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THE MODEL OF OPTIMAL RADIOELECTRONIC STATIONS DEPLOYMENT IN THE MILITARY FIELD COMMUNICATION SITE

Abstract. There are two main problems during deployment of military field (mobile) communication site: 1) compact deployment radioelectronic stations (RESs) in communication site, 2) take into account of electromagnetic compatibility for normal processing of communication site that electric-field strength should be not exceed allowable standard. The necessity of packaged deployment is important especially for combat activities in mountains regions. In this case, hills and elevations can make worse a radio communication. Therefore, RESs should be deployed such that there are not natural obstacles between them. In given paper, there has been analysis of electric field superposition impact of all RES on each separate one for given radiation frequency range. The mathematical model of RES deployment with minimal distance between them with taking into account allowable standard of electric-field strength has been developed and offered. The program algorithm of calculation of RES deployment in the field communication site has been developed.

Keywords: field communication site, electric field, mathematical model, penalty method, packaged deployment, electromagnetic compatibility.

Introduction

During deployment of military field (mobile) communication site, it should be take into account of two main factors:

- 1) compact deployment radioelectronic stations (RES) in communication site,
- 2) electromagnetic compatibility (EMC) for normal processing of communication site when the minimum distance between RESs is calculated.

The necessity of packaged deployment is important especially for combat activities in mountains regions. In this case, hills and elevations can make worse a radio communication. Therefore, RESs should be deployed such that there are not natural obstacles between them [1, 2].

The requisite of the minimum distance between RESs is conditioned that electromagnetic radiation of the antennas of close located RESs can form a high frequency electromotive force with amplitude of the several ten of Volts in radio receiver antenna. It creates an overload of input stages and a disturbance in RESs. The jointly influence of several signals, which form intermodulation interference in input stages of radio receivers and in output stages of radio transmitters, can be find themselves in communication operating frequency band and make worse receiving a desired signal. Therefore, the electric-field strength in RES location point does not exceed the allowable standard.

In given paper, there has been analysis of an electric fields superposition influence of all RESs to each separate one for given radiation frequency range. The mathematical model of the RESs deployment in a field communication site with minimum distance between theirs taking into account of allowable standard of electric field influence has been developed and offered. The program algorithm of RESs deployment in the field communication site has been developed.

Analysis of RESs EMS in the field communication site

Let us use the group evaluation for analysis of RESs EMS in the field communication site [3]. When the EMS group evaluation there has been taken into account of all RESs interference on one RES inside the communication site.

When EMS evaluating, the determined description of electromagnetic condition (take into account of RES power) is used often, because power of interference sources, deployment and orientation of antennas in the site are strictly fixed [3, 4].

The calculation of RES EMS is carried out by the next order:

- calculation of energy characteristics (electric-field strength) of unpremeditated radio interference;
- determination of the level of electromagnetic compatibility providing.

The calculation of energy characteristics of radio interference stipulates determination of the power of combined radio interference reduced input of radio receiver of RES taking into account of radio interference penetration through an antenna-feeder device.

When EMS group evaluation, the total $P_{i\Sigma}$ power of joint radio interference (including intermodulation interference) reduced input i radio receiver of RES from all other RES radio transmitters is calculated.

The determination of the level of RES EMS providing is carried out based on group evaluation of EMS.

The group evaluation of RES EMS is carried out by the next order:

- a) the total $P_{i\Sigma}$ power of radio interference reduced i input of RES receiver is determined;
- b) the permissible level of $P_{i\delta}$ power of radio interference reduced i input of evaluated RES is determined;
- c) the level of total power of radio interference is compared with the permissible level, and the level of

providing of the radio receiver EMS of evaluated RES is determined with other radio transmitters of RESs.

The providing index ([dB] or [W/Hz]) of EMS of the object RES is calculated by formula of

$$\Delta P_{i\Sigma} = P_{i\phi} - P_{i\Sigma},$$

when the group evaluating. This value describes a level of the EMS providing reserve (if it is positive) or a level of the EMS providing lack (if it is negative).

The mathematical model of RES deployment in the field communication site

Let us consider a filed communication site where, for example, RESs works in frequency range of 2÷8 MHz, 30÷90 MHz and 4.4÷5 MHz. The calculation of electric-field strength in the high frequency range can be carried out for wave zone (radiation zone) when

$$d > \frac{2L^2}{\lambda},$$

where d is a distance between an antenna and a measurement point, L is the maximum size of an antenna, λ is a wave length.

The calculation of electric-field strength in radiation zone is carried out usually for electric component of field by Shuleykin-Van-der-Pole formula [5]:

$$E = 245 \frac{F \sqrt{P \cdot Ga}}{d} \left[\frac{mV}{m} \right], \quad (1)$$

where E is electric-field strength, P is a power of transmitter, Ga is an antenna power gain, F is the propagation factor for electromagnetic energy loss in soil:

$$F = 1.41 \frac{2 + 0.3x}{2 + x + 0.6x^2},$$

In the short wave range when there is $60 \lambda > \varepsilon$ condition, x is determined by the next formula:

$$x = \frac{\pi \cdot d}{\lambda \sqrt{\varepsilon^2 + (60 \cdot \lambda \cdot \sigma)^2}},$$

where λ is a length of wave in m , ε is the relative dielectric constant, σ – is a radio wave conductivity in soil (see table 1).

Table 1

Kind of soil	ε	$\sigma, (\text{Ohm}\cdot\text{m})^{-1}$
Humid soil, plane surface	5 - 15	$3 \cdot 10^{-3}$
Humid soil with low green	4	10^{-2}
Dry soil, sand	2 - 10	10^{-3}
Soil covered by large unbroken forest	4	10^{-3}
Cities	3 - 5	$7,5 \cdot 10^{-4}$

For example, if the length of wave $\lambda = 30$, soil is dry, that is, $\varepsilon = 10$ and $\sigma = 10^{-3} (\text{Ohm}\cdot\text{m})^{-1}$, $d < 1000$ m, then

$$F = 1.41 \frac{2 + 0.003x}{2 + 0.01d + 0.6 \cdot 10^{-4} d^2}, \quad (2)$$

Let us substitute (2) into (1), then the electric-field strength is calculated for d distance from RES.

This method of determination of electric-field strength by formulas (1) and (2) is applied for a circle radiation pattern and towards of maximum radiation of main beam.

Thus, if the field communication site with S area is considered and if there are N number of RES with P_i power radiation on this site, then the total level of electric-field strength in the i point of located RES is obtained

$$E_i = \sqrt{\sum_{j \neq i} E_j^2} = \sqrt{245^2 \sum_{j \neq i} \frac{50 \cdot F_j^2 \cdot p_j}{d_{ji}^2}},$$

where $i = j = N$; E_j is an electric-field strength in radiation zone of i RES (1);

d_{ji} is a distance between j radiated RES and i point; F_j is determined for each d_{ji} ($d_{ji} = d_{ij}$).

For providing of electromagnetic compatibility condition, it is necessary that

$$E_i < PL_i,$$

where PL_i is the allowable standard of electric-field strength for given set.

Formulation of the problem. First of all, let us remember that in accordance with [5], the electric-field strength E at r distance can be calculated by next formula

$$E = \frac{W}{r},$$

where W is some constant described a RES power and

$$W = 0.008 \cdot F \cdot \sqrt{P \cdot Ga}.$$

If the sources of electromagnetic radiation create in given point electric field with E_i strength then the total electric-field strength in considered point is calculated by next formula [2]

$$E = \sqrt{\sum_{i=0}^N E_i^2},$$

It is necessary to determine such mutual RES deployment on the horizontal site that two conditions are satisfied:

1) the total electric-field strength in the point of each RES created other RESs doesn't exceed some allowable standard;

2) all RESs are deployed in the bounds of circle with the minimum radius.

Mathematical formalization. For analytical calculation of the mutual RES deployment, let us enter some Oxy Cartesian coordinate system.

Any RES deployment can be connected with coordinate system with any way. The located on the bond of circle with "the shortest radius" RESs are border's ones.

It is clear that:

– there are at least two RESs on the border;
 – the considered two variants of mutual RES deployment are identical if they will coincident after application of the operations combination “rotation around of some point”, “parallel translation” and “symmetrical transformation relative to the some axis”.

So, as appropriate, making these conversions the center of the least circle is put in the origin of coordinates, and one of the border RES is put on the positive semiaxis Ox . Let us take (x_i, y_i) coordinates of A_i ($i = 1, 2, \dots, N$, N is a number of RESs) RES location in the Oxy coordinate system.

The demand of all RESs deployment in the range of some circle with a center in the origin of coordinates can be formulated in the following way as an inequality

$$x_i^2 + y_i^2 \leq r^2, \quad i = 1, 2, \dots, N, \quad (3)$$

where r is a required radius of a circle.

Let us considered that one of the RES, for example with number of $i = 1$, is located on the circle (3) and has $(r, 0)$ coordinates, that is,

$$x_1 = r, \quad y_1 = 0. \quad (4)$$

By the task data, the sources of electromagnetic radiation must be deployed in that way that the part of each RES affect other one is minimum as far as possible.

This demand can be satisfied if the most power RES will placed on the edge of range. Therefore, placed in $A_1(x_1, y_1)$ point the RES has most power W_1 . All RESs form electric field E_j in the $A_j(x_j, y_j)$ point

$$E_j^2 = \sum_{i \neq j} \left(\frac{W_i}{r_{ij}} \right)^2, \quad j = 1, 2, \dots, N,$$

where W_i is power of RES _{i} ,

$$r_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$$

is Euclidean distance between RES _{i} and RES _{j} .

Let us take E^* as the maximum permissible level of electric field strength in each RES point.

Then, there are normal operation conditions for RESs placed in A_j point

$$E_j \leq E^*, \quad j = 1, 2, \dots, N. \quad (5)$$

The task of optimal deployment of RESs can be formulated by next:

– to determine such x_i and y_i that for given W_i and E^* there are (3)-(5) conditions, and at the same time r is the least among possible ranges.

The solution of task. Firstly, let us rewrite (3)-(5) task as a task of conditional minimization relative to $x_1, x_2, \dots, x_N, y_1, y_2, \dots, y_N$ variables:

$$F(x_1, x_2, y_2, \dots, x_N, y_N) \equiv x_1^2 \rightarrow \min,$$

$$x_j^2 + y_j^2 - x_1^2 \leq 0, \quad j = 1, 2, \dots, N$$

$$\sum_{i \neq j} \frac{W_i^2}{(x_i - x_j)^2 + (y_i - y_j)^2} - (E^*)^2 \leq 0, \quad j = 1, 2, \dots, N, y_1 = 0$$

Let us use the penalty function method [6, c.214-216] for solution this task.

Let us take it as:

$$\mathfrak{R}_k(x_1, x_2, y_2, \dots, x_N, y_N) \equiv F(x_1, \dots, y_N) + \lambda_k \sum_{j=1}^N \max^2 \{0, g_j(x_1, x_2, y_2, \dots, x_N, y_N)\} + \quad (6)$$

$$+ K_k \sum_{j=1}^N \max^2 \{0, G_j(x_1, x_2, y_2, \dots, x_N, y_N)\},$$

$$g_j(x_1, x_2, y_2, \dots, x_N, y_N) \equiv x_j^2 + y_j^2 - x_1^2, \quad (7)$$

$$j = 1, 2, \dots, N;$$

$$G_j(x_1, x_2, y_2, \dots, x_N, y_N) \equiv \sum_{i \neq j} \frac{W_i^2}{(x_i - x_j)^2 + (y_i - y_j)^2} - (E^*)^2, \quad (8)$$

$$j = 1, 2, \dots, N,$$

λ_k and K_k are penalty parameters.

Given reasonable selection of initial data, the (6)-(8) solution sequence is converged to some “rational” solution in the case of $\lambda_k, K_k \rightarrow \infty$.

It should be noted that from the point of mathematical view the given task solution is not single. In order to prove this statement, let us construct a solution of the task of four given power RESs deployment for two variants.

There are power values of RESs deployed along circle with $r = 200$ m radius in table 2.

Table 2

Variants	N	1	2	3	4
	Power of RES, W	168.5	187.9	19.3	122.9
I	Location point (x, y)	(200.00, 0.00)	(100.00, 173.21)	(-200.00, 0.00)	(-128.56, 153.21)
	Formed in location point of RES electric-field strength E , mV/m	1.00	1.00	1.00	0.90
II	Location point (x, y)	(200.00, 0.00)	(100.00, 173.21)	(-200.00, 0.00)	(-128.56, -153.21)
	Formed in location point of RES electric-field strength E , mV/m	1.00	0.81	1.00	0.45

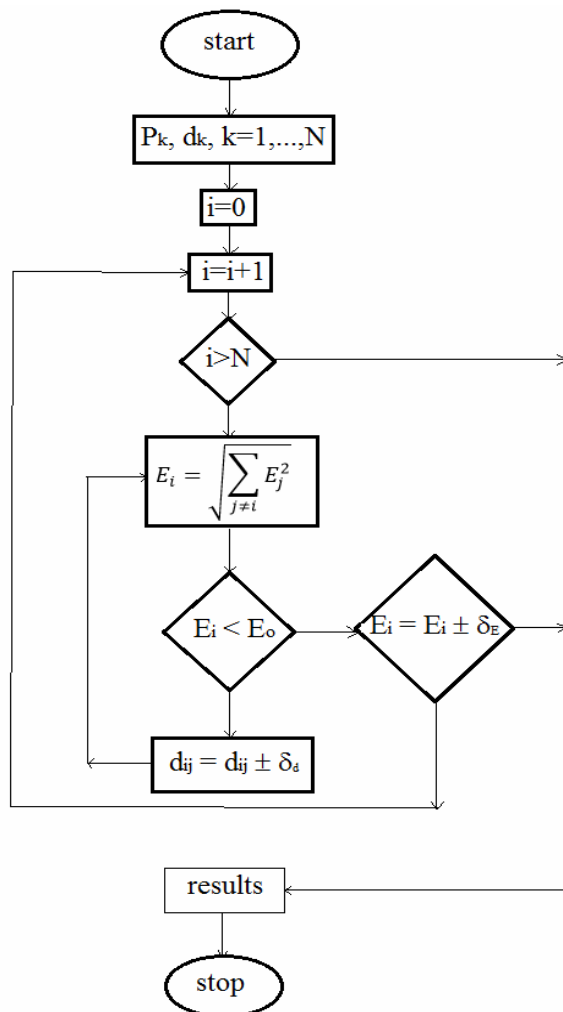


Fig. 1. The block chart of the program calculation algorithm of RESs deployment in a field communication site

Mathematical model of the optimal placement calculation of military field communication site. Сьома міжнародна науково-технічна конференція "Проблеми інформатизації". Черкаси–Харків, 13-15 November 2019. vol.1, p.79.

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Модель завершення оптимальних радіоелектронних станцій в сайті зв'язку військового поля

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Анотація. Під час розгортання військово-польового (мобільного) вузла зв'язку є дві основні проблеми: 1) компактні радіоелектронні станції (ВДЕ) компактної дислокації на вузлі зв'язку; 2) врахування електромагнітної сумісності для нормальної обробки вузла зв'язку, що напружує електричне поле не повинна перевищувати допустимого стандарту. Необхідність пакетованого розміщення важлива особливо для бойових дій у гірських районах. У цьому випадку пагорби та височини можуть погіршити радіозв'язок. Тому ВДЕ слід розгорнути таким чином, щоб між ними не було природних перешкод. У даній роботі проаналізовано вплив впливу всіх ВДЕ електричного поля на кожний окремих для заданого діапазону частот випромінювання. Розроблено та запропоновано математичну модель розгортання ВДЕ з мінімальною відстані між ними з урахуванням допустимого стандарту напруженості електричного поля. Розроблено програмний алгоритм розрахунку розміщення ВДЕ на польовому сайті зв'язку.

Ключові слова: польовий майданчик зв'язку, електричне поле, математична модель, метод штрафних санкцій, пакетне розгортання, електромагнітна сумісність