

Improving the Efficiency of UAV Communication Channels in the Context of Electronic Warfare

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Abstract—The article is devoted to the development of a method for increasing the efficiency of communication channels of unmanned aerial vehicles (UAVs) in the conditions of electronic warfare (EW). The author analyses the threats that may be caused by the use of electronic warfare against autonomous UAVs. A review of some technologies that can be used to create original algorithms for countering electronic warfare and increasing the autonomy of UAVs on the battlefield is carried out. The structure of modern digital communication systems is considered. The requirements of unmanned aerial vehicle manufacturers for on-board electronic equipment are analyzed, and the choice of the hardware platform of the target radio system is justified. The main idea and novelty of the proposed method are highlighted. The creation of a model of a cognitive radio channel for UAVs is considered step by step. The main steps of modelling the spectral activity of electronic warfare equipment are proposed. The main criteria for choosing a free spectral range are determined. The type of neural network for use in the target cognitive radio system is substantiated. The idea of applying adaptive coding in UAV communication channels using multicomponent turbo codes in combination with neural networks, which are simultaneously used for cognitive radio, has been further developed.

Keywords—cognitive radio; software-defined radio; neural networks; coding; electronic warfare; communication channel; wireless communications; spectrum analysis

I. INTRODUCTION

MANY countries have specialized military training centers that provide courses for military UAV operators. These centers have training systems and simulators that allow operators to gain hands-on experience with real or virtual UAVs. Military academies and schools can include UAV operator training in their educational programs. This includes theoretical courses, practical training, and range exercises with real UAVs.

However, there is currently a demand for UAVs that can operate on the battlefield out of the box, without specially trained personnel. This is due to the growing interest in autonomous systems in the military sphere and the expansion of their potential use. UAVs with autonomous functions allow performing certain reconnaissance, surveillance, and combat tasks on the battlefield without the presence of a human on the

ground. This increases the efficiency of operations and reduces the risk to human personnel. The use of autonomous UAVs can help reduce the costs associated with the maintenance and training of skilled operators. Operations of such systems can be less costly and more efficient from an economic point of view.

At present, technologies that ensure full autonomy of UAVs on the battlefield still require further development and improvement. This is especially true of the level of artificial intelligence and machine learning required for UAVs to make the right decisions in changing combat conditions.

It should also be borne in mind that the enemy will fight against UAVs. The use of electronic warfare means enhances the effectiveness of the fight against UAVs, especially if they use radio channels to communicate with the operator. Electronic warfare means can be used to disrupt communication between the UAV and the operator, interfere with GPS navigation and other sensors, as well as interfere with signal transmission and have other various effects on the operation of the UAV.

Electronic warfare tools and technologies are constantly evolving to provide a military advantage in electronic warfare. The enemy uses a variety of electronic warfare tools designed to interfere with or destroy robotics, including UAVs.

The confrontation between UAV communications manufacturers and EW manufacturers is an ongoing process that drives constant innovation and technology improvement. Communications manufacturers are trying to make their systems as immune to interference as possible and provide the highest quality of data transmission, while EW manufacturers are trying to develop new technologies to ensure reliable blocking of data transmission.

However, there is currently a tendency for communication manufacturers to solve this confrontation by using cognitive radio technology. This technology allows for rational use of the radio frequency spectrum and quick switching between different bands, changing frequencies or direction of signal transmission, which reduces the impact of interference and provides more reliable data transmission.

II. ANALYSIS OF RESEARCH AND PUBLICATIONS

Workbook [1] provides a practical approach to quickly learn the software-defined radio concepts needed to work in the field. By prototyping and evaluating real-world digital

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communication systems capable of wirelessly transmitting and receiving data over the radio channel, this paper describes the critical design tradeoffs and challenges, and provides insight into the actual operational behavior of these systems in real-world environments.

Paper [5] describes the development and virtual prototype of a subset of radio situation analysis algorithms designed to deploy opportunistic spectrum access in the target application – a cognitive radio network consisting of several software-defined BitSDR radios.

In Article [7], the authors propose two new predictors based on recurrent neural networks (RNNs) that utilize the powerful time series prediction capabilities of long-term short-term memory or a closed-gate recurrent unit. The performance is evaluated, and the results in terms of prediction accuracy confirm that the proposed predictors significantly outperform the traditional RNN predictor.

In Article [11], the authors draw attention to the power and capabilities of cognitive radio processes and what makes it more powerful than other competitive radios. The focus is on the current state of research, architecture and future possibilities of CR. It emphasizes the areas of application where cognitive radio methods can be implemented and have proven to be superior to existing intelligent and adaptive radios.

III. FORMULATING THE GOALS OF THE ARTICLE

The purpose of the article is to develop a method of countering electronic warfare means for use in wireless data transmission systems of UAVs using cognitive radio and neural network technologies.

IV. PRESENTATION OF THE MAIN MATERIAL

Unmanned aerial vehicles operating on the battlefield without specially trained personnel may face various threats from enemy electronic warfare. In the context of applying the method of counteraction we are developing; we will consider the following threats:

- interference with the communication signal of the control channel between the UAV and the base station – this can lead to loss of communication and control over the UAV, which complicates the mission and may lead to the loss of the UAV;

- generation of electromagnetic signals by EW equipment that interfere with the radio frequency spectrum used by the UAV for communication and surveillance – this can lead to a decrease in signal quality, impaired data transmission, or even signal loss.

This problem can be solved by developing original countermeasures using software-defined radio (SDR), cognitive radio (CR), and artificial neural networks.

Software Defined Radio (SDR) is defined as “a class of reconfigurable/reprogrammable radios whose physical layer characteristics can be significantly modified via software changes”. Figure 1 shows some of the important components that constitute a modern digital communications system [1]. Communication devices, such as a traditional radio system, support a fixed number of channels or frequency bands, but the problem is that the channels and frequency bands must be selected during design, not at a later stage, as there is no mechanism to allow for any adjustment after design, i.e., during operation and according to current needs. In search of a better solution to this problem, a relatively new concept called Software Defined Radio was introduced. It was developed based on the idea of a traditional radio system, but with minor design

changes. In SDR, the behavior of the radio's physical layer and its functionality are determined by software. In SDR, the various components of the radio system, such as the amplifier and filters, are implemented in software instructions rather than in hardware [2].

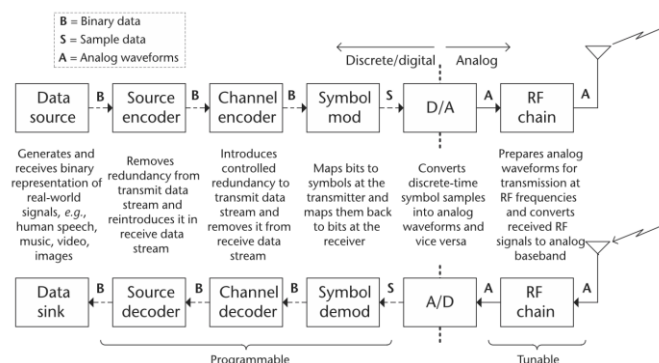


Fig. 1. A modern digital communication system

Given the complexity of the SDR platform and its respective components, it is important to understand the limitations of a particular SDR platform and how different design decisions can affect the performance of the final prototype. For example, it is highly desirable to have real-time baseband processing for spectrum sensing and flexible handoff operations with high computational throughput and low latency. However, if the microprocessor used in the SDR platform is not powerful enough to support the computational operations of the digital communication system, either the overall transceiver design or the low latency and high throughput requirements must be reconsidered. Otherwise, the SDR implementation will not work properly, resulting in transmission errors and poor communication performance [1].

Manufacturers of unmanned aerial vehicles have certain specific requirements for electronic equipment to ensure the reliability and stability of the communication system. The main requirements include the following:

- radio equipment must be energy efficient to ensure long UAV flight time;

- the communication system must have high sensitivity to ensure quality communication over long distances;

- radio equipment must support operation in a wide frequency range to ensure flexibility in the choice of communication channels;

- radio equipment must be protected from external electromagnetic interference and not affect the operation of other electronic devices on board the UAV;

- communication must provide sufficient data transmission speed for the implementation of tasks related to reconnaissance, surveillance, and UAV control;

- radio equipment must provide high reliability of data transmission to ensure high-quality video communication, as well as information about the exact location of the UAV;

- radio equipment must be compatible with other UAV elements, such as sensors, navigation systems, stabilization systems, to ensure their joint operation.

We will use Ettus Research products USRP B200mini as the hardware of our radio equipment (Fig. 2). Ettus Research, a National Instruments company, is the world's leading supplier of software defined radio platforms, including the USRP

(Universal Software Radio Peripheral) family of products. The USRP platform supports multiple development environments on an expansive portfolio of high-performance RF hardware, and enables algorithm design, exploration, prototyping, and deployment of next generation wireless technologies across a wide variety of applications spanning DC to 6 GHz such as cognitive radio, spectrum monitoring and analysis, remote sensing, advanced wireless prototyping, mobile radio, public safety, broadcast TV, satellite communication, and navigation [3].



Fig 2. USRP B200mini

The USRP B200mini Series delivers a 1x1 software defined radio/cognitive radio in the size of a business card. With a wide frequency range from 70 MHz to 6 GHz and a user-programmable Xilinx Spartan-6 FPGA, this flexible and compact platform is ideal for both hobbyist and OEM applications. The RF front end uses the Analog Devices AD9364 RFIC transceiver with 56 MHz of instantaneous bandwidth (Fig. 3). The board is bus-powered by a high-speed USB 3.0 connection for streaming data to the host computer. The USRP B200mini Series also includes connectors for GPIO, JTAG, and synchronization with a 10 MHz clock reference or PPS time reference input signal. There are three configurations in this product family with options for a larger or industrial-grade FPGA. The USRP Hardware Driver (UHD) software API supports all USRP products and enables users to efficiently develop applications then seamlessly transition designs between platforms as requirements expand [3].

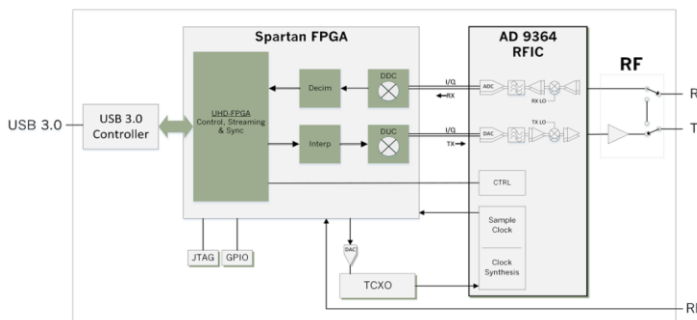


Fig. 3. USRP B200mini Block Diagram

Cognitive Radio is an SDR based communication systems paradigm that focuses on employing highly agile, environmentally aware, intelligent wireless platforms to autonomously choose and fine-tune device operating parameters based on the prevailing radio and network environmental conditions [1].

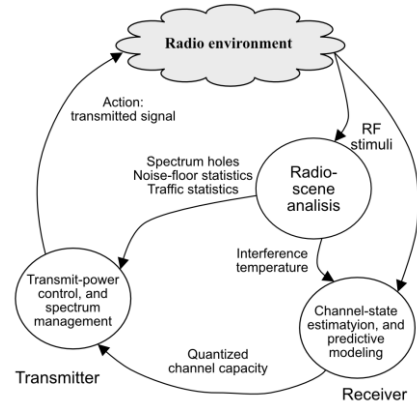


Fig. 4. Basic cognitive cycle

Figure 4 presents three on-line cognitive tasks performed by cognitive radio. The first and second tasks are carried out in the receiver, and the third task is carried out in the transmitter [4].

1. Radio-scene analysis, which encompasses: estimation of interference temperature of the radio environment and vacant frequency channels detection.
2. Channel identification, which encompasses the following: estimation of channel state information (CSI) and prediction of channel capacity for use by the transmitter.
3. Transmit-power control and dynamic spectrum management [5].

The essence of cognitive radio is that wireless devices can survey the radio frequency spectrum and analyze it in real time. Based on the collected data about the available radio frequency bands, a wireless device can make decisions about the use of free spectrum, optimal transmission parameters and other characteristics of the wireless network. The use of cognitive radio allows to ensure efficient use of the radio frequency spectrum, increase productivity and improve the quality of data transmission in wireless networks.

The main idea and novelty of the method under development is that cognitive radio can use frequency bands that are not jammed by enemy electronic warfare equipment and left by the enemy to communicate with its own units by using spectrum reuse and dynamic spectrum access (DSA) technologies. These technologies make it possible to use frequencies that are not currently being used in a given location.

Spectrum sharing provides unimpeded access to the same frequency bands for different categories of users. The most common example of spectrum sharing in cognitive radio networks is the reuse of television white spaces: the spectrum allocated to television broadcasters (primary users, PU) can be used for other wireless communications by secondary users (SU), which was introduced in 2009 as a standard for wireless regional networks IEEE 802.22, WRAN. The work of secondary users is quite unstable due to the absolute privileges of PU and mutually exclusive access to spectrum. The solution to this problem is dynamic spectrum access, which ensures simultaneous operation of PU and SU by identifying free frequency channels and allowing devices to communicate in free parts of the spectrum. Artificial intelligence is used to process signals and make decisions regarding the selection of spectrum bands, transmitter power, time and space dispersion of radio signals, symbol rate, and modulation type. All this

determines the possibility of reusing the spectrum, provided that there is no information about the PU and signals [6].

For our cognitive radio system for UAVs, we will assume that the enemy's electronic warfare equipment will act as the PU. One of the main challenges associated with the implementation of dynamic spectrum access and spectrum sharing methods is the development of control channels. Reliable, dynamically changing control channel algorithms are needed to ensure continuous transmission of control signals between the UAV and the operator's console at both ends of the link, despite the activity of electronic warfare assets. These messages are used to exchange sensing information and coordinate channel access.

Other problems noted in [5] are radio situation analysis and adaptation to PU transmission. Some PUs have specific transmission patterns, such as predefined time and duration of spectrum usage, such as television stations, or may have random channel access, such as state services. At this time, the CR MAC protocol can determine the nature of the PU and adapt its transmission to avoid interference to itself and prevent conflict with the PU. However, this problem is not an issue for us at this time, because we do not plan to work on channels jammed by electronic warfare.

Creating a model of a cognitive radio channel for UAVs will involve the following steps:

1. Determination of channel characteristics (noise level, distortion and signal loss in the communication channel).
2. Determination of transmitter characteristics (power, transmission frequency, modulation and coding).
3. Determination of receiver characteristics (sensitivity, frequency range, demodulation and decoding algorithms).
4. Modeling the behavior of enemy electronic warfare equipment (modeling the spectral activity of electronic warfare equipment in the appropriate frequency range).
5. Use of channel control algorithms - determination of criteria for selecting a free frequency range and determination of an algorithm for changing data transmission parameters in case of interference.
6. Using the obtained channel parameters to model data transmission in cognitive radio.
7. Analysis of the results (to assess the effectiveness of cognitive radio in different conditions).

Taking into account the above steps, it is possible to create a cognitive radio channel model for UAVs. However, it should be noted that creating an accurate channel model can be quite a challenge, as it requires collecting a significant amount of data and processing it. Therefore, in most cases, approximations and simplified models are used to ensure sufficient accuracy [5].

The radio frequency range used for UAVs may vary depending on the specific model and its purpose. Usually, UAVs use the frequency range from 900 MHz to 5.8 GHz, which provides sufficient data transmission speed and reliable connection between the control panel and the UAV. For safety in the air and to avoid interruptions in the operation of other radio communication systems, many countries have restrictions on the use of certain radio frequency bands for UAVs. For example, in the United States and Canada, only the 900 MHz, 2.4 GHz, and 5.8 GHz bands are allowed for commercial use of UAVs. In Europe and most Asian countries, the frequency bands from 433 MHz to 5.8 GHz are allowed.

The data rate required for a UAV can vary considerably depending on its tasks and capabilities. For some applications,

such as capturing video or photographs, a low data rate is sufficient. In other cases, such as intelligence gathering and transmission missions, a high data rate may be required. Typically, data rates for UAVs range from a few megabits per second (Mbps) to several gigabits per second (Gbps), depending on the specific needs and capabilities of the UAV. For example, high-definition (HD) video transmission requires a data rate of at least 6 Mbps, and 4K video transmission requires at least 20 Mbps. However, reconnaissance UAVs can be used not only for video transmission, but also for transmission of other types of data, such as sound, heat or other sensor data. In such cases, the data transmission rate may be lower, depending on the type of data and its volume.

Modern UAVs use digital modulation to transmit images, which allows them to transmit images in high quality and efficiently use the available communication channel bandwidth. One of the most common types of modulation for image transmission is Phase Shift Keying (PSK). PSK allows you to transmit digital data by changing the phase of the carrier wave. Depending on the specific requirements and characteristics of the UAV communication system, different variations of PSK can be used, such as Binary Phase Shift Keying (BPSK), Quadrature Phase Shift Keying (QPSK), or 8-Phase Shift Keying (8-PSK). Each of these PSK options has a different data rate. The use of digital modulation allows you to transmit images in high quality and efficiently use the available bandwidth of the communication channel.

As you can see, the USRP B200mini target hardware platform we have chosen fully meets our requirements for the required radio frequency range, data rate, and instantaneous bandwidth, and supports all the necessary modulation types. The AD 9364 transceiver is optimized for use in radio modules that are small, lightweight and low power consumption.

UAV transmitter power can vary significantly depending on the type and size of the UAV, its application, and regulatory restrictions. Typically, UAVs use low-power transmitters to ensure compactness, low power consumption, and long flight times.

Modeling the spectral activity of electronic warfare equipment in the relevant frequency range can be performed using specialized software or engineering tools. The main purpose of modeling is to study the behavior of an electronic warfare system and determine its impact on electronic devices and systems in the spectral range. The main steps of modeling the spectral activity of electronic warfare equipment include

determination of the parameters of the EW system (this includes parameters such as signal power, bandwidth, frequency ranges and modulation schemes used by EW to generate radio interference);

creation of a spectral activity model (based on the determined parameters of the electronic warfare system, a spectral activity model is created that reflects the time nature of the activity of electronic warfare signals in the relevant frequency range, can be presented in the form of time diagrams, spectral graphs or mathematical equations);

simulation and analysis (specialized software tools are used to simulate the impact of EW spectral activity on radio electronic devices and systems, which allows analyzing the impact of radio interference on the quality and performance of communication systems, identifying possible problems and finding ways to avoid them).

The choice of a free frequency band and an algorithm for changing data transmission parameters in the event of interference are important aspects of the cognitive radio system. The main criteria for selecting a free frequency range may include

- checking spectral availability, i.e. whether the target frequency band is not used by other devices or communication systems;

- assessing the level of interference and interference in the selected frequency band to ensure quality signal transmission;

- compliance with the established rules and restrictions on the use of the radio frequency spectrum in accordance with special requirements previously stored in the device's memory.

As for the algorithm for changing data transmission parameters in case of interference, this may include

- analysis of the received signal to detect the presence of interference or interference;

- parameter adaptation (changing transmission parameters, such as frequency, power, or modulation, to avoid or reduce the impact of interference on signal quality)

- selection of an alternative frequency range (if the current range is unsuitable due to a large amount of interference or poor communication quality, an automatic change to another available frequency range can be performed).

The algorithm for changing the transmission parameters can be based on intelligent solutions, such as machine learning or pattern recognition, to make decisions on the optimal transmission parameters in specific interference conditions.

The neural network for our model is a Long Short-Term Memory (LSTM) network. LSTMs are a type of neural network that is well suited for processing sequential data, such as speech or time series. They are able to memorize long sequences of data and make their short-term memory available for longer periods of time. Using an LSTM network for UAV cognitive radio has several advantages:

- Processing of sequential data - LSTM network is a recurrent neural network that has the ability to efficiently process sequential data, such as time series of radio signals coming from different sources. This is especially useful for cognitive radio, which needs to analyze and model dynamic changes in the spectrum of the radio frequency range;

- context modeling - LSTM network can store and utilize long-term dependencies in data. This allows modeling contextual information that may be important for cognitive radio. For example, taking into account the history of spectrum changes can help to make better decisions about the choice of free frequencies for data transmission;

- generalization capability - LSTM networks can reproduce complex dependencies in data and have the ability to generalize to new data. This is important for cognitive radio because spectral characteristics can change in different conditions and environments. The LSTM network can learn to recognize patterns and dependencies, allowing for more accurate predictions and decisions;

- Adaptability to changing conditions - cognitive radio must be adaptive to changes in the spectral environment and radio conditions. The LSTM network can be trained based on new data and adapt to new conditions. This allows for high operational efficiency of the UAV cognitive radio in changing radio conditions;

the ability to solve sequential tasks, such as predicting future values of the frequency spectrum or recognizing radio signals with dynamic modulation. This makes it possible to use LSTM networks to implement various cognitive radio functions, including free frequency detection, spectrum management, and adaptive coding and modulation.

Thus, the use of LSTM networks for UAV cognitive radio can improve the system's ability to analyze and adapt to changing spectral conditions, ensuring more efficient use of the available radio frequency resource and increasing the performance of communication and spectrum management [7]

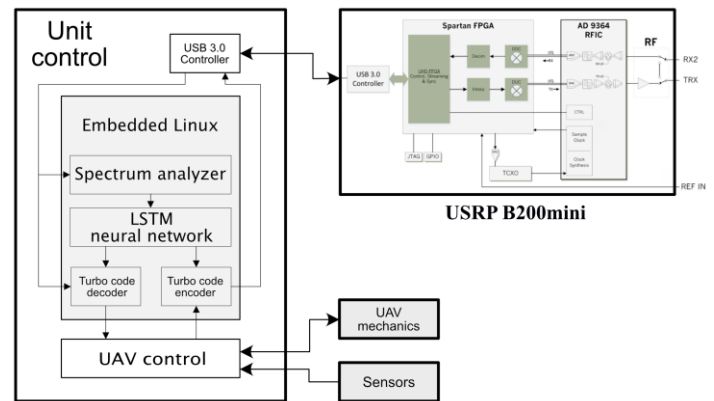


Fig. 5. The model of the communication channel of the UAV using the technologies of software-defined radio, cognitive radio and neural networks, intended for use in UAVs in the case of active use of enemy electronic warfare

V. ANALYSIS OF THE RESULTS

The development of a method to counteract the impact of enemy electronic warfare on the UAV communication channel using cognitive radio technology will include several stages.

The first stage is the analysis of the radio frequency environment, including the identification of potential sources of interference or signal blocking by electronic warfare. This may include the detection and classification of radio frequency signals, analysis of spectral activity, and identification of vulnerable frequency bands.

The next step is the development of adaptive algorithms to ensure continuous and efficient operation of the UAV communication channel. These algorithms may include methods of dynamic channel control, spectral access, and modulation to avoid interference or operate in other available frequency bands.

One of the key elements of the method is adaptive transmission control. This involves developing algorithms to dynamically change transmission parameters, such as power, modulation, coding, and frequency range, to avoid interference from EW assets and ensure reliable transmission.

Since the effects of EW assets may include attempts to intercept or hack communications, it is important to ensure that data transmission is secure and encrypted. This may include the use of data encryption, authentication, and other measures to protect against unauthorized access and misuse. However, these measures will not be considered in this method. We will assume that we already have them by default, they are part of the system for generating useful signals for transmission.

The last stage is testing and verification of the developed method. This involves conducting experiments in a controlled

environment or on real UAVs to verify the effectiveness and reliability of the method in the face of interference from electronic warfare.

Developing a method to counteract the effects of EW means on the UAV communication channel is a complex task that requires a large amount of research, development and testing. At each of the stages mentioned above, it is necessary to conduct a detailed analysis, taking into account the specifics of the UAV and its communication channels, as well as the possible effects of electronic warfare.

To effectively develop a countermeasure, it is necessary to use engineering approaches, mathematical modeling, computer simulation, create experimental samples and validate the results. It is also important to take into account the specific requirements and limitations of UAVs, such as power consumption, size and weight of equipment. A general view of the developed method for counteracting the impact of electronic warfare on the UAV communication channel is shown in Fig. 6.

For our information flows, we also apply adaptive coding using multi-component turbo codes. Turbo codes are among the most efficient codes for data transmission channels. Since cognitive radio uses access to the radio frequency spectrum, which can be saturated and require the use of smaller frequency bands, encoding and decoding technologies such as turbo coding can be useful to ensure greater efficiency in data transmission in limited frequency bands. Using information from a neural network about upcoming changes in the communication channel will reduce the time it takes for the coding system to adapt, which will reduce the number of errors in data transmission and increase the reliability of communication, especially when using dynamic spectrum access.

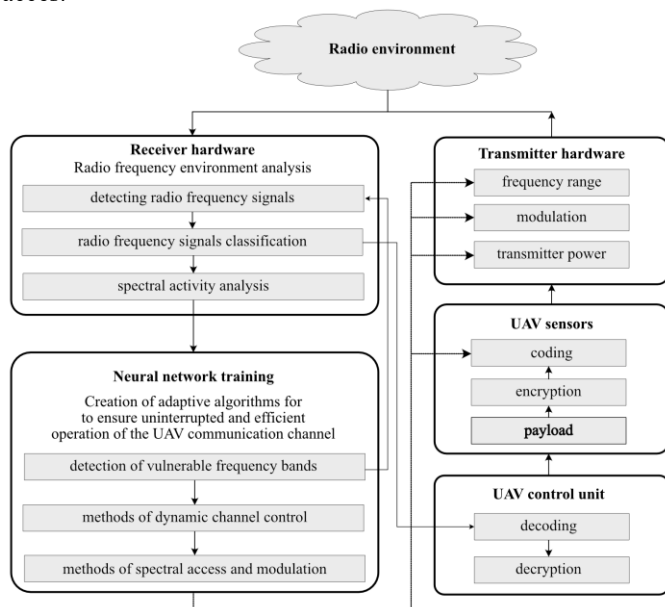


Fig. 6. The method of countering electronic warfare for use in wireless UAV data transmission systems using cognitive radio and neural network technologies

CONCLUSION

Today, it is clear that there is an urgent need for technologies to ensure the autonomy of UAVs on the battlefield. One of the key areas of achieving such autonomy is the creation of models and methods for improving the efficiency of wireless data transmission systems in the conditions of active use of electronic warfare by ensuring the reliability of information. In this article, we have considered the development of a method for countering electronic warfare for use in wireless data transmission systems of UAVs using cognitive radio and neural network technologies. Further research should lead to the creation of original algorithms for countering electronic warfare. We considered the possibility of using SDR radio equipment and open source software and hardware platforms to develop and verify these countermeasures. The idea of applying adaptive coding in UAV communication channels using multi-component turbo codes in combination with neural networks, which are simultaneously used for cognitive radio, was further developed.

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