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KUVSHINOV Oleksiy,
Doctor of Technical Sciences, Professor,
National Defence University of Ukraine, Kyiv, Ukraine,
https://orcid.org/0000-0003-2183-7224
PIKUL Rostyslav,
National Defence University of Ukraine, Kyiv, Ukraine
https://orcid.org/0000-0003-3928-9596

DIRECTIONS OF DEVELOPMENT AND IMPROVEMENT OF MILITARY RADIO COMMUNICATION SYSTEMS WITH AERIAL REPEATER IN THE CONDITIONS OF ACTIVE RADIO-ELECTRONIC COUNTERMEASURE

A promising direction for combating uncrewed aerial vehicles is the placement of small-sized repeaters for terrestrial radio networks on their platform. Considering the significant attention paid to improving military control systems, it is relevant to determine the main trends and directions for developing military radio communication systems with air repeaters in active enemy electronic countermeasures.

The purpose of the article. *The article is aimed at determining the main directions of development and improvement of military radio communication systems with air repeaters to ensure continuous control of units in the area of responsibility for the active use of electronic warfare by the enemy in conditions of active electronic countermeasures, taking into account the current situation of the state of enemy troops (forces).*

Research methods. *System analysis and synthesis were used during the article's writing. This made it possible to analyse military radio communication systems under active electronic countermeasures and offer recommendations for reducing the enemy's influence.*

Presenting the main material. *Many scientific articles are devoted to combat using uncrewed aerial vehicles in modern armed conflicts and countermeasures against them, particularly radio electronic suppression of control and navigation channels. An analysis of trends in the use of military radio communication systems from air repeaters in modern military conflicts of varying intensity has been carried out. The directions for developing and improving the military of these radio communication systems operating under active electronic counteraction of the enemy are allocated. The prospects for further development in terms of their use in the electronic warfare system are outlined. Recommendations for reducing the energy impact of the enemy's electronic warfare means are proposed, choosing the optimal topology of the military radio communication system with air repeaters and modern antenna systems.*

The elements of scientific novelty. *Areas of development and improvement have been determined by choosing the optimal topology of the military radio communication system with aerial repeaters.*

The theoretical and practical significance. *Implementing the mentioned technologies in the military management system will ensure stable management of its troops, combat, and special means in a complex radio-electronic situation with the enemy's active use of radio-electronic warfare. The analysis of trends in the use of military radio communication systems with aerial repeaters in modern military conflicts of varying intensity makes it possible to determine the main directions of their development and improvement. The direction of further research is the improvement of methods of controlling the parameters and modes of operation of military radio communication systems with aerial repeaters under the influence of various types of intentional interference.*

Keywords: *military radio communication system, uncrewed aerial vehicles, radio electronic suppression, aerial repeater, noise immunity.*

Introduction

The military leadership of the armies of the world's developed countries, by new approaches to the construction of the armed forces, pays special attention to the development of military command and control systems, as the main factor in achieving military-strategic advantage. A promising area of combat use of uncrewed aerial vehicles is the placement of small-sized repeaters for terrestrial radio networks on their platform. This is a determining factor in obtaining an information advantage over the enemy, which allows you to manage your troops, combat and special means more effectively.

Problem statement. The main goal is to provide operational and technical capabilities for the organisation of interaction and joint combat use of heterogeneous forces and means in joint operations. Modern military command and control systems must have high combat readiness, bandwidth stability, mobility, accessibility, intelligence security, controllability, and ensure compliance with the requirements for timeliness, reliability and security of information exchange. These tasks must be performed under the active influence of the enemy's electronic suppression system [1–4].

The use of uncrewed aerial vehicles with small-sized air repeaters on their platform as part of military radio communication systems makes it possible to significantly improve the performance of radio networks, increase the connectivity of radio communication facilities in the network, increase both the energy and frequency efficiency of radio channels, and build new architectures of military radio communication systems [5–8].

Taking into account the considerable attention paid to the improvement of military control systems, the topical issue is assigned:

determination of the main trends and directions of development of military radio communication systems with air repeaters under the conditions of active electronic counteraction of the enemy;

research of technologies in the command and control system of troops to ensure stable control of troops (forces) in a complex electronic situation.

Analysis of recent research and publications. Today, there are a significant number of scientific articles devoted to the combat use of unmanned aerial vehicles in modern armed conflicts [9–14] and countering them, in particular, electronic jamming of control and navigation channels (reception of GPS signals) [15; 16].

The analysis of the most relevant methods and techniques for ensuring and increasing the required level of survivability and narrowing the range of scientific research for further optimisation or search for a more successful combination of methods or creation of an improved methodology to increase efficiency in solving problems related to ensuring the required level of survivability of telecommunication networks and systems was carried out [1].

In previous publications, new scientific concepts have been proposed, with the help of which the interaction and coordination of models of elements of military radio communication systems are organised. The existing interference-proof modes of operation have been analysed and practical recommendations for their use under the influence of the main types of intentional interference have been developed [2; 4].

The analysis of the use of Unmanned Aerial Vehicles as air repeaters is devoted to the work [5–8; 17–19] and the algorithms for constructing the topology of radio communication networks with telecommunication aerial platforms are considered, which makes it possible to ensure network connectivity, optimise coverage areas, and minimise the number of telecommunication aerial platforms [20].

Most of the existing methods for controlling the parameters of radio networks need to be supplemented with the basic principles of construction and operation of military radio communication systems, which operate in conditions of active electronic countermeasures and do not take into account the relative location of radio communication means and means of electronic suppression of the enemy.

The analysis of the publications allows us to conclude that it is relevant to determine the totality of the main trends inherent in military radio communication systems with air repeaters in modern military conflicts of varying intensity.

Purpose of the article. To determine the main directions of development and improvement of military radio communication systems with air repeaters to ensure continuous control of units in the area of responsibility for the active use of electronic warfare by the enemy in conditions of active electronic countermeasures, taking into account the current situation of the state of enemy troops (forces).

Principal Research Results

Modern military radio communication systems are complex systems with a distributed multi-communication structure. The advantages of using air repeaters (radio stations) on uncrewed aerial vehicles are obvious:

a significant increase in the coverage area compared to ground repeaters;

increasing the connectivity of network radio stations;

the possibility of flexible operational control of the network topology by moving uncrewed aerial vehicles, in contrast to radio networks with ground repeaters.

Increasing the flight altitude of the air repeater will increase the coverage area (or, with the same communication range, reduce the required transmitter power, which, first of all, will extend the time of continuous flight of uncrewed aerial vehicles. Consider the military radio communication system, which consists of two levels (Figure 1) [2].

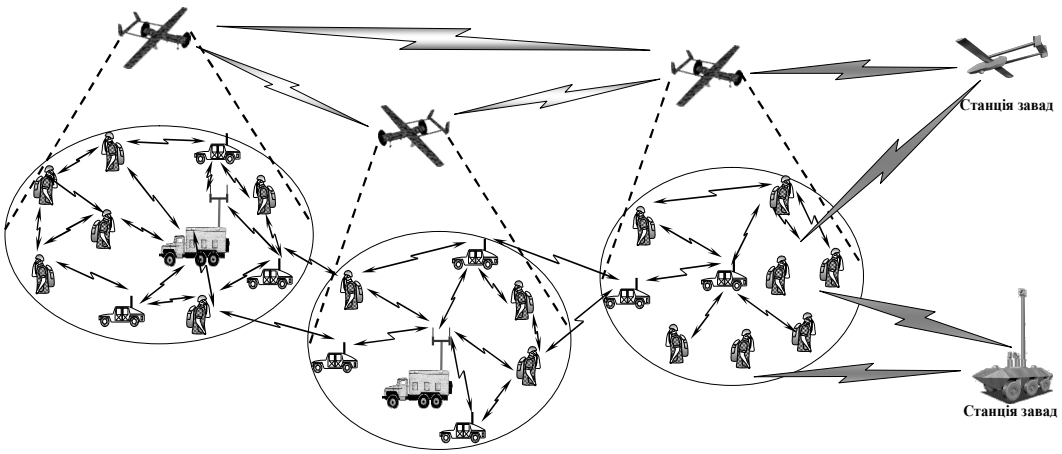

Figure 1 – Option for building a military radio communication system with air repeaters

A set of ground nodes of military radio communication systems is formed by terrestrial radio networks (level 1). A ground network node will be understood as a vehicle, combat vehicle, command and staff vehicle, mobile base station, military personnel, etc., which are equipped with radio communication facilities terrestrial radio network, organisation of backup (additional) radio communication with terrestrial nodes, increase of coverage area, improvement of information exchange quality indicators (bandwidth, energy efficiency, transmission time, etc) by changing its topology (and, accordingly, reducing the intensity of changes in the topology of the terrestrial network), routing. The scheme considers the enemy's capabilities to deliberately interfere with military radio communication systems through ground and air electronic warfare. Analysing the experience of building military radio communication systems with air repeaters made it possible to determine the main directions of their development and improvement. Let us consider the main ones.

Selection of the topology of the military radio communication system with air repeaters. One of the main tasks of managing military radio communication systems with air repeaters is the management of their topology. The topology determines the potential indicators of the network functioning (connectivity, bandwidth, survivability, etc) for the transmission of information flows and the quality of service to subscribers [20]. The topology of military radio communication systems is dynamic and constantly is exposed to external destabilising factors, therefore, the use of a transport air radio network should be aimed at increasing the structural survivability and reliability of the system, the bandwidth of radio networks, the quality of data transmission routes between subscribers and their mobility.

There are the following options for setting the problems of synthesis of the topology of military radio communication systems with air repeaters according to [20]:

the criterion of minimum use of hardware resource (calculation of a communication topology with a minimum number of air repeaters under specified limitations (bandwidth, message transmission time, etc) can act as limitations.

the criterion of structural reliability (calculation of the coherent topology of the network under specified constraints);

time criterion (calculation of the coherent topology of the network, which minimises the maximum delay of message transmission in the network under specified restrictions).

It should be noted that the synthesis of the topology of large-dimensional networks encounters several difficulties associated with the network's large dimensionality, the problem's multi-extremity to be solved, and the incompleteness of existing optimisation methods. This leads to the need to use a decompositional approach. Under such conditions, the general problem of topology synthesis is divided into several subtasks according to specific priorities of efficiency criteria.

The characteristics of information exchange in military radio communication systems are primarily influenced by the means of electronic suppression of the enemy. As evidenced by the experience of repelling the full-scale armed aggression of the Russian Federation, conducting the Anti-Terrorist Operation and the Joint Forces Operation on the territory of Donetsk and Luhansk regions, hostilities and peacekeeping operations of recent decades, electronic jamming means are capable of high efficiency and in suppress radio communication systems built on traditional principles for a short time. It is also possible to reduce the impact of electronic jamming on the radio communication system by changing the topology of military radio communication systems.

From the point of view of attenuation of the interference signal at the input of the receiver, when determining the height and trajectory of the barrage of the air repeater on the Unmanned Aerial Vehicles, the characteristics of the directionality of its antenna were taken into account. The analysis of the terrain (construction of a profile, a set of profiles between the location of the Unmanned Aerial Vehicles and the point of installation of the jammer antenna) to use its protective properties.

In [19], deliberate interference's effectiveness on the receivers of air repeaters and ground means depends on the relative location of radio communication facilities and means of electronic suppression of the enemy. Interference noise immunity of signal transmission in military radio communication systems is estimated by the probability of false reception, which depends on the signal/interference ratio at the receiver input [9]:

$$\text{Aerial repeaters} = f(Q^2),\ Q^2 = (\text{electronic jamming})^2, \quad (1)$$

where ERL is the strength of the electric field created by the radio link transmitter on the receiver antenna;

the electronic suppression of the enemy establishes the strength of the electric field.

The calculations carried out showed that the following are the most effective among the options for suppressing military radio communication systems using an air repeater with noise interference [18]:

low-power electronic warfare air station (on uncrewed aerial vehicles) – ground radio stations;

a powerful ground electronic warfare station is an air repeater.

Based on the collection of information on the state and parameters of the functioning of military radio communication systems, it is possible to change the topology of military radio communication systems for a specific signal and interference situation by changing the positions of air repeaters. Therefore, when planning the trajectory of Unmanned Aerial Vehicles with air repeaters, it is necessary to analyse the terrain (build a profile, a set of profiles between the point of location of Unmanned Aerial Vehicles and the installation point of the antenna of

the electronic jamming station to make the most effective use of its protective properties in terms of signal attenuation by interference. At the same time, it is necessary to ensure:

coverage of the required geographical area (all correspondents of the network serviced by the repeater, taking into account their possible movement);

the minimum required lifting height of uncrewed aerial vehicles;

it is necessary to distance oneself from the obstacle maker.

Adaptive change of parameters of military radio communication systems. One of the directions for increasing the efficiency of the functioning of military radio communication systems in active electronic countermeasures is the use of adaptive signal formation and processing methods. The algorithm of their functioning fills in the missing a priori information about changing communication conditions. It is used to control radio links' parameters and modes of operation to ensure the necessary quality indicators [2]. This requires the implementation of an automated process of adaptation to the signal and jamming situation in military radio communication systems.

Adaptive management of parameters and resources of military radio communication systems provides appropriate correction of its operating modes and algorithms for the functioning of its elements in case of any change in network parameters, and to the greatest extent, meets the requirements for continuity and efficiency of command and control of troops. However, implementing the adaptive control principle requires the maximum amount of information about the state of the network and the availability of a network of service channels. That is, military radio communication systems should ensure quality control of their functioning, transmission of measuring and control information, and dynamically change their structure and parameters depending on the current situation on the network to achieve extreme or maintain specified values of communication efficiency indicators. At the same time, the current state of the radio link functioning is assessed, and one or more of its parameters are purposefully changed to maximise the performance efficiency of the information transfer process.

The control parameter of adaptive radio links can be the operating frequency, radio signal strength, antenna type and pattern, information transmission rate, type of modulation, type of interference-resistant code, frame (packet) length, frequency tuning speed and algorithm, etc.

Assessment of the electronic situation. The development and implementation of adaptive methods of information exchange require the creation of effective procedures for monitoring the state of communication channels and the quality of information transmission. To solve this problem, it is necessary to involve the methods of modern mathematical statistics, in particular, testing statistical hypotheses regarding the parameter (group of parameters) that characterises the state of the communication channel [2].

For effective adaptive management of resources and parameters of military radio communication systems in the conditions of active electronic countermeasures, essential tasks are operational (in close to real time) assessment of the state of communication channels, determination of directions to neighboring network nodes, identification of interference and determination of their spatial, frequency and energy parameters. All of the above will be called an assessment of the radio-electronic situation.

During the assessment of the radio-electronic situation, the following basic operations are performed:

assessment of the proper coordinates of radio communication facilities;

assessment of directions (bearings) on neighbouring network correspondents and their signal levels at the receiving point;

evaluation of the obstacle's arrival direction and its level at the point of reception.

Thus, combined methods for assessing the electronic situation were the most effective in active electronic countermeasures. They are based on a combination of direct and indirect methods of assessment of the state of the communication channel. Thus, in combination with the process of intelligent identification of radio emissions, provided that antenna arrays are used in radio communication facilities, it is possible to assess the frequency characteristics of the selected communication channels with parallel determination of spatial parameters of radio emissions, and at the same time to ensure, at the same time, the formation of an integral assessment of the radio-electronic current situation.

Application of adaptive antenna arrays. One of the most effective methods of increasing the interference noise immunity of military radio communication systems with PR is using adaptive antenna arrays [17]. Antenna arrays are usually called radiating systems, with many discrete emitters arranged in an orderly manner.

The parameters of adaptive antenna arrays (first of all, the directivity characteristic) are automatically changed in such a way as to provide the best possible conditions for receiving a sound signal against the background of variable external influences (interference), or signal transmission, based on the tasks solved by the means of radio communication [18] (for example, to form a maximum radiation pattern in the direction of the correspondent and minimums in the directions to other users closest to it).

One of the most promising areas for developing this type of antenna technology is digital antenna arrays. An essential feature of the functioning of digital antenna arrays is the digital beamforming of the directivity characteristic. This makes it possible to effectively implement dynamic optimisation of the coverage area based on the operational retargeting of digital receiving beams by groups of correspondents, depending on their location on the ground.

During modern warfare, the role of Unmanned Aerial Vehicles for various purposes, as the main elements of the air component of the intelligence, communication, navigation and destruction system (where they will be used

as the main strike elements and information nodes) will only grow. At the same time, it should be expected that the main direction of their application will be the integrated and synchronised use of the air strike component as part of combat groups of different purposes, simultaneously with other means of solving a wide range of tasks at all levels of control.

Conclusions and Perspectives for Further Research

The analysis of trends in the use of military radio communication systems from air repeaters in modern military conflicts of varying intensity allows us to determine the main directions of their development and improvement, namely:

selection of the optimal topology of the military radio communication system with air repeaters, taking into account the relative location of radio communication facilities and means of electronic suppression of the enemy;

adaptive change in the parameters of military radio communication systems depending on the signal and jamming situation;

operational assessment of the radio-electronic situation in the communication channels of military radio communication systems from air repeaters;

application of adaptive antenna arrays on air repeaters and terrestrial radio communication facilities.

It has been established that using air repeaters significantly reduces the effectiveness of electronic jamming of radio links by both ground and air means of electronic warfare. Radio stations are almost the same as terrestrial ones. Therefore, the prospect for the further development of military radio communication systems, from the point of view of application in the electronic warfare system, is the simultaneous use of ground jammers to suppress air repeaters (radio stations) and air or ground jammers to suppress terrestrial radio stations. At the same time, to reduce the energy impact of both ground and air interference transmitters of the enemy, it is recommended to make the optimal choice of network topology for aerial repeaters, rational choice of altitude and trajectory of loitering uncrewed aerial vehicles, as well as the use of directional antennas and adaptive antenna arrays.

Introducing these technologies into the command and control systems of troops will make it possible to ensure stable control of their forces, combat, and special means in a difficult radio-electronic situation with the active use of electronic warfare by the enemy.

Further research aims to improve the methods of controlling the parameters and modes of operation of military radio communication systems with air repeaters in exposure to various types of intentional interference.

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НАПРЯМИ РОЗВИТКУ ТА УДОСКОНАЛЕННЯ ВІЙСЬКОВИХ СИСТЕМ РАДІОЗВ'ЯЗКУ З ПОВІТРЯНИМИ РЕТРАНСЛЯТОРАМИ В УМОВАХ АКТИВНОЇ РАДІОЕЛЕКТРОННОЇ ПРОТИДІЇ

КУВШИНОВ Олексій Вікторович, доктор технічних наук, професор, Національний університет оборони України, Київ, Україна, https://orcid.org/0000-0003-2183-7224

ПІКУЛЬ Ростислав Володимирович, Національний університет оборони України, Київ, Україна, https://orcid.org/0000-0003-3928-9596

Перспективним напрямом бойового застосування безпілотних літальних апаратів є розміщення на їхній платформі малогабаритних ретрансляторів для наземних радіомереж. Враховуючи значну увагу, що надається вдосконаленню систем військового управління, актуальним є визначення основних тенденцій розвитку військових систем радіозв'язку з повітряними ретрансляторами в умовах активних засобів радіоелектронної протидії противнику.

***Метою статті є** визначення основних напрямів розвитку та вдосконалення систем військового радіозв'язку з повітряними ретрансляторами для забезпечення безперервного управління підрозділами в зоні відповідальності за активне застосування противником засобів радіоелектронної боротьби в умовах активних заходів радіоелектронної протидії з урахуванням сучасного стану військ (сил) противника.*

***Методи дослідження.** Під час написання статті було використано системний аналіз і синтез. Це дало змогу проаналізувати військові системи радіозв'язку в умовах активних заходів радіоелектронної протидії та надати рекомендації щодо зменшення впливу противника.*

***Аналіз останніх досліджень та публікацій.** Значна кількість наукових статей присвячена бойовому використанню безпілотних літальних апаратів у сучасних збройних конфліктах та заходам протидії їм, зокрема – радіоелектронному придушенню каналів управління та навігації.*

***Виклад основного матеріалу.** Проведено аналіз тенденцій використання військових систем радіозв'язку від повітряних ретрансляторів у сучасних військових конфліктах різної інтенсивності. Виокремлено напрями розвитку та вдосконалення військовими цих систем радіозв'язку, що функціонують в умовах активної радіоелектронної протидії противнику. Окреслено перспективи їх подальшого розвитку в частині використання в системі радіоелектронної боротьби. Запропоновано рекомендації щодо зниження енергетичного впливу засобів радіоелектронної боротьби противника, вибору оптимальної топології системи військового радіозв'язку з повітряними ретрансляторами та використання сучасних антенних систем.*

***Елементи наукової новизни.** Визначено напрями розвитку та вдосконалення, обираючи оптимальну топологію системи військового радіозв'язку з повітряними ретрансляторами.*

***Теоретична та практична значущість статті.** Впровадження зазначених технологій у систему управління військами дасть змогу забезпечити стійке управління нею, бойовими та спеціальними засобами в умовах складної радіоелектронної обстановки з активним використанням противником засобів радіоелектронної боротьби.*

***Висновок і перспективи подальших досліджень.** Аналіз тенденцій використання військових систем радіозв'язку з повітряними ретрансляторами в сучасних військових конфліктах різної інтенсивності дає змогу визначити основні напрями їх розвитку та вдосконалення. Напрямом подальших досліджень є удосконалення методів керування параметрами та режимами роботи військових систем радіозв'язку з повітряними ретрансляторами під впливом різних видів навмисних перешкод.*

***Ключові слова:** військова система радіозв'язку, безпілотні літальні апарати, радіоелектронне придушення, повітряний ретранслятор, завадозахищеність.*

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