when using conventional measuring equipment;
4. Conduct an experiment to investigate the effect of flame and smoke on the signal strength of distributed wireless networks, which will reveal the features that distinguish fire and smoke from other types of interference.

4. Materials and methods for studying the effect of flame on the signal strength of distributed multi-segment wireless computer networks

Neural network positioning methods are based on measuring signal levels from all nearby access points or base stations whose coordinates are known. After creating a software or hardware solution of the neural network, it is necessary to create a mathematical model of positioning and perform network training.

Many mathematical models are known that can describe the relationship between the distance to an object and the signal level, and a new case model can be developed.

Therefore, we can conclude that the methods of positioning a mobile station using artificial neural networks can provide a fairly high accuracy.

The proposed method of positioning is based on the values of the RSSI, which is determined as follows [23]:

$$RSSI = -10n \cdot logd + A, \quad (1)$$

where d is the distance, A is the transmitter power, n is the signal propagation constant, in the free space n = 2.

The method, based on the nesting of neural networks, requires training of the network on a fairly large sample, which is obtained on the basis of preliminary analysis. After that, if the training is successful, the neural network can perform an assessment of the location of the mobile station. The obtained estimate will be formed as an estimate of the coordinates of the location of the station. The generalized algorithm of operation of the location system based on the neural network can look like this [39-43]:

- preliminary analysis of the localization area is carried out;
- the structure of a neural network and algorithm of its training is chosen;
- neural network training is performed on the basis of collected data;
- The trained neural network is tested;
- The adequacy of the received estimations is checked.

Usually as a neural network for spatial localization use multilayer perceptrons with one hidden layer. The number of input neurons is proportional to the number of antennas in the system, and the number of output neurons is proportional to the dimension of space. As a neural network learning algorithm, the backpropagation algorithm is most often used.

The RSSI value from several nearest base stations (at least three) to the desired mobile station enters the neural network, at two outputs of which, after appropriate processing, the coordinate value (latitude and longitude) of the mobile station appears.

The proposed neural network (Fig. 1) is a multilayer perceptron - one of the easiest ways to combine neurons into a network. The input layer consists of $k \le 6$ neurons x_i, i = 1… k. The hidden layer consists of m neurons y_j, j = 1… m, and $m = 2(k + p) + 1$.

The original layer consists of p = 2 neurons zn, n = 1…p. Input and latent neurons are interconnected by synapses with weights w_{ij}, latent and output neurons are interconnected by synapses with weights v_{jn}. The inputs of the neurons of the input layer receive signals s_i, which are *RSSI* values from base stations. Each input neuron xi transmits the obtained value, multiplied by the corresponding weights, to all neurons of the hidden layer.

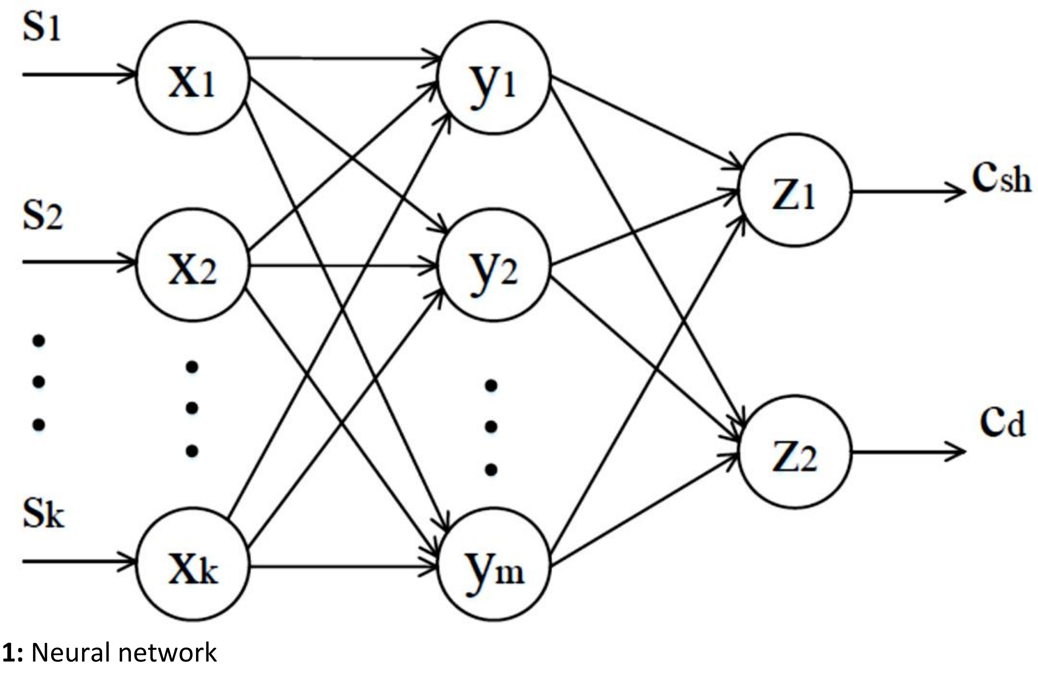

Figure 1: Neural network

The proposed neural network functions as follows. Each latent neuron y_j adds the obtained weighted values of $x_i w_{ij}$ and calculates the value of y_{jS} by formula (2)

$$y_{jS} = -\sum_{i=1}^{k} x_i \cdot w_{ij} + w_{0j}, \quad (2)$$

where w_{0j} is the displacement of the latent neuron.

The value of the activation function for each hidden neuron is calculated by the formula (3)

$$y_i = f(y_{jS}). \quad (3)$$

In this case, the activation function is a function of the hyperbolic tangent calculated by the formula (4)

$$f(a) = \frac{e^a - e^{-a}}{e^a + e^{-a}}. \quad (4)$$

Each original z_n neuron adds the obtained values and calculates the values of z_{nS} by the formula (5)

$$z_{nS} = \sum_{i=1}^{k} y_i \cdot v_{ij} + v_{0j}, \quad (5)$$

where v_{0n} is the displacement of the original neuron.

The value of the activation function, which is a function of the hyperbolic tangent, for each source neuron is calculated by the formula (6)

$$z_n = f(n_{ns}). \quad (6)$$

The output values of the output neurons are the values of the latitude and longitude of the location of the mobile station, i.e.

$$z_1 = C_{sh};\ z_2 = C_d.$$

Both output neurons calculate the error taking into account the reference output value t_n by the formula (7)

$$\delta_n = (t_n - z_n) \cdot f`(z_{nS}), \quad (7)$$

weight adjustment: $\Delta v_{jn} = h \cdot \delta_n \cdot y_j$ and offset adjustment: $\Delta v_{0n} = h \cdot \delta_n$, where h – learning rate.

Hidden neurons calculate the total error of the original neurons, which enters the j-hidden neuron

$$\delta_{jS} = \sum_{i=1}^{p} \delta_n \cdot v_{jn},$$

error value $\delta_j = \delta_{jS} \cdot f`(y_{jS})$; adjustment of weights $\Delta w_{ij} = h \cdot \delta_j \cdot x_i$ and offset adjustment $\Delta w_{0j} = h \cdot \delta_j$.

The values of the weights are updated according to the formulas (8)

$$w_{ij} = w_{ij} + \Delta w_{ij};\ v_{ij} = v_{ij} + \Delta v_{ij} \quad (8)$$

Neural network training continues until the total standard error is minimized

$$E_s = \frac{1}{2} \sum_{n=1}^{p} \sum_{q=1}^{L} (z_n^q - t_n^q)^2,$$

where L is the dimension of the training sample.

The network has three classes of devices: FFD-routing devices that use the development of the authors [1-4, 44] (Full Function Device – a device with a full set of functions – R), coordinating devices that use developments [1, 4], and additional uses a GPS signal to determine its position (anchor nodes,) (Coordinators – FFD with additional system resources depending on the complexity – G) and RFD-end devices that use the development [23] (Reduced Function Device - a device with a limited set of functions – S).

Multi-segment networks are formed on the basis of distributed, having more than 2 devices, by connecting to the devices R or G adjacent networks (segments), which can increase their range by many kilometers. In addition, each R device connects to the same segments with S and G devices, as in the right and left parts of the figure. (Fig. 2).

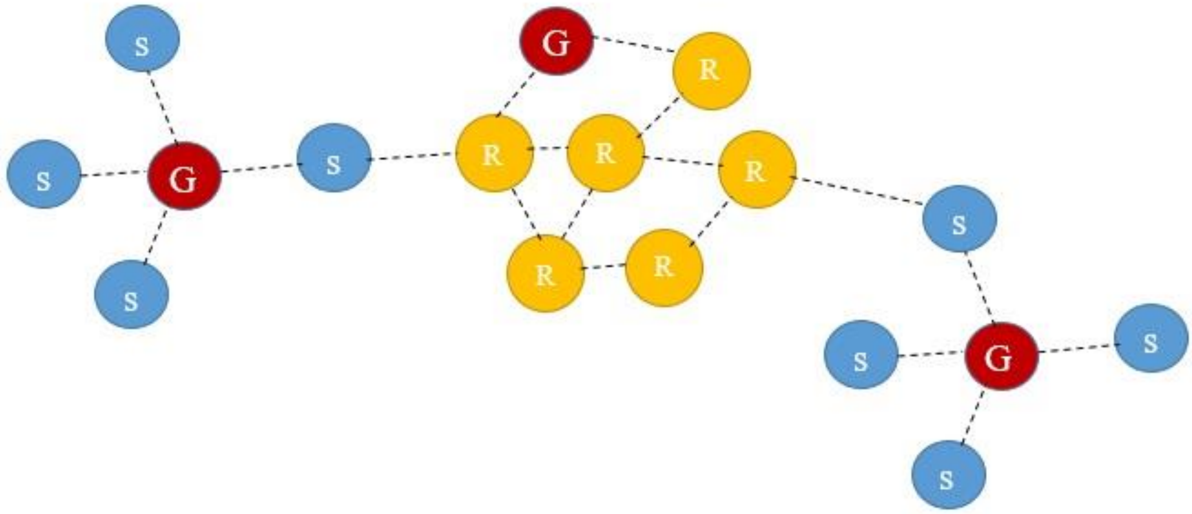

Figure 2: Sensor network model

In a multi-segment distributed wireless network for monitoring and detection of emergency situations, it is possible to use the distance between adjacent anchor devices, which is found in areas with the best signal level, as a reference. The reference distance can be used both within one segment and within all network segments, correcting for a drop in the radio signal level [23].

In R, it is proposed to use, in order to determine the distance to neighboring nodes, both the radio signal and the beam of the laser rangefinder, which is aimed at the object on which the neighboring node is fixed.

The SNDWAY SW-M80 laser rangefinder was used. Its connection to network devices is based on the methods presented in [1-4], which were previously performed by the authors. This is done in order to be able to adjust the obtained distance values on the basis of two alternative values, in order to increase accuracy.

The second purpose of such duplication is the ability to obtain at least one of the indicators, if the other, due to an emergency situation on the route of the signal (beam), it is physically impossible to obtain [23].

To conduct an experiment to determine the distance between the objects of a distributed multi-segment wireless computer (sensor) network, in order to identify the point of occurrence of an emergency situation (fire), an algorithm for "bypassing" network devices in areas of no direct visibility [44]:

positionsi=ϕ;
msgi=nil;
if ni ∈ *U then* {if it is an anchor node};
Start Walking();
start posTimer.
end if
posTimer timeout.
(*xi, yi*):=getGpsPosition();
Send *position*(*xi, yi*) to all *nj* ∈ *Ni*.
Restart posTimer.
msgi=position(*xk, yk*)such that *distk=distanceEstimitation(msgi);*
positionsi:= positionsi ∪ {(*xk, yk, distk*)};
if size (positionsi)<=3 then { if there are enough positions };
(*xi, yi*):= *positionComputation*(*referencesi*);
end if.

This algorithm was modeled in the MATLAB system, on the example of a network within the radius of which is a rectangular building (Fig. 3).

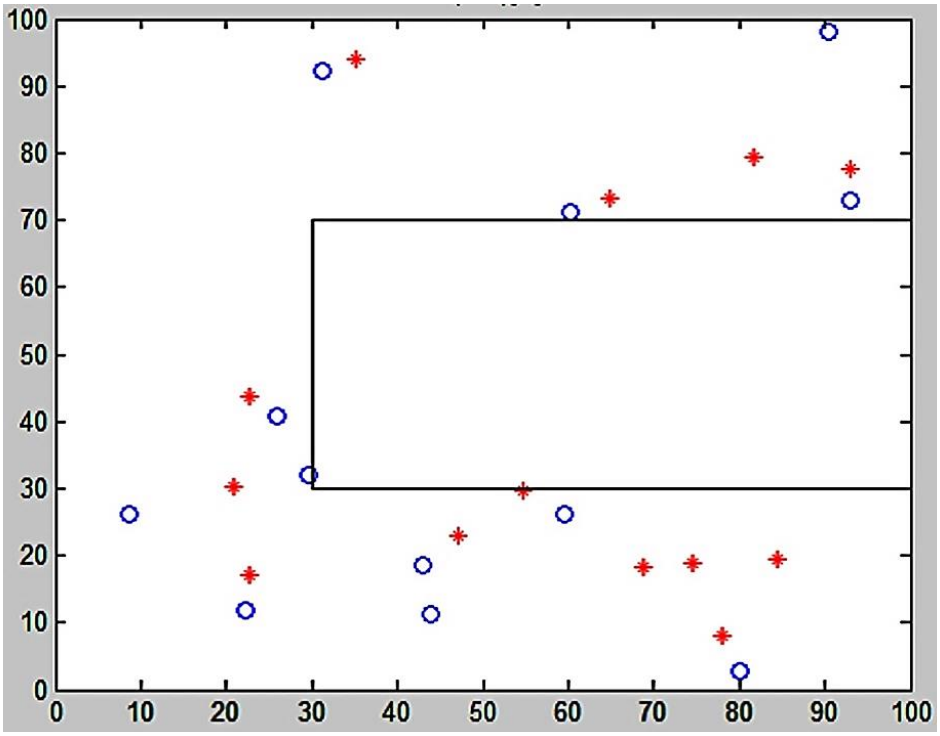

Figure 3: The result of modeling the deployment of the network in the area of no direct visibility in the area of 100x100 m

To conduct an experiment to obtain data on the signal power drop, depending on the range, in the area of indirect visibility, the application Lizard Systems WiFi Scanner is proposed (Fig. 4).

Figure 4: WiFi Scanner application window

R devices are shown in red, and Member Node and G are shown in blue.

This application is a very powerful system. It allows you to monitor more than 10 parameters of wireless computer networks, including the decrease in signal strength with increasing distance.

5. The results of the study of the effect of flame on signal power in multi-segment distributed wireless networks

The task of direct scientific research of this work is experimental and practical detection of attenuation of signal power and data transmission in the open field, as well as in the forest at different distances. Experimental evaluation of signal attenuation was performed in three stages.

The first part of the experiment was to measure the signal strength and bandwidth of the channel in the open at the stadium, with no obstacles to the signal. Measurements were performed with a distance change every five meters.

The second part of the experiment was conducted in a deciduous (oak) forest, medium density, with flat terrain with densely growing shrubs. The average height of the trees was 15 m, the average diameter of the trunks was 0.3 m, and the bushes were 2 m high.

Measurements were made every ten meters. The transmitter and receiver were located at a height of 1.2 m from the ground and were optimally directed at each other. The third part of the experiment was performed when exposed to the signal of the flame of fire, with the distance between the receiving and transmitting device was 6 m

In this part of the experiment, the forest fire of the underlying surface was simulated. Data transmission was performed using Wi-Fi IEEE 802.11 technology in the frequency range of 2.4 GHz and a signal power of 100 mW at an antenna gain of not more than 6 dB, which is the allowable range of the standard [23]. Measurement of signal strength was performed using a personal computer, WiFi Scanner software version.

The signal intensity was measured in dBm and displayed on the oscillogram, which is a graph of the power of the signal coming to the receiver from the time of its arrival (Fig. 4).

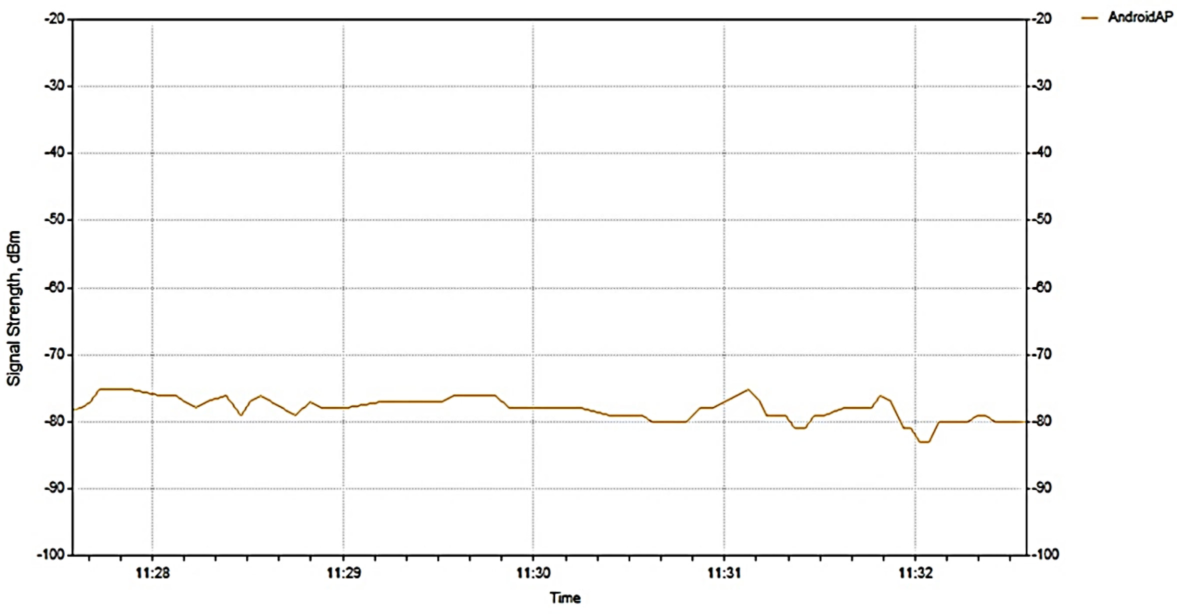

Figure 4: Oscillogram of signal power dependence on the time of its arrival

The peak values of the signal power are visible on the oscillogram. The signal was recorded, on average, 4 minutes on each section of the distance. The results thus obtained were subsequently averaged.

A comparative evaluation of the measurement of the signal power dependence on the distance in the open space (straight line) and in the forest area (dashed line) was performed. The graph of this assessment is shown in Fig. 5.

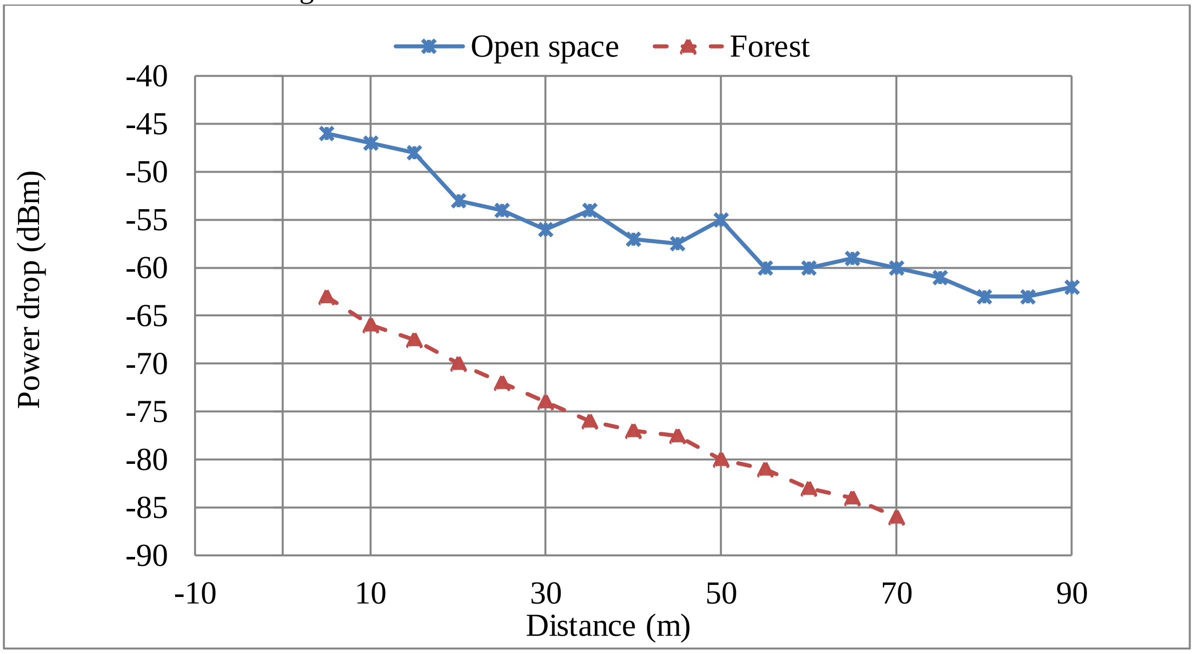

Figure 5: Graph of signal power dependence on distance in different environments

The signal strength decreases as the distance between the transmitter and receiver increases. In the open at a distance of 90 meters, the signal decreased by 15 dBm. The amount of information transmission ranged from 1.85 Mbps to 1.65 Mbps, and as the distance increased, the volume decreased accordingly.

In the forest, the signal is significantly weakened, this is due to the passage of the signal through the thick bush in the first ten meters of the experiment and already at 70 meters the signal becomes much lower, approaching the threshold sensitivity.

This is quite enough, because the maximum distance between neighboring devices of the distributed network, within one segment, is 50 meters.

When the flame affected the transmitted signal, a decrease in the signal power c - 46.7 dBm to - 47.6 dBm was observed, respectively, a decrease in the power ≈– 1 dBm.

This is primarily due to the fact that in the flame, as a result of a chemical reaction, mobile positive ions and negative particles - electrons are formed.

Thus, the concentration of charged particles in the flame plasma is 10^{12} ions/cm^3. These particles in turn affect the propagation and signal strength.

6. Discussion of the results of studies of the effect of flame on signal power in multi-segment distributed wireless networks

The disadvantage of this study is that as a result of the experiment, a wireless computer was deployed in a heterogeneous area. The received signal power is 30% less than in the open.

The advantage is that despite this, the network continues to operate at the minimum sensitivity limit and measure the distance to neighboring objects with a tolerance of $\delta \approx 2$ m.

These indicators allow to determine the position of the emergency situation (fire) with sufficient accuracy. It should also be noted that when simulating a leaf fire, the display of the laser rangefinder SNDWAY SW-M80 displayed "ERROR".

This error is due to the fact that flames and smoke are environments that do not reflect the laser beam. In rare cases, if reflected, it reaches the rangefinder receiver with significant distortion that makes it impossible to determine the distance to the object with sufficient accuracy.

Rain and fog are also such environments, but they would cause such errors within the range of the entire network, not just a single area.

A useful result of this study is the identification of parameters that allow the separation of flames and smoke from other natural and man-made phenomena that may occur in the forest.

Therefore, it can be concluded that if the movement of network devices in the study area did not occur, and the rangefinders transmit the signal "ERROR" only in a separate area, which eliminates the possibility of rain or fog. In this case, if the measurement of the signal power in this area for more than 2-3 minutes shows a drop of ≈ – 1 dBm, then with a high probability we can conclude the occurrence of an emergency situation (fire).

After all, if a non-transparent object appears between adjacent devices, the laser rangefinder will send the distance to this object, not the "ERROR" signal.

This study is a continuation of a series of experiments to determine the linear angular dimensions between objects of wireless computer networks.

On the other hand, it is the first in terms of studying the effects of flame and smoke on the parameters of the localization system. In the following researches it is planned to analyze the dependence of network parameters on different stages of combustion.

7. Conclusions

1. The method of measuring the distance between the objects of distributed wireless networks is proposed, in order to calculate the position of the emergency situation (ignition source), which allows the deployment of the network and assess the position of its objects. This allows you to monitor the occurrence of fires, by means of multi-segment distributed wireless networks, expanding the coverage area, within each segment, up to 100x100m.
2. The equation of the distribution of the error in calculating the position of the objects of wireless computer (sensor) networks, in order to make adjustments to the process of localization of the fire area. This equation allows us to estimate the occurrence of an emergency situation (ignition source) with an error of $\delta \approx 2$ m, which is sufficient accuracy.
3. The algorithm of "bypassing" devices of wireless networks is investigated, which allows to measure the distance in the zones of absence of direct visibility, which allows determining the position of the neighboring object when the signal power drops by 30%. This result is almost impossible when using conventional measuring techniques.
4. An experiment was performed which showed that flame and smoke are such environments that cause a signal of error of the laser rangefinder, cause a drop in radio signal power ≈ – 1 dBm. It is substantiated why other environments and objects, such as rain, fog or opaque objects, cannot cause such indicators in the aggregate.

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