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THE METHOD OF OPTIMIZING THE DISTRIBUTION OF RADIO SUPPRESSION MEANS AND DESTRUCTIVE SOFTWARE INFLUENCE ON COMPUTER NETWORKS

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ABSTRACT

Context. Currently, generalized methodical approaches to the development of scenarios of complex radio suppression and electromagnetic influence of typical special telecommunication systems have been developed. However, during the development of possible cases for the complex application of radio suppression and destructive software influence,the problem of optimizing the resource of these means and its distribution according to the goals of radio suppression and objects of destructive computer influence arose, which has not yet been fully resolved.Especially in the literature known to the authors, there is no method for optimizing the resource distribution of radio and computer influence, used for the development and practical implementation of optimal scenarios of destructive influence on computer networks of enemy military groups in military operations.

Therefore, it is necessary to formulate a problem and develop a method of optimizing the distribution of the resource of radio suppression and destructive software influence for the development of possible scenarios of the enemy's violation of information exchange in a standart telecommunication network.

Objective. The purpose of the research is to develop a method for optimizing the distribution of the resource of radio suppression and destructive software influence for the development of scenarios of information exchange violations by the enemy in the telecommunications network.

Method. To achieve the purpose of the research, the methods of nonlinear optimization of heterogeneous resource distribution, mass service theory, and expert evaluation were comprehensively applied and developed in the field of modeling of information conflict.

To determine the coefficients of protection of objects from radio-electronic and destructive computer influence, expert evaluation methods are used, in particular, the method of frequencies of preferences of the decision-maker using the Thurstone method. This method requires only one expert (a decision-maker), minimal communication time with him, minimal expert information (full ordering of weighting factors) and can be applied with a small number of evaluated weighting factors.

To solve the problem of optimal distribution of a heterogeneous resource of means of destructive influence, to ensure the value of the multiplicative objective function of an arbitrary form is not less than the given one, the method of successive increments is applied.

To determine the efficiency indicator of information exchange violation, the methods of mass service theory are applied, which allows to formalize special telecommunication systems as a set of mass service systems – subsystems of digital communication and computer networks.

Results. The formulated problem and the entered indicators made it possible to solve the problem of determining the minimum resource of means of destructive influence and their optimal distribution according to the purposes of radio suppression on the objects of destructive program influence in order to achieve the required level of disruption of the efficiency of information exchange in special telecommunication systems.

Conclusions. According to the results of the article, a method for optimizing the distribution of the resource of radio suppression and destructive software influence has been developed for the development of possible scenarios of information exchange violations by the enemy in a typical telecommunications network.The verification of the proposed method was carried out by comparing the theoretical results with the results of simulated modeling of scenarios of violation of the information exchange in the telecommunications network by the enemy.

KEYWORDS: information exchange, computer radio network, computer attack, protection of information, radio suppression, optimization of resource allocation, destructive influence.

ABBREVIATIONS

TN is a telecommunication network;

TSM is a tactical section of management;

LCRN is a local computer radio network;

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DPI is a destructive program influence;
LCN is a local computing network;
TPN is a tactical packet network;
CCCN is a combat control computer network;
RES is a radio-electronic struggle;
DST is a destructive software tool;
UAV is an unmanned aircraft vehicle;
WS is a workstation;
UAVTM is an unmanned aerial vehicle – trouble maker;
MSSis a mass service system;
COCC is acombat operations control center;
COT is a compact obstacle transmitter;
DCI is a destructive computer influence;
GCN is a global computing network;
OTS is an operational tactical situation;
SRG is a subversive reconnaissance group;
CIT is a compact interference transmitter;
TS is a telecommunication system;
EI is an electromagnetic influence.

NOMENCLATURE

β is a intensity of information aging;

H is a number of control units in which the enemy solves the task of disorganization;

h is a control link number;

k^{pws} is a security weight factor of workstations;

k^{pp} is a security weight factor of DCI targets;

k^{pnc} is a security weight factor of typical TPN nodal centers;

k_h^{pws} is a security weighting coefficient of the PC in the h-th link of management when the DST is introduced;

k_v^{pp} is a security weighting coefficient of the DCItarget of the v-th type;

k_h^{pnc} is a security weight factor nodal center TNin the$h$-th management chain;

l is a number of ratings on the x_i and x_j indicator scales;

m is a number of compared pairs in the plane Pk_iOPk_j;

N_h^{nc} is a number of workstations in LCNTN;

N_h^{nc} is a number of nodal centerTNin the h-th chain of management;

p_{ij} is a percentage ratio of the number of pairs of objects for which the arrow is “directed from criterion$i$ to criterion$j$”;

P_h^{pui}, P_{nec}^{pui} is a probability of untimely receipt of information about the crisis situation in the h-th link of management and its necessary importance for the disorganization of state administration, respectively;

$Q_{hv}(r_{hv})$ is a hv-th component of the transformed objective function;

$R\left(w^{mcsd}, w^{dis}\right)$ is a resource spent by the enemy on the implementation of the РП scenario of the nodal centers of TN and DCI on computer networks;

$R_h\left(w_{hv}^{mcsd}, w_h^{dis}\right)$ is a function of the resource used to implement the method of radio suppression and destructive software influence on computer networks in the h-th link of control;

$r_{hv}\left(w_{hv}^{mcsd}, w_h^{dis}\right)$ is a hv-th resource function component;

T^{ri} is a time of receiving information about changes in the situation in the event of a crisis situation;

T^{ct} is a critical delay time for information about a crisis situation;

$T_h^{ri}\left(w_{hv}^{mcsd}, w_h^{dis}\right)$ is a time of receiving information about the operational and tactical situation in the h-th chain of command;

T_{h-1}^{ri} is a time of receiving information about the crisis situation in the relevant management link, at which it achieves the fulfillment of the suppression efficiency criterion;

$\overline{T}_{hv}\left(w_{hv}^{mcsd}, w_h^{dis}\right)$ is an average time of transaction data processing in the target of the v-th type of DPI in the h-th management link;

T_h^{ct} is an aging time of information about the crisis situation in the h-th management link;

V is a number of types of DST targets in computer networks of TN;

v is a number of the DST target type;

w^{mcsd} is a number of DST used to suppress computer networks;

w^{dis} is a number of UAV-TM (TPN) used to suppress TN nodal centers;

w_{hv}^{mcsd} is a number of DST, which are implemented in PCs of local computing networks in each h control link to suppress each v type of DCI targets;

w_h^{dis} is a number of UAV-TM s used to suppress TPN nodal centers in each h control link;

z_{ij} is an unknown normalized variable;

$Q_h(R_h)$ is a transformed objective function.

INTRODUCTION

The development of organizational and technical methods of protection of TN, containing radio networks, mobile and computer means of TSM, which are consolidated by means of protected radio lines in LCRN and integrated into global (regional) LCRN (hereinafter, typical TN) is extremely relevant in the conditions of conducting hybrid military operations [1–9]. At the same time, there is an urgent need to develop scenarios of possible actions of the enemy during the conduct of radio suppression and computer attacks on TN [3–11].

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The objectof study – is the processes of distribution of a heterogeneous resource of means of destructive influence on information exchange.

The subjectof study – is a method of optimizing the distribution of a heterogeneous resource of means of destructive influence on information exchange.

The purpose of the work is to develop a method for optimizing the distribution of resources of radio suppression and DPI for the development of scenarios of violation of information exchange in TN by the enemy.

1 PROBLEM STATEMENT

A military operation is being considered, during which the task of disorganization by the enemy of the command of the opposing army corps by means of radio suppression and destructive influence on the computer network is solved [1–3, 4, 6, 9].

Analysis of military control systems shows that computer networks of combat control, the structural diagram of which is shown in Fig. 1, consist of LCN, LCRN, TPN, which are hierarchically combined in the CC CN [1, 3, 6, 7, 9–14]:

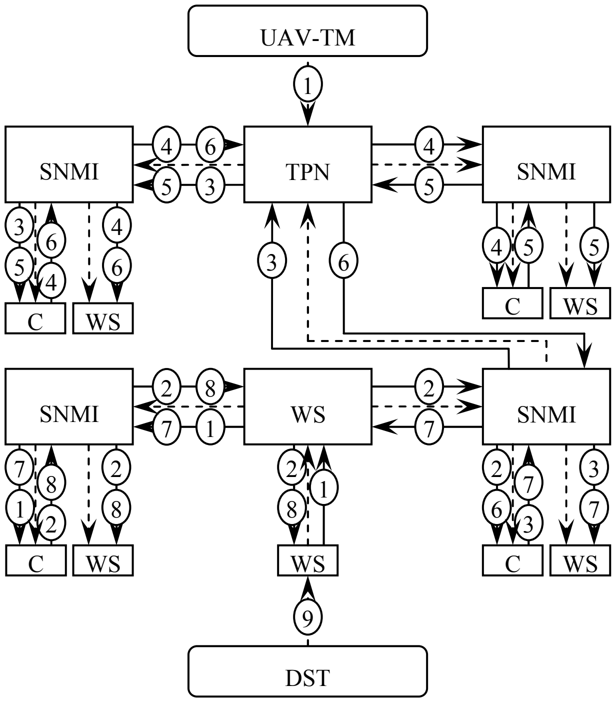

Figure 1 – Structural diagram of a model of the construction of computer networks of a typical army corps of the armed forces, as an object of RESand DCI in modern military operations

– workstations of platoon, company, and battalion commanders united by the ADDSI protocol (analogous to X.25) by means of the combat radio communication system (EPLRS, NTDR, SINCGARS SIP);

– workstations and servers of automated information systems of combat control centers of battalions, brigades, divisions and army corps, connected by cable lines using the Ethernet protocol.

The GCN is formed by local computer networks of various control units, united by means of a tactical packet network according to the X.25 protocol. TPN consists of routers, packet switches of node centers and separate radio relay communication channels of the MSE type system [1, 2]. The structural diagram of the mathematical calculation model of radio and software-computer suppression of army corps computer networks is shown in Fig. 1. Accordingly, data is exchanged between all vertical and horizontal links of the typical army corps of the armed forces of the leading countries of the world.

The adversary, in the conditions of conducting hybrid military operations, affects the CC CN in a complex way, combining the radio-electronic influence of RES devices on lines, node centers and communication lines of a typical TN with means of radio suppression and DST on elements of wireless computer networks [1, 2, 11–17].

The grouping of the enemys RES forces and means includes software-computer and radio suppression subsystems.

As part of the software-computer suppression subsystem, there is a set of DST.The radio suppression subsystem includes jamming transmitters on the UAV, Fig. 1.

DST using special sabotage actions are introduced in the LCN working stations of the army corps; UAV are launched in the areas of the TPN nodal center and create radio interference.

Introduced into the DST workstation, fig. 1, carries out a “denial of service” attack, causing a decrease in the speed of data processing by servers, overloading the LCN bus and duplex TPN communication channels with data packets; UAV-TM suppress the TPN nodal center, causing redirection of data flows through unsuppressed nodal centers and overloading of the corresponding TPN duplex communication channels, fig. 1.This leads to an increase in the time of transmission of information about the operational and tactical situation and, ultimately, its aging at the time of receipt by the concerned officials.

Computer networks of the army corps, fig. 1, are presented as a set of hierarchically united MSS, and DCI, UAV-TM affect their functioning by overloading [12, 18]. Here, the MSS are marked with rectangles: C is a two-node, two-phase MSS with an intermediate storage device of finite capacity, which simulates a server; WS – a two-node two-phase MSS with an intermediate storage device of finite capacity, which simulates a workstation; SNMI – single-node multi-input with random selection of a service request, which simulates an Ethernet bus; PM – single-node multi-input round-robin polling in the case of time distribution, which simulates the EPLRS radio network; TPN is a multi-node single-phase with waiting, which simulates the TPN of the MSE system. Circles indicate the process of transferring data about OTS: 1 – from the WS of reconnaissance means, platoon, company, battalion commanders to the battalion’s COCC server; 2 – from the battalion’s COCC server to the brigade’s COCC server and the battalion’s WS; 3 – from the brigade’s COCC server to the division’s

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COCC server and brigade's COCC server; 4 – from the division's COCC server to the army corps'COCCserver and the division's WSCOCC; 5 – from the army corps COCC server to the division's COCC server and the army corps'WSCOCC; 6 – from the division's COCC server to the brigades COCC server and the divisions WS COCC;7 – from the brigade COCC server to the battalion COCC server and the brigade WSCOCC; 8 – from the battalion's COCC server to the battalion's WSCOCC and the WS of platoon, company, and battalion commanders. Dashed arrows indicate the impact on the elements of the MSS;9 – introduction of DCI into the computer network by the software-computer suppression subsystem; 10 – radio suppression of the TPN nodal center.

It is necessary to optimize (solve the task of minimizing the resource objective function under a set of constraints) the resource of means of radio suppression and destructive software influence of the enemy on a typical computer network of the AK (according to Fig. 1 for use in a modern military operation.

With,as a resource target function for the implementation of the appropriate scenario of radio suppression and DCI on computer networks, it is advisable to consider the weighted additive number of DST intended for suppression of various targets of DCI and jamming transmitters on UAV of CIT, entered by SRG, intended for radio suppression of nodal centers typical TN:

$$R\left(w^{mcsd}, w^{dis}\right) = k^{pws} k^{pp} w^{mcsd} + k^{pnc} w^{dis} . \qquad (1)$$

The task of optimal distribution of the resource used to implement scenarios of radio suppression of the nodal center, communication lines and DCI on computer networks of a typical TN is specified as follows: form the following matrix $W^{mcsdopt} = \left\| w_{hv}^{mcsdopt} \right\|$, $h = 1...H$, $v = 1...V$ of minimum quantities of DPI means, which are introduced in LCNworkstations in each h chain of command to suppress each v type of DCItargets, and the following matrix $W^{disopt} = \left\| w_{h}^{disopt} \right\|$, $h = 1...H$, minimum quantitiesof minimum number of UAV-TM, COT, used to suppress TNnodal centers in each h control chain, which ensure the fulfillment of the criterion of effectiveness of radio suppression and DSI $P_h^{pui} \geq P_{pec}^{pui}$, taking into account the weighting coefficients of security of WS k_h^{pws}, DPI goals k_v^{pp} and nodal centers, TN communicationlines k_h^{pws} :

$$S^{opt} = \arg\min \left\{ R_h \left(w_{hv}^{mcsd}, w_h^{dis} \right) \right\}, \qquad (2)$$

$$R_h\left(w_{hv}^{mcsd}, w_h^{dis}\right) = \sum_{v=1}^{V} r_{hv}\left(w_{hv}^{mcsd}, w_h^{dis}\right) =$$

$$= \sum_{v=1}^{V} k_h^{pws} k_v^{pp} w_{hv}^{mcsd} + k_h^{pnc} w_h^{dis} , \qquad (3)$$

$$h = 1...H, \ v = 1...V,$$

subject to restrictions:

$$p_h^{pui}\left(w_{hv}^{mcsd}, w_h^{dis}\right) \geq p_{nec}^{pui} , \qquad (4)$$

$$w_{hv}^{mcsd} \in \{0,1,2,..., N_{ws}\}, \ w_h^{dis} \in \left\{0,1,2,..., N_h^{nc}\right\}, \qquad (5)$$

$h = 1...H, \ v = 1...V.$

2 REVIEW OF THE LITERATURE

General issues of conducting radio suppression and DCI on computer networks are considered in [1–10].

Approaches to computer networks modeling are also described in [12–18], criteria for assessing their security are presented in [15–18].

However, the known results are not specified for solving the tasks of applying the scenario approach in the development of methods of protecting TN from radio suppression and DST of the enemy, taking into account indicators of violation of the efficiency of information exchange [4–18].The specifics of the targeted practical use of the object of research considered in this article are relatively little presented in the publications open to print.According to the authors, a certain generalization and the possibility of civilian use of the research results allow the results to be put to the public's discretion.

The simulation modeling carried out by the authors showed that in practice, under the conditions of modern measures for the radio-electronic protection of TN of the army corps, the enemy needs to increase the number of radio suppression means of UAV-TM, COT and DCI (hereinafter – the resource) in order to achieve the required level of disruption of the efficiency of information exchange, but the procedure for optimizing means has not been developed [4–9, 15–18].

Methodical approaches to the development of complex radio suppression and EI scenarios of typical TN are developed in [4–9, 12, 15–20]. It was concluded that in the practice of conducting hybrid military operations, the adversary for radio suppression of the hub center and communication lines of typical TN can comprehensively use radio suppression means on UAV-TM, COT, which carry SRG, and for the impact on wireless computer networks – DST [4–7].

At the same time, during the development of possible scenarios for the complex use of radio-suppression means and DST, the task of optimizing the resource of these means and its distribution for the purposes of radio-suppression and the DCI object arose.

The procedures for optimizing the resources of the means of destructive influence on TN and optimal

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distribution for radio suppression targets and DST objects in order to achieve the desired level of violation of the efficiency of information exchange in TN by the enemy in a special period have not been developed in the foreign and domestic literature known to the authors.

Therefore, the task of developing a method of optimizing the distribution of the resource of radio suppression means and destructive software influence for the development of scenarios of violation by the enemy of information exchange in the telecommunications network is relevant and is considered in this article.

3 MATERIALS AND METHODS

To solve the optimization problem in the statement (1)–(6) and achieve the goal of the article, it is necessary to solve a number of partial scientific problems.

First of all, developing the procedure for determining the weighting coefficients of the objective function (1) requires a further scientific solution.

The issue of determining the weighting coefficients of the objective function (1) requires further scientific resolution.

The conducted analysis showed that in order to determine the weighting coefficients when searching for the extremum (1), it is potentially possible to consider methods of approximation of the utility function in generalized convolutions [4–6]. It was concluded that known methods of pairwise comparisons, point estimates on a frequency scale, and individual preferences determine the weighting factors that are difficult to use in generalized convolutions. At the same time, the methods of approximation of the utility function are used only when the utility function can be represented in an additive form, while the weighting coefficients are determined according to the contribution of the components to the total utility [18–20].

However, the weighting coefficients calculated by such methods differ in essence from the weighting coefficients k^{pws}, k^{pp}, k^{pnc} of the security of radio suppression targets, because the latter are not part of the efficiency function and, on the contrary, express the resistance of radio suppression targets to its increase. Then, to estimate k^{pws}, k^{pp} the weighting coefficients k^{pws}, k^{pp}, k^{pnc} of the security of radio suppression targets, methods of pairwise comparisons, precise evaluations on a scale, frequencies of person preferences can be applied, but their application requires, as input data, expert information. In such a situation, the solution to the problem lies in the field of integration of methods for determining weighting factors and expert evaluation.

The analysis of the methods showed that a compromise option is the choice of the frequency method of the decision-maker's preferences [15–20] using the Thurstone method [14–20]. This method requires only one expert (a decision-maker), minimal communication time with him, minimal expert information (full ordering of weighting factors) and can be applied with a small number of evaluated weighting factors.

The essence of the frequency method of the decision-maker's preferences for solving problem (1) is as follows.It is necessary to determine the weighting coefficients k^{pws}, k^{pp}, k^{pnc} of the qualitative indicators "security of the WS" x^{pws}, "security of the DPI target" x^{pp},"security of the nodal center of the TN" x^{pws} respectively. For each of the specified groups of indicators, a procedure is carried out, which consists of the following stages:

1) a single ordinal scale is developed for all indicators so that the minimum quality for each indicator corresponds to the origin of the coordinates of the space of indicators $X = x_1 \times x_2 \times ... \times x_n$;

2) the person making the decision compares all the objects located in each coordinate plane $x_i O x_j$,connecting them with arrows, and the arrows areplaced from the best object to the worst;

3) the number of arrows directed from indicator*i*to indicator *j* is counted, which characterizes the importance of indicator*i*in relation to indicator*j*. The total number of arrows a_{ij} will be the number of cases in which indicator*i*is more important than indicator*j*. According to the results of the calculation, the matrix $A = \left\| a_{ij} \right\|$ of the Thurstone method is formed;

4) the *P* matrix is constructed. *P*– is the proportion of cases when indicator *i* was more important than indicator *j*: $P = \left\| p_{ij} \right\|, 1 \le i, j \le n$, where p_{ij} – percentage ratio of the number of pairs of objects for which the arrow is "directed from criterion *i* to criterion *j*", moreover $p_{ij} = \frac{a_{ij}}{m}$, where $m = \frac{l^2 \left(l^2 - 2l + 1 \right)}{4}$. The matrix element *P* satisfies the condition $p_{ij} + p_{ji} = 1$;

5) p_{ij} expressed in standard deviations are determined by the iterative method:

$$p_{ij} = \int_{-\infty}^{z_{ij}} \frac{1}{\sqrt{2\pi}} e^{-z^2/2} dz; \tag{6}$$

6) the "importance" of indicator *i*, expressed in standard deviations, is calculated $\bar{z}_i = \frac{z_i}{n}$ де $z_i = \sum_{j=1}^{n} z_{ij}$;

7) formula (6) determines the probability p_i, corresponding to $\bar{z}_i$;

8) normalization of p_i is carried out, and the weighting factor is found k_i.

So, the proposed method of frequency preferences of the decision-maker allows solving the problem of determining the security coefficients of radio suppression

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and DCI targets, which can be used in optimizing the allocation of the resource used for the implementation of radio suppression and DPI scenarios on TN elements. The method requires minimal communication time with only one expert and minimal expert information.

Secondly, when solving problems (1)–(6) the next important stage of optimization is the determination of constraints on the parameter of the objective function (1).

Based on the results of the imitative simulation, it was determined that in practice, radio suppression and DCI on TS elements leads to an increase in the probability of untimely "delivery" of information about the crisis situation by officials (authorities) of various branches of state administration. In Fig. 1 presents the graphs of the dependence of the probability $p_{rs}^{ld}(t)$ in different control links on the intensity of interfering packets for different values of the number of WS s in which DST are introduced. An increase in the intensity of packets leads to an increase in the probability of untimely receipt of information about a crisis situation, while suppressing server disruptions is more effective at lower levels of management.

Graphs of the dependence of the probability of untimely "delivery" of information about a crisis situation on the number of WS s, in which DST are implemented to suppress the server, Ethernet LCN buses, packet networks have a non-linear nature, therefore, when solving the problem of optimizing the resource allocation of radio suppression means and DPI of TN, it is necessary to apply non-linear methods.

Taking into account the limitations on the scope of the publication, we specify the least covered in the literature and researched in Ukraine issues of probability determination [4].

$$p_{rs}^{ld}(t) = P\left(T^{ri} \le T^{ct}\right) = 1 - e^{-\beta}, \text{ where } \beta = \frac{T^{ri}}{T^{ct}}. \quad (7)$$

The methods of determining the indicator T^{ri} in each specific case are determined by the features of the TNconstruction. At the same time, the TScan be formalized as a set of MSS`s – subsystems of digital communication and computer networks [4–9, 12, 18].

When determining the parameter T^{ri} in the conditions of the DPI for a typical TN, it is advisable to model computer networks as a set of hierarchically combined MSS`s. To implement the proposed approach, in [4] a methodological basis for mathematical modeling of DCI on TN computer networks was developed, in which computer networks are represented as a set of hierarchically combined MSS`s, and the introduced DST and radio suppression means affect their functioning by overloading.

Thirdly, it is necessary to choose a method of solving problems (1)–(6). Problem (1)–(6) is the problem of determining the minimum necessary resource to ensure the value of the multiplicative objective function of an arbitrary form is not less than the specified one.The optimal distribution of the resource can be solved by the method of successive increments [19–20].

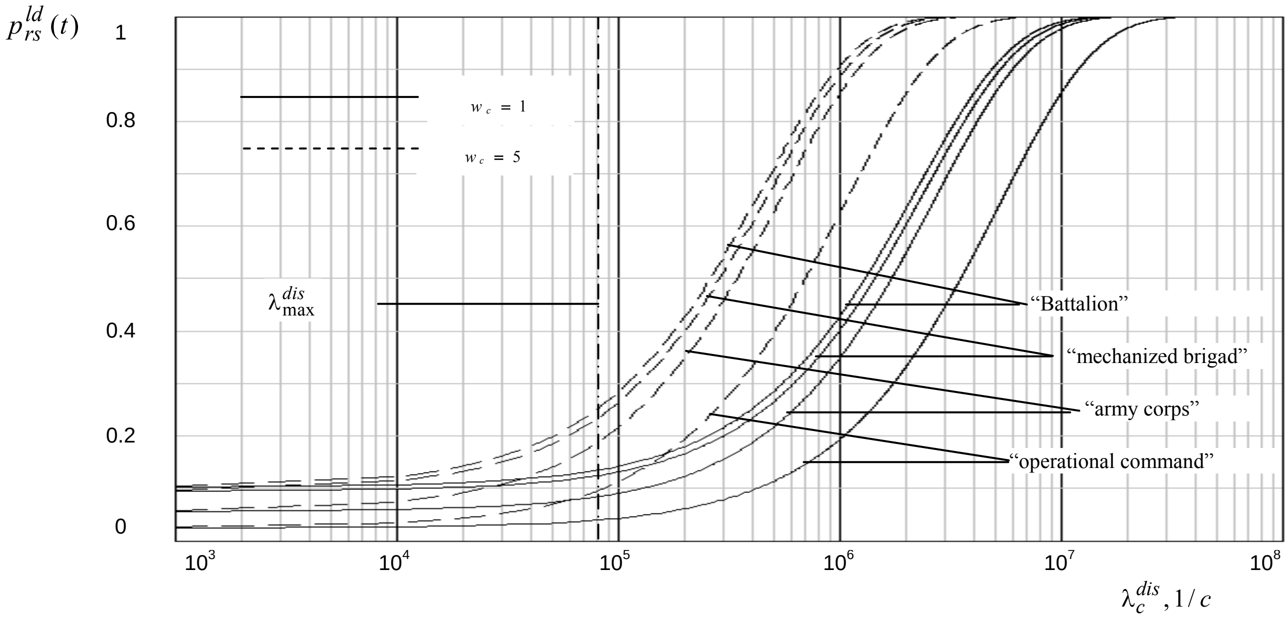

Figure 2 – Dependence of the probability of untimely "delivery" of information about a crisis situation in the control units "tactical unit", "connection", "unification" on the intensity of interfering packets for different values of the number of WS s of the TN computer network

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The method of successive increments allows you to effectively solve problems such as: finding a series $X^o = \{x_i^o\}_n = \min_{x_i}\{x_i\}_n = \min_{x_i}\sum_{i=1}^{n} x_i$, which ensures the value of the additive function is not less than the specified:

$$F(X) = \sum_{i=1}^{n} F_i(x_i) \geq F^{giv}(X) \tag{8}$$

with a linear restriction on the variables:

$$\left(X = \sum_{i=1}^{n} x_i\right) \leq b,\ b > 0\,, \tag{9}$$

under the conditiontheir integers and non-negativity:

$$x_i \in \{0,1,2,\ldots,b\}, i = 1,2,\ldots,n. \tag{10}$$

To reduce the problem (1)–(6) to the conditions (7)–(9), it is necessary to ensure the additive nature of the target function, the independence of its components, as well as the transition from variables w_{hv}^{mcsd}, w_h^{dis} to the function $R_h\left(w_{hv}^{mcsd}, w_h^{dis}\right)$.

Fulfillment of the condition of additivity of the target function will be ensured by the transition from the function of the probability of untimely receipt of information about the crisis situation to the function of the time of receipt of information about the operational-tactical situation, which is additive. Then, we get the objective function:

$$T_h^{ri}\left(w_{hv}^{mcsd}, w_h^{dis}\right) = T_{h-1}^{ri} + \sum_{v-1}^{V} \overline{T}_{hv}\left(w_{hv}^{mcsd}, w_h^{dis}\right) \geq$$

$$\geq -T_h^{ct} \ln\left(1 - p_{nec}^{pui}\right),\ h = 1 \ldots H. \tag{11}$$

In cases where some components $\overline{T}_{hv}\left(w_{hv}^{mcsd}, w_h^{dis}\right)$ of the objective function turn out to be dependent, it is advisable to switch to their combinations, which are formed by sequentially sorting the values of one parameter while the second parameter is fixed, while the formed components will be independent.

Sinceforeachvalue w_{hv}^{mcsd}, w_h^{dis} thevaluesareknown $T_h^{ri}\left(w_{hv}^{mcsd}, w_h^{dis}\right)$ and $R_h\left(w_{hv}^{mcsd}, w_h^{dis}\right)$, then, putting the value R_h as independent, it is possible to assume that the value of the function is also known $Q_h(R_h)$, because it is equal to the value of $T_h^{ri}\left(w_{hv}^{mcsd}, w_h^{dis}\right)$. So, the set of function values $T_h^{ri}\left(w_{hv}^{mcsd}, w_h^{dis}\right)$ is uniquely mapped to the set of function values $Q_h(R_h)$, which ensures the transition from variables w_{hv}^{mcsd}, w_h^{dis} to the function $R_h\left(w_{hv}^{mcsd}, w_h^{dis}\right)$:

$$T_h^{ri}\left(w_{hv}^{mcsd}, w_h^{nc}\right) = T_{h-1}^{ri} + \sum_{v=1}^{V} \overline{T}_{hv}\left(w_{hv}^{mcsd}, w_h^{nc}\right) =$$

$$= T_{h-1}^{ri} + \sum_{v=1}^{V} F_{hv}\left(w_{hv}^{mcsd}(R_h), w_h^{nc}(R_h)\right) =$$

$$= T_{h-1}^{ri} + \sum_{v=1}^{V} Q_{hv}(r_{hv}) = Q(R_h). \tag{12}$$

Then, taking into account (8)–(12), problem (4)–(7) will take the form:

$$S^{opt} = \arg\min\left\{R_h\left(w_{hv}^{mcsd}, w_h^{dis}\right)\right\}, \tag{13}$$

$$R_h\left(w_{hv}^{mcsd}, w_h^{dis}\right) = \sum_{v=1}^{V} r_{hv}\left(w_{hv}^{mcsd}, w_h^{dis}\right) =$$

$$= \sum_{v=1}^{V} k_h^{pws} k_v^{pp} w_{hv}^{mcsd} + k_h^{pnc} w_h^{dis}, \tag{14}$$

$$h = 1 \ldots H, \quad v = 1 \ldots V\,,$$

subject to restrictions:

$$\Theta_h\left(R_h\left(w_{hv}^{mcsd}, w_h^{nc}\right)\right) \geq -T_h^{ct} \ln\left(1 - P_{nec}^{pui}\right), \tag{15}$$

$$w_{hv}^{mcsd} \in \{0,1,2,\ldots,N_{ws}\}, \quad w_h^{dis} \in \left\{0,1,2,\ldots,N_h^{nc}\right\}, \tag{16}$$

$$h = 1 \ldots H,\ v = 1 \ldots V.$$

For optimization, we will use the process of sequential distribution of the resource w_{hv}^{mcsd}, w_h^{dis} in some portions $\Delta w_{hv}^{mcsd(t)}, \Delta w_h^{dis(t)}$ respectively, at the t-th step of the process. If, at the t-thstep of the process, the argument of the hv-thcomponents of the resource function receives an increment $\Delta w_{hv}^{mcsd(t)}, \Delta w_h^{dis(t)}$, then will receive the increment $\Delta r_{hv}^{(t)}$ of hv-thcomponent of the resource functionand, accordingly, the transformed target function:

$$\Delta Q_h\left(R_h^{(t)}\right) = \Delta Q_{hv}\left(r_{hv}^{(t)}\right) =$$

$$= \Delta Q_{hv}\left(r_{hv}^{(t-1)} + \Delta r_{hv}^{(t)}\right) - Q_{hv}\left(r_{hv}^{(t-1)}\right) = \Delta Q_{hv}. \tag{17}$$

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The average efficiency of use of each of the Δr_{hv} resource units at the t-th step of the process is determined by the ratio:

$$e_{hv}^{(t)} = \frac{\Delta Q_{hv}\left(r_{hv}^{(t)}\right)}{\Delta r_{hv}^{(t)}}, \; h = 1...H, \; v = 1...V. \qquad (18)$$

The optimization method will consist in the sequential distribution of the resource in portions $\Delta r_{hv_t}^{(t)}$, the value of which and the index hv_t are determined in accordance with the maximum efficiency of the use of each unit of the resource at each step of the process.

The optimal step value $\Delta r_{hv}^{(m)}$ is determined from the condition:

$$\left(e_{hv}^{(m)} = \frac{\Delta Q_{hv}^{(m)}}{\Delta r_{hv}^{(m)}}\right) = \max_{\Delta r_{hv}}\left(e_{hv} = \frac{\Delta Q_{hv}}{\Delta r_{hv_t}}\right), \qquad (19)$$

$$h = 1...H, \; v = 1...V.$$

The index hv_t of the component of the resource function, at which the largest value of the quantity $e_{hv}^{(m)}$, is reached at the t-th step of the process, is determined in accordance with the condition:

$$e_{hv_t}^{(m)} = \max e_{hv_t}^{(m)}, \; h = 1...H, \; v = 1...V. \qquad (20)$$

As a result, the matrices are obtained:

$$W^{mcsd\ opt} = \left\| w_{hv}^{mcsd\ opt} \right\|, \quad W^{dis\ opt} = \left\| w_{h}^{dis\ opt} \right\|,$$

$$h = 1...H, \; v = 1...V,$$

which form the optimal distribution of the resource used for the implementation of scenarios of radio suppression and DPI of the enemy on the TS.

So, the method makes it possible to optimize the allocation of the resource used to implement possible scenarios of radio suppression and computer impact of TS.

4 EXPERIMENTS

Based on the likely nature of the application, the initial data regarding the composition of the connections, parts and subdivisions of a typical army corps is shown in Table 1.

Control of connections and parts of army corps is carried out using an automated control system of the ATCCS type, the technical basis of which is computer networks.

Table 1 – Initial data for the experimental application of the resource optimization method

	Output data for scenario optimization	A typical stage of a military operation
		conducting hostilities to maintain the defense line
“battalion”	the number of PC in the network of commanders	30
	the number of LCNCOCCat the most important radio-electronic objects	130
	the number of battalions in the brigade	14
“brigad	number of PC in LCNCOCC	34
	the number of LCNCOCCat the most important radio-electronic objects	11
	the number of brigades in the division	3
“division”	number of PC in LCNCOCC	30
	the number of LCNCOCCat the most important radio-electronic objects	8
	number of divisions in army corps	3
	the number of nodal centerTPN	15
	the deployment distance of the nodal center TPN from the battle line	60
“army corps”	number of PC in LCNCOCC	30
	the number of LCNCOCCat the most important radio-electronic objects	12
	the number of PC	60
	the number of nodal center TPN	14
	the deployment distance of the nodal center TPN from the battle line	60–80

The main components of computer networks are:

– computer tools:

– Appliqué-type workstations of company (battery) and platoon commanders under the control of Microsoft Windows operating systems;

– Appliqué-type workstations of officials of combat control centers of battalions, brigades, divisions, army corps under the control of Microsoft Windows operating systems;

– servers of automated information systems of combat control centers of battalions, brigades, divisions and army corps under the control of Microsoft Windows operating systems;

– routers of node centers of a tactical packet network under the control of the Sun Solaris operating system;

– means of communication:

– Means of the combat radio communication system of the “brigade and below” control units such as EPLRS, NTDR, SINCGARS SIP;

– radio relay means of the AN/TTC-46, AN/TTC-48, AN/TRC-190 type of expansion nodes of the automated communication system of the MSE type;

– radio relay means of the AN/TTC-47, AN/TRC-113, AN/TRC-143, AN/TRC-190 type of nodal centers of the automated communication system of the MSE type.

Officials’ workstations and COCC servers operate under the control of Microsoft Windows and Sun Solaris family operating systems[1].

In order to disorganize the management of connections and parts of army corps, the enemy needs to achieve the effectiveness of methods of radio and software-computer suppression of computer networks not lower than 0.8 in the control links: “battalion” – $h = 1$;

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"brigade" – $h=2$; "division" – $h=3$; "army corps"– $h=4$. For this purpose: 1) introduce software and computer suppression tools of the TCP, UDP flood type into the workstations of local computer networks – to suppress servers ($v=1$), type ICMP flood – to suppress the Ethernet bus ($v=2$), type ICMP flood – to suppress TPN lines ($v=3$), which carry out a "distributed denial of service" attack;2) suppress the TPN nodal centers in the areas of responsibility of divisions ($h=3$) and army corps ($h=4$) with jamming transmitters on UAV.

Then the tasks (1)–(4) of the optimal distribution of the means of radio and DST computer networks of the army corps in operations are specified as follows: to form the following matrix $W^{mcsdopt}=\left\|w_{hv}^{mcsdopt}\right\|$, $h=1,2...4$, $v=1,2,3$ of the minimum quantities of DST, which are implemented in WS s of local computer networks in each *h* chain of command to suppress each *v* type of DCI targets, and the following matrix $W^{disopt}=\left\|w_{hv}^{disopt}\right\|, h=3,4$ of the minimum number of UAV-TM s used to suppress TPNnodal centers in each *h* chain of control, which ensure the fulfillment of the intelligence electronic device efficiency criterion $p_h^{pui} \ge p_{nec}^{pui}=0.9$ taking into account the weighting coefficients of WS protection k_h^{pws}, the objectives of DCI k_v^{pp} and TPN nodal centers k_h^{pnc}:

$$S^{opt}=\arg\min\left\{R_h\left(w_{hv}^{mcsd},w_h^{dis}\right)\right\},$$

$$R_h\left(w_{hv}^{mcsd},w_h^{dis}\right)==\sum_{v=1}^{3}k_h^{pws}k_v^{pp}w_{hv}^{mcsd}+k_h^{pnc}w_h^{dis},$$

$$h=1,2,3,4;\ v=1,2,3.$$

under constraints of type (6)–(7).

In order to solve the task of optimal distribution of means of radio suppression of computer networks and DST, it is necessary to determine the aging time of information about the operational and tactical situation and the weighting factors of the security of LCNworkstations k_h^{pws}, DCI targets k_v^{pp}, TPN nodal centers k_h^{pnc}, Table 2.

Table 2 – The results of determining the aging time of information for various control units of a typical army corpsin a military operation

Probability of finding a typical object of shooting damage in the area	Information aging time in management units T_h^{ct}, hours.			
	"battalion"	"brigade"	"battalion"	"army corps"
$P^{id}=0.9$	0.3	1.4	1.6	4.2

To determine the weighting coefficients k^{pws},k^{pp},k^{pnc} $h=1,2,3,4$; $v=1,2,3$ of the quality indicators "security of the WS" x^{pws}, "security of the target of the DCI" x^{pp},"security of the nodal centerTPN" x^{pnc} respectively, the following procedure was carried out:

– A single ordinal scale was developed for all indicators so that the minimum quality for each indicator corresponds to the origin of the coordinates of the indicator space $X^{pws}=x_1^{pws}\times x_2^{pws}\times x_3^{pws}\times x_4^{pws}$; $X^{pp}=x_1^{pp}\times x_2^{pp}\times x_3^{pp}$; $X^{pnc}=x_3^{pnc}\times x_4^{pnc}$; all objects lying in each coordinate plane are compared $X_i^{pws}OX_j^{pws},X_i^{pp}Ox_j^{pp},X_i^{pnc}Ox_j^{pnc}$, connecting them with arrows, and the arrows are placed from the best object to the worst;

– The calculated number of arrows directed from indicator *i* to indicator *j*, which characterizes the importance of indicator *i* in relation to indicator *j*. The total number of arrows $a_{ij}^{pws},a_{ij}^{pp},a_{ij}^{pnc}$; is the number of cases in which indicator*i*is more important than indicator *j*. According to the calculation results, the matrices of the Thurstone method are composed:

$$A^{pws}=\begin{Vmatrix}0&1&2&1\\8&0&1&0\\7&8&0&2\\8&9&7&0\end{Vmatrix},\quad A^{pp}=\begin{Vmatrix}0&8&5\\1&0&2\\4&7&0\end{Vmatrix},\quad A^{pnc}=\begin{Vmatrix}0&2\\7&0\end{Vmatrix};$$

– Constructed matrices P^{pws},P^{pp},P^{pnc} – are the fractions of cases when indicator*i*was more important than indicator *j*:

$$P^{pws}=\begin{Vmatrix}0.00&0.11&0.22&0.11\\0.79&0.00&0.11&0.00\\0.78&0.89&0.00&0.22\\0.89&1.50&0.82&0.00\end{Vmatrix},$$

$$P^{pp}=\begin{Vmatrix}0.00&0.93&0.59\\0.11&0.00&0.22\\0.42&0.78&0.00\end{Vmatrix},\quad P^{pnc}=\begin{Vmatrix}0.00&0.26\\0.88&0.00\end{Vmatrix}.$$

– Defined matrix elements P^{pws},P^{pp},P^{pnc}, expressed in standard deviations:

$$Z^{pws}=\begin{Vmatrix}0.00&-1.22&-0.76&-1.22\\1.23&0.00&-1.22&-2.00\\0.77&1.23&0.00&-0.76\\1.23&6.35&0.77&0.00\end{Vmatrix},$$

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$$Z^{pp} = \begin{Vmatrix} 0.00 & 1.23 & 0.14 \\ -1.22 & 0.00 & -0.76 \\ -0.13 & 0.77 & 0.00 \end{Vmatrix}, \quad Z^{pnc} = \begin{Vmatrix} 0.00 & -0.76 \\ 0.77 & 0.00 \end{Vmatrix}.$$

– Calculated “importance” of indicator$i$, expressed in standard deviations:

$$\overline{Z}^{pws} = \begin{Vmatrix} -0.80 \\ -0.50 \\ 0.31 \\ 2.09 \end{Vmatrix}, \quad \overline{Z}^{pp} = \begin{Vmatrix} 0.46 \\ -0.66 \\ 0.21 \end{Vmatrix}, \quad \overline{Z}^{pnc} = \begin{Vmatrix} -0.38 \\ 0.39 \end{Vmatrix};$$

– Defined probabilities P^{pws}, P^{pp}, P^{pnc} that correspond to $\overline{Z}^{pws}, \overline{Z}^{pp}, \overline{Z}^{pnc}$:

$$P^{pws} = \begin{Vmatrix} 0.21 \\ 0.31 \\ 0.62 \\ 0.98 \end{Vmatrix}, \quad P^{pp} = \begin{Vmatrix} 0.68 \\ 0.25 \\ 0.58 \end{Vmatrix}, \quad P^{pnc} = \begin{Vmatrix} 0.35 \\ 0.65 \end{Vmatrix};$$

– normalization was carried out P^{pws}, P^{pp}, P^{pnc}, and the weighting coefficients of the security of workstations, targets of software and computer suppression, nodal centers of TPNarmy corps were found, which are presented in Table 3.

The determined optimal composition of radio suppression and DST means allow to disrupt army corps management at the appropriate stage of the operation, provided that the place and time of application are agreed upon.

Table3 – Results of optimizing the distribution of means of radio and software-computer suppression of computer networks of a typical army corps at the stage of maintaining the first line of defense

Control link of atypicalarmy corps	Number of DST introduced in PC LCNCOCC of control units to suppress targets			The number of interference transmitters on UAVs to suppress TPN nodal centers	Time of receiving information about OTS, which is achieved as a result of suppression, h.	The limit time of receiving information about OTS, at which the required suppression efficiency is achieved, h.
		Ethernet bust LCN	TPN			
“battalion”	8	0	2	8	2.8	2.4
“brigade”	0	0	4	2	4.2	4.1
“division”	5	0	4	0	7.31	6.1
“army corps”	0	0	4	2	12.41	12.2

Based on the simulation results, the dependences of the probability of untimely “delivery” of information about the situation (see Fig. 2) on the intensity of “interfering”packets were obtained. At the same time, the values of the number of PC s of the TN computer network, in which the DST were introduced, were chosen equal to 1 and 5, respectively. the intensity of interfering packets varied between $10^3$and 10^8.

It was concluded that an increase in intensity leads to an increase in the probability of untimely receipt of information about a crisis situation, while suppression of server disruptions is more effective at lower levels of management.

Based on the experimental application of the developed method, it was concluded that, in practice, the complex influence of radio suppression and DST on the elements of the TS of military systems leads to an increase in the probability of untimely “delivery” of information about the situation on the battlefield, which can lead to a breakdown in management in the relevant sections.

5 RESULTS

The task was formulated and a method was elaborated to optimize the resource of radio suppressors and DCI in the development of scenarios of the enemy’s influence on the elements of a typical network of combat control of a military unification of army in military operations.

To determine the coefficients of protection of objects from radio-electronic influence and destructive computer influence of the target additive function, the method of the frequency of individual preferences is used, which finally combined the solution with the Terstoune`s method. The research showed that in order to solve the problem of optimal distribution of a heterogeneous resource of means of destructive influence, provided that the value of the multiplicative objective function of an arbitrary form is not less than the given one, it is advisable to apply the method of successive increments. At the same time, in order to determine the indicator of the efficiency of the contravention of information exchange, the methods of the mass service theory are used, which allows to formalize the combat control networks as a set of mass service systems – subsystems of digital communication and computer networks, and to propose a general method of optimizing the distribution of the resource of radio suppression and DPI, and development of scenarios of interruption by the enemy of information exchange in combat control networks in modern military operations. The essence of the proposed method is the sequential distribution of the resource in portions $\Delta r_{hv_t}^{(t)}$, the value of which and the index $_{hv_t}$ are determined in accordance with

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the maximum efficiency of use of each resource unit at each step of the process. At the same time, the weighting coefficients of the security of radio targets and software-computer suppression of the target function (1) are determined based on the frequency method of the decision-maker's preferences.

Based on the results of the imitative simulation, it was concluded that in practice, radio suppression and DCI on TS elements leads to an increase in the probability of untimely "delivery" of information about the crisis situation by officials (bodies) of various branches of state administration.

6 DISCUSSION

The results obtained in the article are the development of a scenario approach for predicting possible actions of the enemy to disrupt the efficiency of information exchange in the networks of combat control of units (combinations) of army in military operations.

The obtained results are different from the known results in the field of optimization of resource distribution of computing networks. In the article, for the first time, it became possible to comprehensively apply the mathematical apparatus of the theory of optimizing the distribution of heterogeneous resources, mass service and expert evaluation, based on the development in the field of substantiation of scenarios of disruption of information exchange in combat control networks within the framework of information confrontation in modern military operations. This made it possible for the first time to carry out a task statement and develop a method of optimizing the resource of radio suppression and DCI in modern military operations.

The method uses the well-known mathematical apparatus of the theory of optimal resource distribution in conditions of non-linearity of the additive resource function. However, for the first time, additional restrictions on the resource target function specific to military operations, which are due to the achievement of the desired infringement of the operational efficiency of information exchange in combat control networks that are in the information conflict on the battlefield, were taken into account.

In contrast to the known results, which are close in terms of the research direction, the peculiarities of the additive nature of the target function are taken into account, when developing scenarios of radio suppression and DPI of elements of combat control networks, an approach is developed to take into account the security coefficients of the corresponding elements of combat control networks, which are objects of radio suppression and DPI in the information struggle. The solution to this problem can be obtained by the frequency method of the decision-maker's preferences [14–20] using the Terstoune`s method [14–20]. It is substantiated that this method requires only one expert (a decision-maker), minimal communication time with him, minimal expert information (full arrangement of weighting factors) and can be applied with a small number of evaluated weighting factors.

To fulfill the condition of additivity of the target function, a transition from the function of the probability of untimely receipt of information about the situation on the battlefield to the function of the time of receipt of information about the operational-tactical situation, which is additive, was ensured. At the same time, in order to determine the minimum necessary resource to ensure the value of the multiplicative target function of an arbitrary form not less than the specified one, the possibility of using the known method of successive increments is substantiated.At the same time, in order to determine the minimum necessary resource to ensure the value of the multiplicative objective function of an arbitrary form not less than the specified one, the possibility of using the known method of successive increments is substantiated.

The application of a set of methods is specified to the level of a generalized method that can be used in calculations of the efficiency of information exchange in TS.

The correctness of the application of the developed mathematical apparatus is shown by its practical application for a specific simplified operational-tactical situation that may arise on the battlefield. The obtained results do not contradict the known theoretical propositions and logical understanding regarding the organization of information confrontation in the defense operation of a typical army corps.

CONCLUSIONS

The research proposes a method for optimizing the resource allocation of radio suppression and DPI during information exchange. The advantage of the method is that it allows for the first time to formalize and solve the problem of optimal resource allocation used to implement methods of radio and software-computer suppression of computer networks in an information conflict, as a problem of determining the minimum necessary resource to ensure the value of the multiplicative target functions of an arbitrary form not less than a given one, using the method of successive increments.

The method is quite simple from the point of view of numerical implementation and is not critical to the choice of the optimization procedure. The results of the experiments confirm the effectiveness of the proposed method in the tasks of protecting TN from radio suppression and DPI of the enemy, taking into account indicators of infringement of the efficiency of information exchange.

The scientific novelty for the first time, the method of optimizing the distribution of the radio suppression resource and DPIwas proposed for the development of possible scenarios of infringement of the information exchange by the enemy in a typical TN when organizing an information confrontation.

The developed method differs from the known ones in that, for the first time, it takes into account when developing scenarios of destructive impact on TS, the enemy's complex use of radio suppression and software influence.

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The practical significance of the research results is the developed method that allows determining in practice the minimum set of radio suppression and DCI means, which ensures the required level of disruption of the efficiency of information exchange in various branches of state administration.

The generalized method is concretized to the level of algorithms, which simplifies its further implementation in the form of applied software products that can be used in the development of scenarios of an attacker's actions to disorganize goverment administration.

The results obtained in the article are normalized and can be used in engineering calculations of the efficiency of information exchange in TS.

Prospects for further research in this direction consist of the development of theoretical bases for determining the scenarios of possible enemy actions in the conditions of the enemy's complex use of radio suppression, electromagnetic and computer influence on TN elements.

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МЕТОД ОПТИМІЗАЦІЇ РОЗПОДІЛУ ЗАСОБІВ РАДІОПОДАВЛЕННЯ ТА ДЕСТРУКТИВНОГО ПРОГРАМНОГО ВПЛИВУ НА КОМПЮТЕРНІ МЕРЕЖІ

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АНОТАЦІЯ

Актуальність. На даний час узагальнені методичні підходи до розробки сценаріїв комплексного радіоподавлення та електромагнітного впливу типових спеціальних телекомунікаційних систем розроблені. Однак, при розробці можливих сценаріїв комплексного застосування засобів радіоподавлення та деструктивного програмного впливу виникла задача оптимізації ресурсу цих засобів та його розподілу по цілях радіоподавлення та обєктах деструктивного компютерного впливу яка досі не вирішена у повному обсязі. Зокрема, у відомій авторам літературі не розроблений метод оптимізації розподілу ресурсу засобів радіо та компютерного впливу, використовуваного для розробки та практичної реалізації оптимальних сценаріїв деструктивного впливу на компютерні мережі військових угруповань противника у військових операціях.

Тому, необхідно провести постановку задачі та розробити метод оптимізації розподілу ресурсу засобів радіоподавлення та деструктивного програмного впливу для розробки можливих сценаріїв порушення противником інформаційного обміну у типовій телекомунікаційній мережі.

Мета. Метою дослідження є розробка метода оптимізації розподілу ресурсу засобів радіоподавлення та деструктивного програмного впливу для розробки сценаріїв порушення противником інформаційного обміну у телекомунікаційній мережі.

Метод.Для досягнення мети дослідження комплексно застосовані та розвинені у галузь моделювання інформаційного протиборства методи нелінійної оптимізації розподілу різнорідного ресурсу, теорії масового обслуговування та експертного оцінювання.

Для визначення коефіцієнтів захищеності обєктів радіоелектронного та деструктивного компютерного впливу застосовані методи експертного оцінювання, зокрема, метод частот переваг особи, що приймає рішення із застосуванням методу Терстоуна. Цей метод вимагає лише одного експерта (особу, що приймає рішення), мінімального часу спілкування з ним, мінімальної експертної інформації (повного упорядкування вагових коефіцієнтів) та може застосовуватись при невеликій кількості оцінюваних вагових коефіцієнтів.

Для вирішення задачі оптимального розподілу різнорідного ресурсу засобів деструктивного впливу, для забезпечення значення мультиплікативної цільової функції довільного вигляду не менше заданого, застосований метод послідовних прирощень.

Для визначення показника оперативності порушення інформаційного обміну застосовані методи теорії масового обслуговування, що дозволяє формалізувати спеціальні телекомунікаційні системи, як сукупність системи масового обслуговування – підсистем цифрового звязку та компютерних мереж.

Результати. Здійснена постановка задачі та введені показники дозволили вирішити задачу визначення мінімального ресурсу засобів деструктивного впливу та оптимального розподілу їх по цілях радіоподавлення на обєктах деструктивного програмного впливу для досягнення потрібного рівня порушення оперативності інформаційного обміну у спеціальних телекомунікаційних системах.

Висновки. За результатами статтірозроблено метод оптимізації розподілу ресурсу засобів радіоподавлення та деструктивного програмного впливу для розробки можливих сценаріїв порушення противником інформаційного обміну у типовій телекомунікаційній мережі. Перевірку запропонованого методу здійснено шляхом порівняння теоретичних результатів з результатами імітаційного моделювання сценаріїв порушення противником інформаційного обміну у телекомунікаційній мережі.

КЛЮЧОВІ СЛОВА: інформаційний обмін, компютерна радіомережа, компютерна атака, захист інформації, радіоподавлення, оптимізація розподілу ресурсу, деструктивний вплив.

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