Method of Increasing the Efficiency of Managing Energy Potential Protected Radioliniy Terahertz Range using Artificial Intelligence

Volodymyr Saiko[1], Serhii Toliupa[1], Volodymyr Nakonechnyi[1], Mykola Brailovskyi[1], and Teodor Narytnik[2]

[1] *Taras Shevchenko National University of Kyiv, 24 Bohdana Havrylyshyna str., 04116, Kyiv, Ukraine*
[2] *Institute of Electronics and Communication of the Ukrainian Academy of Sciences, 2b Les' Kurbas ave., 03148, Kyiv, Ukraine*

Abstract

A structural-functional model of constructing the receiving system IR-UWB signals in the range of very high frequencies of the elements of intelligent control, which is based on a separate plane of physical infrastructure and plane management that allows you to automate efficiently manage the process of joint use of resources physical infrastructure and methods of artificial intelligence. In contrast to existing models receiving of IR-UWB signals terahertz (THz) range, it is able to provide protocol and infrastructural collect the necessary data for intelligent algorithms. The proposed physical infrastructure has a module training and optimization, which involves the use of existing simulation model radio THz range from 110 to 170 GHz for testing of intelligent algorithms control power capacity radioliniy IR-UWB signals in the range of very high frequencies. The developed algorithm collecting data involves tracking the status of blocks receiving complex for efficient collection of data actually to use changing values as metrics Euclidean distances well and metrics functional technical parameters in relation to the number of clusters.

Keywords

Protected systems, terahertz radio lines, artificial intelligence methods, energy saving.

1. Introduction

The development of 5G networks and the further increase in the density of small cells and access points leads to the need to pay significant attention to the radio channel between the access point and the Internet. In many cases, the use of a wired connection to organize such a communication channel is impractical for economic reasons. In these circumstances, a wireless connection that works in the terahertz (THz) range and frequency are an attractive resource for building a high-speed wireless network connection.

At the same time, national regulators of many countries have been identified terahertz range of frequencies and set limitations on the spectral power radiation ultrawideband signals (NSHS) for their unlicensed first use. In virtue of limitations on the spectral density range radiation NSHS device connection is 10-50 meters, so the main area of application NSHS connection - this wireless network

CPITS-II-2021: Cybersecurity Providing in Information and Telecommunication Systems, October 26, 2021, Kyiv, Ukraine
EMAIL: vgsaiko@gmail.com (V. Saiko); tolupa@i.ua (S. Toliupa); nvc2006@i.ua (V. Nakonechnyi); bk1972@ukr.net (M. Brailovskyi); director@mitris.com (T. Narytnik)
ORCID: 0000-0002-3059-6787 (V. Saiko); 0000-0002-1919-9174 (S. Toliupa); 0000-0002-0247-5400 (V. Nakonechnyi); 0000-0002-3148-1148 (M. Brailovskyi); 0000-0001-8071-6356 (T. Narytnik)

communications and wireless sensor networks of small radius of action (local and personal networks). For that to expand the scope of application of technology NSHS terahertz communication should increase the range of action of receiving and transmitting devices in the mode of "point to point".

2. Formulation of the Purpose of Research and Justification of Its Actuality.

The steady increase in the variety and volume of information flows in a telecommunication network, the urge to solve scientific and practical task of developing infrastructure gear -pryymalnyh of a range of very high frequencies to ensure effective management radioliniy IR-UWB signals THz range on the basis of algorithms, machine learning and neural networks with regard setting energy efficiency.

For you to solve this problem is of interest complex (combined) application:

- methods of receiving a multibeam signal;
- principles of construction and algorithms of signal formation and processing in multiposition communication systems;
- methods of artificial intelligence and machine learning.

Development of innovative methods to increase the efficiency of managing the use of energy potential of radiohertz range lines to increase noise immunity and range of low-orbit communication system is a new scientific direction [1,2]. Modern approaches to solving these scientific and technical problems do not allow to obtain the expected results.

The aim of this work is to develop methods increase the efficiency of managing the use of the energy potential radioliniy on the basis of spatially distributed devices [3], which uses terahertz band waves for ensuring improve noise immunity, and range of action channel communication systems due to the base of tall aeroplatform.

3. Summary the Stated Objectives

There is a method of receiving a multi-beam signal [4], which consists in the fact that when receiving periodically determine the number and time delays of the components of the multi-beam signal, for which:

–determine the time domain of multipath;

–conduct search signal in the area multipath and define the evaluation of search numbers and time delay component multipath signal;

–generate updated number and time delays of the components of the multibeam signal;

–find the time delays of the components of the multi-beam signal of the current period, constantly updating the updated time delays of the components of the multi-beam signal;

–using these time delays, form soft decisions about information symbols.

The disadvantage of this method is the fact that the choice of threshold h, which is used to identify clusters of rays based on the initial evaluation of pulse characteristics of the channel. However, the disadvantage of this approach is the fact that the estimates obtained from the analysis of the received test signal and is virtually in all the ways there is a serious engineering problem selection threshold adoption decision is either not indicated or she is given enough attention.

In [4] in quality threshold chosen h, is proportional to power noise. Thus, the known methods are inefficient because they reduce the speed of information, and in addition are not partially brought to constructive engineering algorithms. Therefore, it is necessary to find a more effective solution to this problem.

In addition, the implementation of this method does not take into account the fact of distortion of the time form of the pulses of the receiving system IR-UWB signals THz bands [5,6]. Although the results of the study on the transmission of UWB signal of picosecond duration through the idealized model of the radio channel terahertz channel 110-140 GHz show that the main type of distortion of the temporal shape of the pulse is its expansion from the initial duration of 140 ps to 250 ps, which is primarily low frequency and bandpass filters of the transmitting and receiving paths [7].

The expansion of the pulses leads to a decrease in their amplitude, which reduces the efficiency of pulse selection against the background of noise and interference. This is due to the fact that in a nonperiodic sequence of pulses, the average duty cycle $\bar{Q}$, as the ratio of the signal duration T_c to the total time of the pulse duration in the signal, will be equal to:

$$\bar{Q} = \frac{T_c}{\tau n} = \frac{1}{V\tau n}, \tag{1}$$

where V is the transmission rate, n is the number of pulses in the signal, τ is the pulse duration.

And accordingly, the average duty cycle of the signal should be as high as possible 1. Otherwise, each of the signals will be a dense flow of pulses, which will prevent code division of signals in a network where many terminals operate simultaneously. The average duty cycle of the signals, in essence, determines the possibility of ensuring their orthogonality, ie the possibility of signal separation.

One should also note that the value of the average duty cycle $\bar{Q}$ determines the average power of the transmitted signal $\bar{P}$, if you know the peak power of the pulses P_i i by the following formula:

$$\bar{P} = {}^{P_i}\!/_{\bar{Q}} \tag{2}$$

Therefore, the only way to increase the signal power with restrictions on the duration and number of pulses is to increase the amplitude (peak power) of the transmitted pulses.

The authors in [4] did not propose a mechanism for monitoring and controlling the duration of the UWB signal and, accordingly, a model for effective control of the use of energy potential of radio lines.

3.1 General Architecture of the Innovative Solution

The authors propose the use of intelligent algorithms based on trained models of artificial intelligence, which will be used at the physical level of the proposed architecture of the receiving system IR-UWB signals THz bands using algorithms based on artificial intelligence, as well as at the control plane level (Fig. 1).

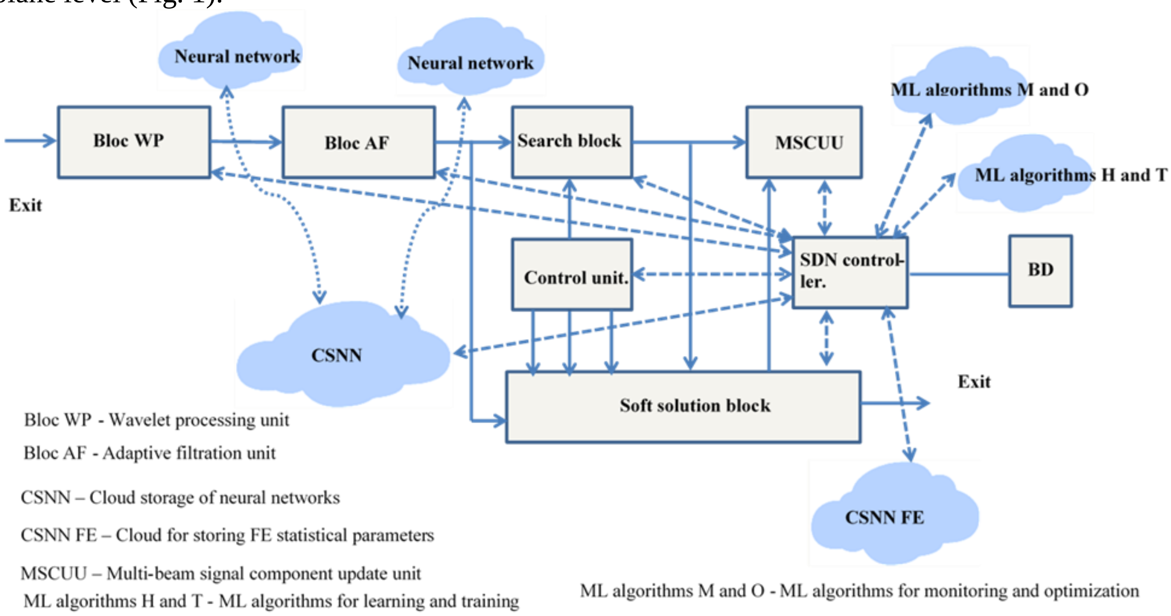


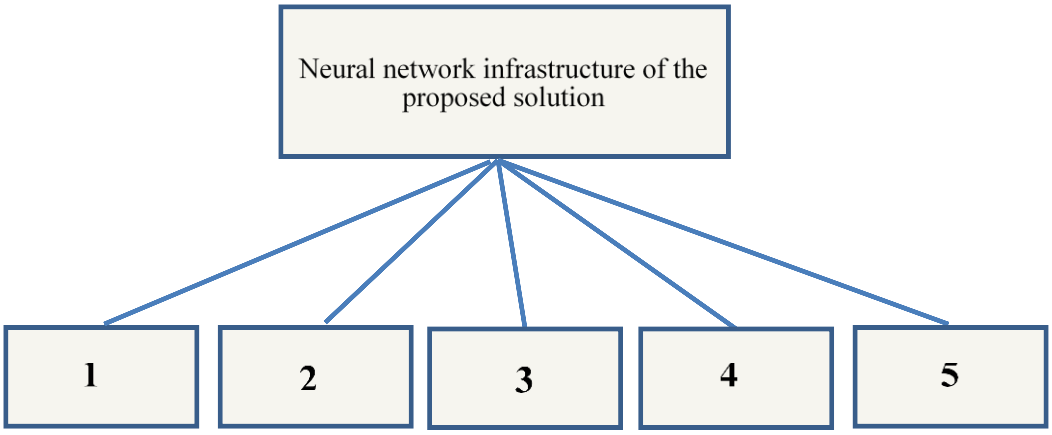
Figure 1: Block diagram of the proposed architecture of the receiving system of the THz band using algorithms based on artificial intelligence

The work of these algorithms is focused on managing the use of energy of radio lines with IR-UWB signals and as a result of optimizing the use of resources of their energy potential. For example, the use of neural network-based algorithms to implement wavelet transform avoids a large number of calculations and greatly speeds up the search for wavelet decomposition coefficients to make more efficient use of the spectral resources of the communication channel.

Intelligent control algorithms on the SDN controller can perform optimization at the level of the whole complex. However, for such algorithms that operate at the physical level and the management level must have the appropriate infrastructure for data collection, training, testing and updating of relevant trained models.

Figure 2 shows the neural network infrastructure of the developed innovative solution. Its components are the following modules:

- operation of ML algorithms on SDN controller;
- neural network training;
- training and optimization of the neural network;
- operation of algorithms using a neural network on blocks of an innovative solution.



1- Module of operation of ML algorithms on SDN controller

2- Neural network training module

3- Module of training and optimization of the neural network

4- Communication channels for updating the neural network and related software

5- Module of algorithms using neural network on blocks of innovative solution

Figure 2: Neural network infrastructure of the developed innovative solution

Maintaining this infrastructure should cost less than the benefits it should provide. Many works present the use of single algorithms based on neural networks that optimize a particular process or part of the device [8]. However, they do not present how data collection, neural network training, and software updates are performed. That is, it does not show how the complete feedback infrastructure should work for algorithms that optimize the operation of the receiving complex of IR-UWB THz signals using neural networks.

3.2 Model of Signal Pre-Processing using Wavelet Processing

The existing methods [8] that use wave filtering by wavelet transform in neural network image classification systems cannot be directly applied to models and algorithms for effective control of the use of energy potential of radio lines. Therefore, an important area of further research is the adaptation of currently known methods of artificial intelligence to the monitoring and optimization of multiposition systems based on low-power transceivers for the construction of inter-satellite communication channels terahertz range of low-orbit satellite systems with distributed architecture.

The search unit (see Fig.1) has a device that determines the value of the decision function for a given discrete time delays of the multipath, compares the value of the generated decision function with a given threshold h and generates estimates of search time delays of the beam component over the threshold h.

As is well-known, when receiving broadband multi-beam signals, a search procedure is also performed, which, as a rule, is a scan of the uncertainty area with the detection of the signal at each of its points.

The disadvantage of the known treatment approaches multipath signal along through the use of search procedure is that during this search procedure signal radiation is not considered the impact of multipath signal components to each other. As a result, the probability of erroneous detection of beam signals increases. In addition, there is no optimization of the number of beam signals used to obtain soft decisions about information symbols, which leads to inflated requirements for hardware implementation without increasing the quality of the selected information.

From this point of view, it is advisable to introduce a tracking procedure and identify changes in the properties of non-stationary processes in the signal search algorithm, as well as adaptation to changes in the noise level.

The block diagram of the signal pre-processing system using wavelet processing to obtain the input image of the neural network of the proposed approach is presented in Fig. 3.

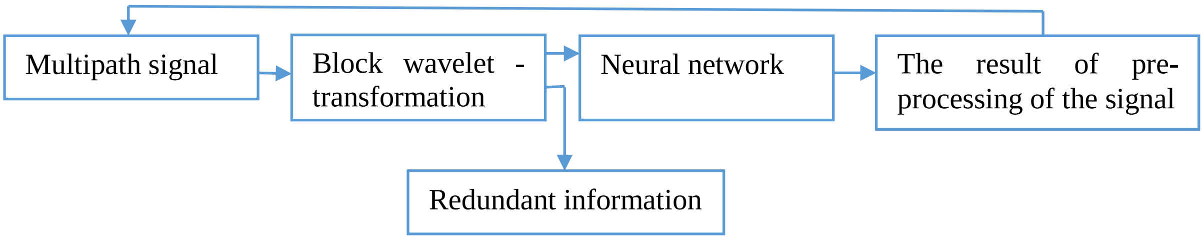


Figure 3: Blok diagram of the proposed system pre- processing multipath signals

The peculiarity of the proposed approach is that in order to adapt digital signal processing to a time-varying noise, in solving the problem of recognizing the presence or absence of a signal at a given interval, a method based on wavelet transform and neural network is proposed.

Wavelet transform allows you to more accurately localize the frequency properties of the signal over time and does not increase the amount of data in the transition from the time representation of the signal to its representation in the wavelet region. The best frequency separation is provided by the filter with the highest frequency response. Such a trait is characteristic of Dobeshi's wavelet.

As the order of the Dobeshi filter increases, its frequency response tends to be ideal. But it is necessary to consider that application of the filter with the long impulse characteristic leads to very appreciable distortion. Therefore the most appropriate use of the filter Daubechies 4 kofleta 2 and simmleta. Biortohonalni wavelets Daubechies allow to reduce the amount of computation by the decomposition by using short filters [9–13].

The algorithm for dividing the intervals of signal presence or absence is constructed taking into account the peculiarities of the multipath signal propagation, which are described perceptually by the model. The model divides the spectrum of a multibeam signal into frequency bands, into so-called critical intervals.

The developed algorithm uses a wavelet - the transformation of a multibeam signal on the biotogonal basis of Dobesha, and to decide on the types of interval (segment) of the signal—a neural network on a multilayer perceptron.

Compared with traditional spectral methods, wavelet transform provides a more accurate localization of the signal in time and frequency (in the decomposition subbands) and has a fast implementation algorithm. The biotogonal basis preserves the phase ratios of the frequency components of the signal after its recovery by inverse wavelet transform.

Further improvement of the proposed method was achieved by reducing the dimension of the input vector of the perceptron, which allowed to reduce the number of training samples and speed up the learning process. Reducing the dimensionality of input vectors in neural network learning, based on the principal components algorithm.

The results of the study of the dependence of the probability of recognition error on the dimensionality of the feature vector after the transformation by the method of principal components is shown in Fig. 4. The presented results show that the dependences for the total probability of recognition error (curve above) and root mean square error (RMS) transformation are almost monotonically decreasing, with the selection of principal components and reducing on this basis the dimensional space of features gives a more significant effect with increasing correlation signs.

The Levenberg-Marquardt Algorithm (LMA) algorithm was used to train the multilayer perceptron, which is the most common algorithm for minimizing quadratic deviations. Its advantages, in comparison with the method of gradient descent, are the high speed of calculations.

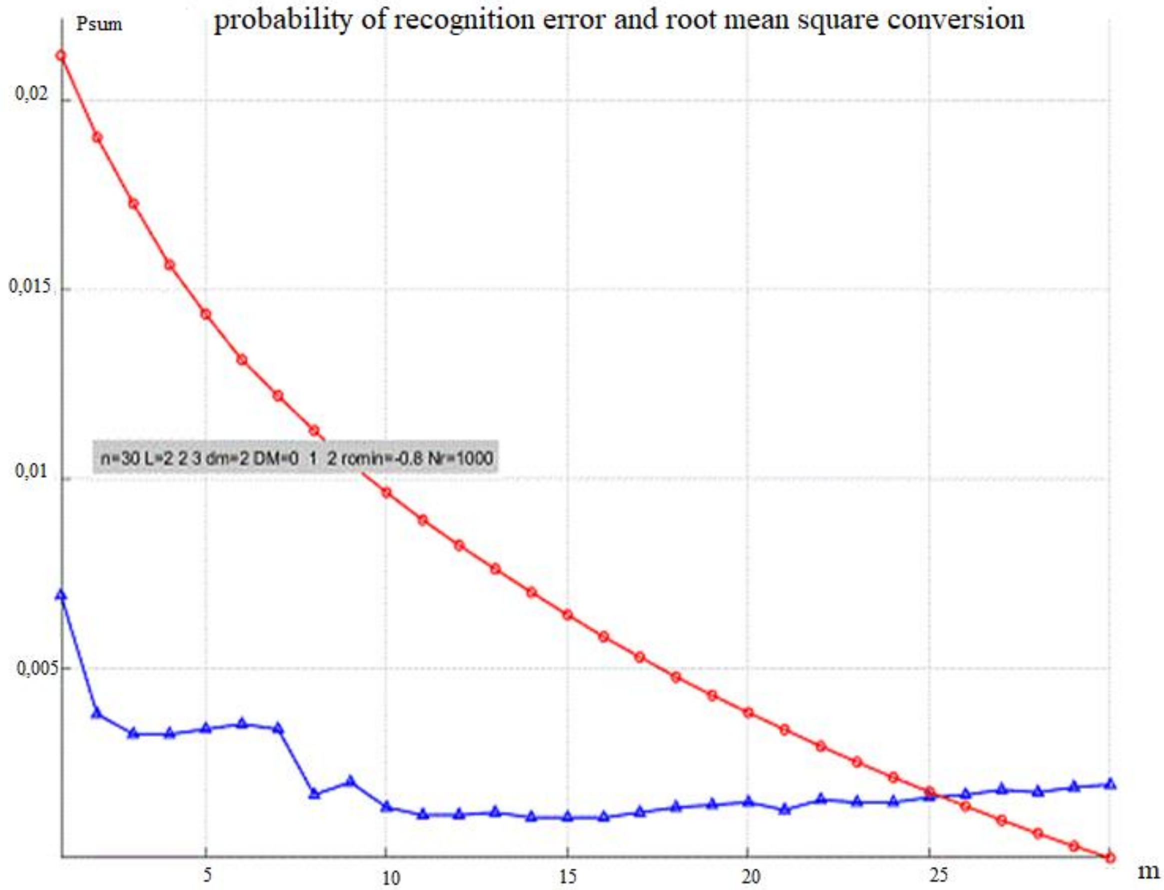


Figure 4: Dependences for the total probability of error and UPC transformation on the dimension of the feature vector after the transformation algorithm of the principal components

3.3 The System of Monitoring and Optimization of the Proposed Solution

In the developed architecture it is proposed to use the module of training and testing which allows to adjust intelligent control algorithms, namely processes of preparation, testing and an estimation before their deployment in the innovative decision.

Simulated data or data from a real receiving system of IR-UWB signals of THz bands can be used for training or testing of such algorithms. This approach allows you to better prepare for the launch of such algorithms on real networks and reduce the associated risks (Fig. 1).

To evaluate such algorithms, it is necessary to introduce certain functional metrics of the developed system, on the basis of which these algorithms will be evaluated. The training and testing module includes a simulation model of a wireless telecommunications system in the terahertz range based on the use of IR-UWB multibeam signals of picosecond duration with appropriate components for maximum proximity to the operation of the actual developed receiving device.

As a quality environment simulation modeling of selected software complex NI Multisim 13.0 [14]. This is due to the fact that in the CAD Microwave Office it is not possible to connect to the receiving path of the terahertz frequency (TH) band active model of the receiver IR-UWB signals, which is assembled from individual elements. Feature of modeling receiver IR-UWB signals is the fact that, in the first place it is necessary to collect a simulation model that corresponds to the transmitter part in what is also happening formation of IR-UWB signal in a Gaussian monotsykla. The idealized simulation model of the THC band radio line will be built on the basis of the parameters and the structural scheme of the current model of the THz band transceiver [7].

Functional metrics of the developed system of evaluation of overtrained neural network should be the usual functional parameters of this solution: signal-to- noise ratio, pulse duration of UWB signal, efficiency of use of spectral resources of communication channels and others. If the overtrained model for a certain algorithm has led to deterioration of functional parameters then this model should be returned or should be removed from the storage module.

For that to intelligent algorithms for control given the correct result should collect sufficient set of data, by which is meant the optimum amount of data with which training models considered complete and is not observed so -called process overfitynhu.

An SDN controller is usedt collect functional data, which directly carries out the process of collecting the relevant data from the blocks of the receiving system IR-UWB signals of the THz band.

Each unit receiving system is a source of information for ML algorithms, as can be and the purpose of their use. The main data processing before training neural networks is carried out on the SDN controller. All the collected functional parameters that are necessary for the training of neural networks are stored in the FE cloud. Only intelligent algorithms on the SDN controller have access to these parameters. If there is a change in the state of the receiving system IR-UWB signals in the range of extremely high frequencies, which requires retraining of the respective models, the corresponding algorithms carry out the procedure of retraining them on the basis of new FE parameters. After that, the corresponding trained models in the cloud are replaced. When a new version of the model for the corresponding block appears, the block downloads the updated version of the model.

In work used cluster approach to determine states receiving system IR-UWB signals in band very high frequency of training without the supervision of the use of ML algorithms k- means (k - average) and c- means (c - average) for developed algorithm collecting data [15, 16].

This approach allows you to determine on the basis of a certain period of time the necessary states of the proposed device or the emergence of new states. Besides that, this approach allows to take into account the greater number of functional technical parameters with minimal change in software security.

An important part of intelligent algorithms management is the collection of direct data for the study. One of the features were using these algorithms in telecommunication radio networks THz range is the variability of conditions in the sector, as well as appearances and new and disappearance of current conditions that require additional collection of data and overtraining neural networks.

In the study [8, 9] the application of algorithms based on neural networks for the implementation of wavelet transform in receiving systems is presented. But these works do not present how the collection of certain functional technical data. Therefore, the development of an algorithm for rational data collection for neural networks from the respective blocks of the receiving system is quite relevant.

The developed algorithm of data collection provides tracking of a condition of blocks of a receiving complex for rational data collection actually using change of values, both metrics of Euclidean distances, and metrics of functional technical parameters, in relation to number of clusters.

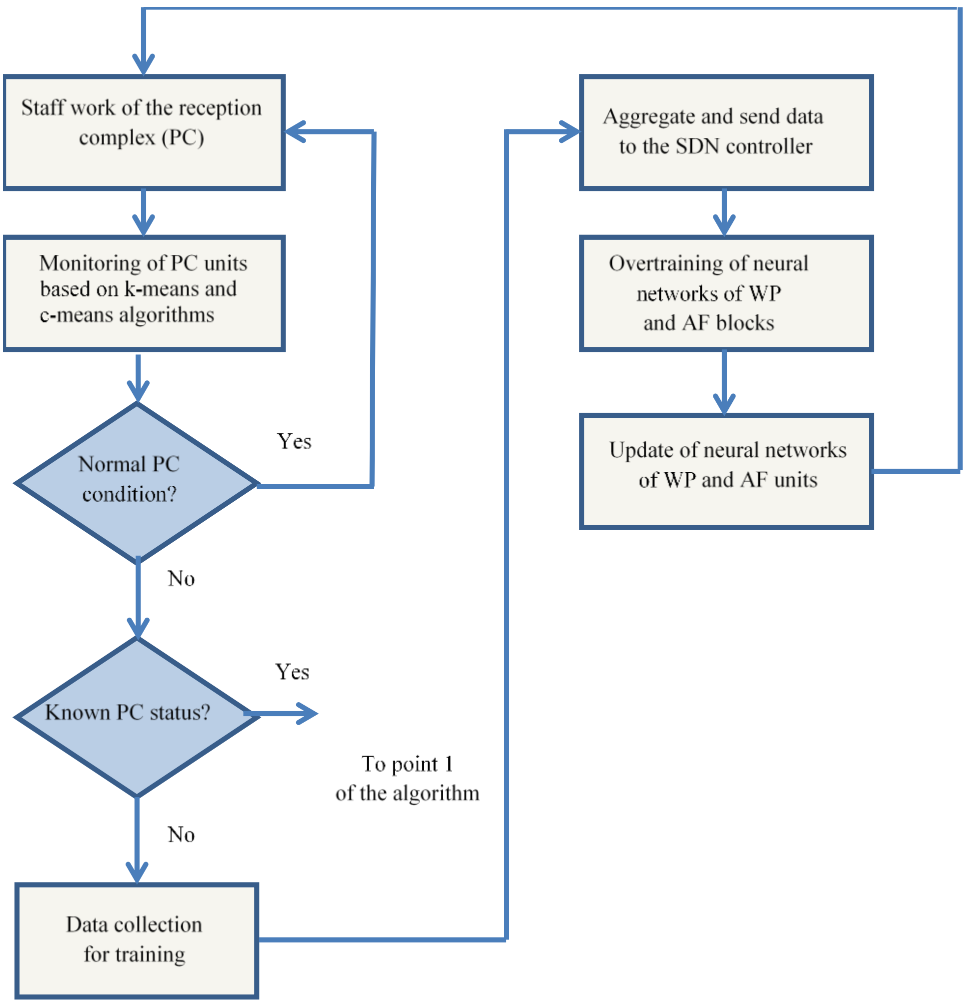


Figure 5: Block diagram of the algorithm for tracking the state of the receiving complex for the collection and retraining of the corresponding neural networks

The novelty of this approach is in contrast to the classical implementation that the introduced metrics signal-to-noise ratio and pulse duration UWB signal, instead of Euclidean distance metrics, which allows to take into account the spatial characteristics of signal propagation in the process of self-optimization of the developed receiving structure.

4. Conclusion

1. An algorithm for tracking a multibeam signal of a system for receiving signals from spatially spaced low-power transmitters has been developed, the feature of which is the specification in the process of tracking not only the time positions of components, but also their number. A distinctive feature of the developed algorithm is that it is built using wavelet - processing to obtain the input image of the neural network.

2. The structural-functional model of construction of the receiving system of IR-UWB signals of THz bands with elements of intelligent control of the receiving complex at the physical level and control of the complex is offered. Unlike the existing infrastructures of the receiving system IR-UWB signals THz bands, these radio networks are not able to provide protocol and infrastructure collection of the necessary data for intelligent algorithms. The proposed infrastructure has a training and optimization module, which provides for the use of the existing simulation model of the THz radio line in the range from 110 to 170 GHz to test intelligent algorithms for controlling the energy potential of IR-UWB radio lines of the THz band.

3. Further research is aimed at modeling and studying the effectiveness of the proposed solutions based on the developed simulation model of energy potential control of IR-UWB radio lines THz signals, as well as the development of a web application that will reflect the real state of the developed receiver. functional parameters to obtain the desired results.

5. References

[1] V. Saiko, et al., Increasing Noise Immunity between LEO Satellite Radio Channels, in: 15th International Conference on Advanced Trends in Radioelectronics, Telecommunications and Computer Engineering, TCSET, 2020, pp. 442–446.

[2] V. Saiko, et al., Terahertz Range Interconnecting Line for LEO-System, in: 15th International Conference on Advanced Trends in Radioelectronics, Telecommunications and Computer Engineering, TCSET, 2020, pp. 425–429.

[3] V. Saiko, Algorithm of signal processing of a multiposition system using the principle of spatially distributed radiation, in: 3rd International scientific and practical conference. Eurasian scientific congress (March 22-24, 2020), Barca Academy Publishing, Barcelona, Spain, 2020, pp. 155–160.

[4] A. Harmonov, V. B. Manelis, Method of receiving multibeam signals, search method and method of forming soft solutions when receiving multibeam signal and device for their implementation, 2005. Patent RU № 2251802. Issued May 10, 2005.

[5] T. Narytnik, et al., Energy calculation of the terahertz radio link, Telecommunications and Radio 78(6) (2019) 537–557. doi:10.1615/TelecomRadEng.v78.i6.60.

[6] G. Avdeenko, et al., Simulation of a terahertz band wireless telecommunication system based on the use of IR-UWB signals, Telecommunications and Radio Engineering 78(10) (2019) 901–919.

[7] T. M. Naritnyk, et al., Investigation of transmission of modulated IR—UWB signals by terahertz radio communication system, Digital Technologies 24 (2018) 17–32.

[8] N. I. Chervyakov, S. V. Boldyrev, The use of discrete wavelet transform and network technology in the construction of signal processing systems, Infocommunication Technologies in Science, Production and Education 3 (2008) 149–153.

[9] Hu, Z., et al., Development and operation analysis of spectrum monitoring subsystem 2.4–2.5 GHz range. Lect. Notes Data Eng. Commun. Technol. 48: 675–709 (2020). https://doi.org/10.1007/978-3-030-43070-2_29

[10] I. Bogachuk, V. Sokolov, V. Buriachok, Monitoring subsystem for wireless systems based on miniature spectrum analyzers, in: 2018 International Scientific-Practical Conference Problems of Infocommunications. Science and Technology (2018). https://doi.org/10.1109/infocommst.2018.8632151.

[11] Carlsson, A., et al., Sustainability Research of the Secure Wireless Communication System with Channel Reservation. 2020 IEEE 15th International Conference on Advanced Trends in Radioelectronics, Telecommunications and Computer Engineering (TCSET), 2020. https://doi.org/10.1109/tcset49122.2020.235583

[12] E. V. Burnaev, Apply wavelet transform to signal analysis, MIPT, Moscow, 2007.

[13] N. K. Smolentsev, Wavelet analysis in Matlab, DMK Press, Moscow, 2020.

[14] A. N. Shesterkin, System of modeling and research of radio electronic devices Multisim 10, DMK Press, Moscow, 2012.

[15] S. Skiena, Data science: a training course, Dialektika, Kyiv, 2020.

[16] C. Aggarwal, Neural Networks and Deep Learning, Dialektika, SPb., 2020.