Optimizing Methods in Military Radio-Networks Planning and Management

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ABSTRACT

The paper presents application of optimisation methods in planning and resource management for military wireless networks. Basic stages of planning and resources management in military wireless systems are presented. The optimal radio resource allocation problem is formulated as well as the optimal resources management for traffic service with the changed quality of service is described. Chosen simulation results are also presented here.

1.0 INTRODUCTION

The military radio-networks have gained increased interest over the last years. The next-generation radio-networks will be converged platform to broadband wireless access. The broadband radio-networks especially wireless mobile access objectives are to:

- provide a technological response to accelerated growth in the demand for broadband radio-networks connectivity,

- provide a wide range of telecommunications services all performed by fixed networks and special services of mobile communications via handheld, portable, vehicle-mounted, movable and fixed terminals in the different radio environments,

- ensure seamless services provisioning across the multitude of wireless networks with the optimum delivery of user's demands and Quality of Service (QoS),

- open new spectrum frontiers and creating new market opportunities.

Next generation radio-networks will be characterized by horizontal communications between different access technologies such as cellular, cordless, WLAN, short-range connectivity, broadcasting systems, and wired networks. Multimedia applications, especially in real-time communications, become important services in military radio-networks. These applications usually should be transmitted by continuous media with QoS guaranteed metrics (loss, delay, jitter, errors etc.). Regardless, which multiple standard will be widely deployed, packet switching will be common used for delay-tolerant as well as delay-nontolerant applications.

Taking into account the ability to tolerate the delay, most of services, provided by radio-networks, can be divided into four different QoS classes:

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- conversational – for voice traffic,
- streaming – for audio and video traffic,
- interactive – for database read types of traffic,
- background – for best effort traffic.

To provide the guarantee QoS for above mentioned classes, optimal usage of the soft capacity of radio-network is a very important problem. Therefore, to provide QoS guarantee and avoid processing and communications overheads, an efficient resource management is needed. Radio resource management (RRM) and QoS are strictly related to each other.

The RRM algorithms should maximize the number of satisfied users within the available radio bandwidth. A user is satisfied if its session quality is above the acceptable level for an insignificant amount of time. The most often used QoS measures are the blocking probability and outage probability caused by significant increase of interference level in the service area. We can denote outage probability as $P_{out}(t) = \Pr[\rho(t) < \mu_{th}]$ where $\rho = E_b / N_0$. So, this is probability of bad quality during the session.

The radio resources allocation (RRA) becomes one of the main questions of military radio-networks systems planning and management. The mobility of military users, specific conditions of electromagnetic waves propagation, heterogeneous phenomena of multimedia traffic and disadvantages grid create significantly difficult environment for developing of effective radio resources management procedures, especially channel assignment, power control as well as data traffic control.

2.0 CHARACTERISTIC OF MILITARY RADIO-NETWORK ENVIROMENT

Following elements make up a set of radio resources: space, power, frequency and time. These elements determine two global criteria that are widely used to characterise the efficiency of radio-network systems i.e.: area coverage coefficient and required QoS. The first one characterises system's ability to provide services to mobile users regardless their location within an operational area. In our case, QoS is defined as a percentage of time when signal-to-noise ratio (SNR) or signal-to-interference ratio (SIR) exceed the assumed threshold value. This allows for selection of radio-resource allocation procedures. An adequate criteria should also be used for evaluation of signal detection in interference as well as noise presence. Maximal permissible value of bit-error-rate BERmax is a measure mostly used in digital systems.

Radio-network topology is represented by ordered spectral-spatial structure. In a large spatial systems, the same channel can be reused at the appropriate distance. In this case, the interference environment of the cell i is defined by surrounding cells disturbing the receivers in this cell. In multi-access systems, the interference environment is limited to these cells where the same channels are used at the same time. In CDMA systems for example, each transceiver should be considered as potential source of interference because the same frequency band can be used in whole network.

In practice, the size of service area varies and it depends on the value of transferred traffic. The expected users demands are usually analysed for services in various terrestrial regions like urban, rural, routes, etc. in order to evaluate the cell densities and to define the number of frequencies in each cell as well the cells size.

For radio-networks with various traffic the following two mutually exclusive requirements should be considered:

- the number of access points should not be limited to achieve good coverage and required spatial redundancy of wireless system in deployment area,

- the number of access points should be minimized to reduce interferences and cost of the whole system.

Therefore, the initial access points locations are generated randomly within the deployment area with cells radiuses which correspond with spatial distribution of expected traffic.

In our methodology, some significant differences between commercial and military radio-networks are taken into consideration. In general, users of military systems require wireless access only within the limited area where military forces will be deployed. Moreover, coverage redundancy in some selected areas is often required in order to meet specific requirements resulting from terrain configuration and its morphology, electronic warfare (EW) strategy, system's mobility, etc. In some cases, especially if the number of wireless access stations is relatively small, system engineer can define their precise locations but in general case it occurs more effective to generate initial location of all station within selected area, according to users demands and then to optimise the solution. The necessity of coexistence of many radio networks based on different modulation methods like spread spectrum FH, DS and different multiple access schemes like TDMA, CDMA, within limited area of military forces deployment, creates specific demands to fulfillment electromagnetic compatibility criteria.

3.0 RADIO RESOURCE MANAGEMENT OBJECTIVES

Maximal utilizing of system's radio resources shows RRM as an optimizing process. The optimization should be realized both during system planning and QoS management when system operates. For this reason, we use some system data, which include system characteristics especially system disposed resources as well as traffic parameters.

To characterize the objectives of radio resources management, we introduce the following indexes:

- N – number of access points in the system covering area $\boldsymbol{S}$,

- $\boldsymbol{S} = (S_1, S_2, \ldots, S_N)$ - set of cells areas,

- $\boldsymbol{M} = (M_1, M_2, \ldots, M_N)$ - set of number of users,

- $\boldsymbol{K} = (K_1, K_2, \ldots, K_N)$ - set of channels utilized in each cell,

- $\boldsymbol{P} = (P_1, P_2, \ldots, P_N)$ - set of power levels transmitted by each access point,

- $\boldsymbol{\Lambda} = (\Lambda_1, \Lambda_2, \ldots, \Lambda_N)$ – set of traffic intensity in the cells,

- $\boldsymbol{\Delta S} = (\Delta S_1, \Delta S_2, \ldots, \Delta S_N)$ – set of overlaps in area covering,

- $\boldsymbol{\iota} = (\iota_1, \iota_2, \ldots, \iota_N)$ – set of acceptable interference.

Effective RRM leads to optimal choice of resources parameters for demand QoS. In military radio-network system planning, radio resource optimisation corresponds with the optimisation of the set of access points and theirs localization. The estimation constrains and conditions are: QoS, area coverage and telecommunications infrastructure in dynamically changes of the radio environment.

During the radio-network operation, RRM algorithm performs the following tasks:

- assignment of one or more access points from set ***N***; call admission control (CAC) procedure decides if and where the new or handed over connection is accepted or rejected,

- assignment of one or more channels: codes for wideband CDMA (W-CDMA) and combination code-timeslot for time division CDMA (TD-CDMA) from set ***K***. Rate and time schedulers (RS and TS) can be used here as usual. The RS assigns a code appropriate for the connection, and the TS decides when these resources can be used,

- assignment of transmitting power for the access points and mobile stations from set ***P***. The power level is assigned adequately to the radio channel conditions and required connection quality,

- diiversity in resource management between several connections (traffic classes).

There are two basic classes of RRM algorithms: static and dynamic RRM. In dynamic RRM, resources are assigned adequately to the current traffic and transmission conditions. Dynamical estimation of radio resources is realized using several measures like interference level, radio channels characteristics, current load of access point, traffic characteristics, and quality of several services classes.

Analysis of military radio systems shows that transmitted power, transmission rates, correlation characteristics of codes, number of users and theirs activities are the most important factors limiting system capacity. The fast and accurate power control can compensate too large decreasing of SNR at the receiver input and keep it above the threshold level. However, in bad link conditions transmitter level can be much higher, causing increase of interference in other ongoing calls. To limit such phenomenon, two alternatives are proposed for mobile radio-networks:

- power and rate adaptation; in case of bad conditions, the transmission power is limited to $P_{\max}$ while transmission rate is reduced to meet needed QoS,

- truncated rate adaptation, in bad conditions, the data rate is adapted with a fixed transmission power $S < S_{\max}$ or transmission is suspended, causing transmission delay.

In the second method, the power gain is better as in the previous case, but the time delay can limit its this method usage only for delay tolerant services.

To assign the channels (codes or/and time slots), one of the below methods can be used:

- in centralized allocation, when one central unit (CU) manages a group of radio access points using two algorithms:

  - intra-group RRM algorithm,

  - interference matrix RRM algorithm,

- in decentralized management, the channels segregation algorithm is proposed.

Intra-group management is based on measurements of the radio path losses between radio access point and each mobile station. Next the gain matrix G is calculated.

This algorithm goes as follows:

- choose a free time slot randomly or by some heuristic method,

- from the gain matrix ***G*** estimate receiver signal-to-interference ratio (SIR) for all existing calls on that slot. The set of power levels ***P*** is chosen that enables satisfied E_b/N_0 for the new (or handed over) call in that time slot,

- if the set ***P*** is found, the time slot is assigned to these calls. If any power set satisfies assumed conditions, the next free time slot is temporarily assigned to the new call and repeat the process of ***G*** estimation.

This process is stopped, if no more time slots is to be checked.

Interference matrix algorithm uses the concept of zones covered by one or more radio access points. The time slot used in one zone can be excluded from usage in the other one MS that is located in the same zone or in neighboring ones.

The channel segregation algorithm in CU reduces the processing power demand in CU as well as avoids the particular planning of radio network. Due to the self-adaptive learning capability of this method, it is also avoids the knowledge of matrix ***G***. The slots are assigned in order using so called priority list of slots. This list is made and updated basing on the relationships between priority level and interference level estimated for this slot.

The next question in RRM is call admission control (CAC) to avoid the system overload. The CAC methods can use the following criteria:

- accept a new or handoff call if the total transmission power is smaller than a assumed threshold with some safety power margin,

- accept a new or handoff call if the transmission power per traffic channel is smaller than a assumed threshold.

The next question is such RRM that respects the connection QoS changes during mobile station movement. Here, the bandwidth reservation can provide better QoS on communications, but it is required the time to provide with calculation.

4.0 CHARACTERIZATION OF OPTIMIZATION METHODS

4.1 Classification of algorithms

All optimization methods used for radio resource management can be divided into six groups of algorithms:

- exact algorithms,
- sequential algorithms,
- heuristic algorithms,
- algorithms based on neuronal nets,
- genetic algorithms,
- typical algorithms of mathematical programming.

Each mentioned above algorithm groups may be applied to manage individual area of radio resources (frequency channels, time channels, code channels, power resources, area resources – number of access points). First of all, the following basic criteria decided on application range of given group methods are used:

- promptness of obtaining solution,
- minimization of error with respect to optimal solution,
- calculation complexity,

- calculation expenditures,
- complexity of practical realization,
- solution stability,
- minimization of input data.

Exact algorithms These algorithms require knowledge of all the acceptable solutions of the given problem. As optimal a solution given minimal (maximal) value of so called cost function is selected. These algorithms obtain guarantee optimal solution but they require a lot of calculation expenditures. These algorithms are preferred in planning of small local systems.

Sequence algorithms The ordered searching of all acceptable solutions is realized in these algorithms. It is realized by division of the range of the whole parameters values into some subsets. Next, the suboptimal solution is calculated for each subset. The calculation is finished if the cost function gives permissible error value. An example of such algorithm is the *Vertexes Reduction* algorithm (VR). These algorithms may be implemented into procedures of the channel allocation (frequencies, time, codes).

Heuristic algorithms These algorithms resemble the sequence methods of searching of optimal solution. In this case, the subset is stochastically chosen to analysis. The examples such algorithm are *Tabu Search* (TS) and S*imulated Allocation* (SA). They can be also used as procedures of the channel allocation (frequencies, time, codes) and planning access points location.

Algorithms based on neuronal nets. An essence of function of these optimizing methods will be presented on example of solution of channel allocation problem. The channel allocation procedure should optimise the global network interferences. In network of N access points, constraints are defined by the symmetrical interference matrix.

Genetic algorithms These optimization methods base on the genetic phenomena like natural selection of population, heredity, etc.

Typical algorithms of mathematical programming. The optimization algorithm *Complex* is an example of the non-linear mathematical programming method application for management of power resources. The *Complex* – Box's method can be used for optimisation of the power distribution of the access points. The emitted power optimisation procedure is equivalent to minimization of common area of cells.

4.2 Example using optimization methods

4.2.1 Channel allocation problem (CAP)

In the channel allocation problem (CAP), the basic aim is the minimisation of spectral needs and the inter-channel interference. We can meet three main types of constraints to avoid the interference between channels – CCC (Co-Channel Constraint), ACC (Adjacent-Channel Constraint) and CSC (Co-Site channel Constraint). So, the goal of channel allocation problem (CAP) is to find a channel assignment for every requested call with the minimum number of channel subject to the above three constraints.

The CAP includes methods of the channel management as well as methods of the channel selection. Thus generally, each CAP consists of two groups of issues. First group includes some optimising methods and algorithms that make possible formation of channel sets. The other one consists of some methods for management of sets of channels. Here, we can distinguish the following classes of channel management methods – Dynamic Channel Assignment (DCA), Fixed Channel Assignment (FCA) and Hybrid Channel Assignment. In FCA, the channel allocation is fixed for the entire set of operations (cells). In DCA, all channels are available in all cells. DCA methods are more effective for indoor traffic or for CDMA system than the FCA method but its implicitly assumes the existence of a central controller, that can in real-time assign the channels on demand, while maintaining sufficient reuse distance among co-channel access points.

In our works, we compared the *vertexes reduction* (VR) algorithm with the three (*tabu search* (TS), *simulated allocation* (SA), *maximum node degree* (MD)) general-purpose algorithms for channel assignment. All of them are based on the graph colouring techniques. In the simulation experiments we have used a regular model of cellular radio system. In this way, we could make assessment of system parameters influence on its efficiency and in consequence on the QoS of the military radio system model. In this passage, we want to notice that any analysed algorithm does not requires a regular model of cellular system.

Here, the blocking probability P_{bl} is a basic QoS measure. The Erlang B model has been used to model traffic density in military radio system. This model is based a model of serving without queuing. The value of blocking probability has been calculated on the basis of Erlang first formula i.e.:

$$P_{bl} = \frac{\frac{A^C}{C!}}{\sum_{k=0}^{C} \frac{A^k}{k!}} \tag{1}$$

where: A – offered load, C – number of channels per base station.

The occurrence interference in radio system causes limitation of accessible channel number. Thus the number of channels per base station differs from nominal value. It increases the medium value of blocking probability. The assessment of P_{bl} value has been curried out for different offered load value. Simulation research have been performed for $A = 10\,\text{erl}$ and $A = 15\,\text{erl}$. The medium blocking probability as a function of relative number η of assigned channels for each base station is presented in Figure 1.

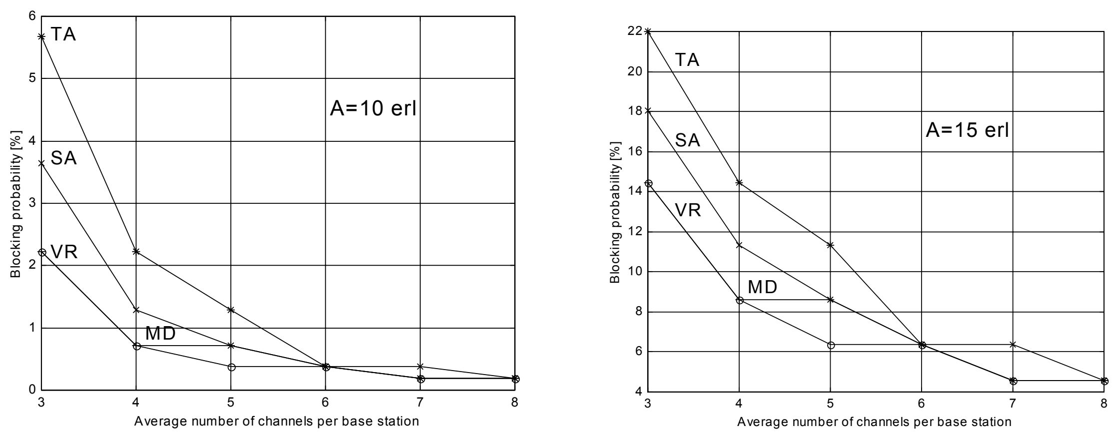

Figure 1 The medium blocking probability as an function of relative number of assigned channels for different values of the parameter *A* ($A = 10\,\text{erl}$, $A = 15\,\text{erl}$)

In the simulation experiments, the *vertexes reduction* algorithm produces much better solutions. Furthermore VR algorithm involves a smaller computational complexity. In particular case, when VR algorithm is used, the simulation experiments are obtained in very small computational time. This shows that the VR algorithm is appropriate for the military radio-network systems where the traffic demand of each cell varies at short intervals.

4.2.2 Codes segregation using neural network KSOFM algorithm

In CDMA, channels are created by using the specific code sequences. These sequences are used both for the spectrum spreading, access and for synchronisation. Here, a signal-to-noise ratio (*SNR*) is generally dependent on a number of users $\boldsymbol{N}$ and on correlation factors $\boldsymbol{r_{k,i}}$ between sequences used for transmission [6]. The output bit error rate (*BER*) is a measure of interference influence on transmission quality. *BER* value is usually estimated by standard Gaussian approximation and it can be used to evaluate receiver input $\boldsymbol{SNR_i}$ for radio resources allocation (RRA) procedures.

Here, the method based on the Hopfield neural network (HNN) with Kohonen self-organised future maps (KSOFM) is proposed for codes segregation [6].

Let N – number of base stations (BS) in network, $K(I)$- number of channels accessing in the interference environment of each BS, C- symmetrical interference matrix that size is NxN, $k_i(I)$- number of channels used by the i BS, L- traffic matrix. Minimising procedures can be formulated as:

$$k_i : s^* \in \boldsymbol{K} \rightarrow \underset{r\in \boldsymbol{K} \cup j \in N}{\forall} V_{i,s} = \min V_{j,r} \tag{2}$$

where: s* is the channel be assigned to call in cell i, $V_{i,s}$ is the cost of this channel assignment:

$$V_{i,s} = \sum_{r=1}^{K} \sum_{j=1}^{N} w_{j,r} \cdot c_{i,j} \cdot r_{s,r} \tag{3}$$

Here $w_{j,r}$ is the weight coefficient, $c_{i,j}$ – element of matrix C that is proportional to the interference level in i cell from j cell, $r_{s,r}$ – cross-correlation coefficient of two sequences s and r .

Figure 2 shows a structure of self-organized neural network with N inputs and R outputs, used in optimisation process. R is also a number of neurons (nodes). An element $w_{j,r}$ is the synaptic weight of connection of input x_i with neuron r.

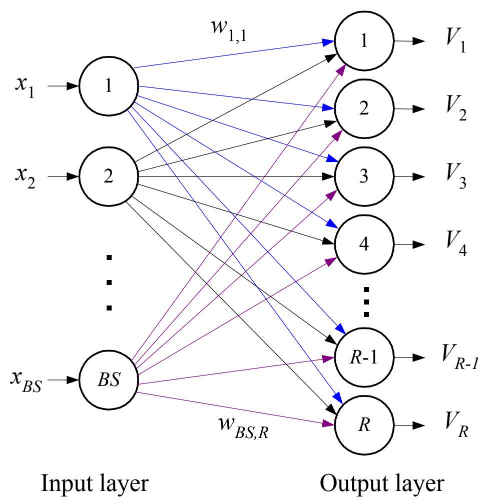

Figure 2. A structure of self-organised neural network

On the basis of above analyses, the simulation program was elaborated in C++. It enabled to evaluate the BER as a function of E_b/N_0 . The generators of M-, Gold, de'Bruin and Jennings as well as Walsh (Walsh-Hadamard) orthogonal sequences were implemented in this program.

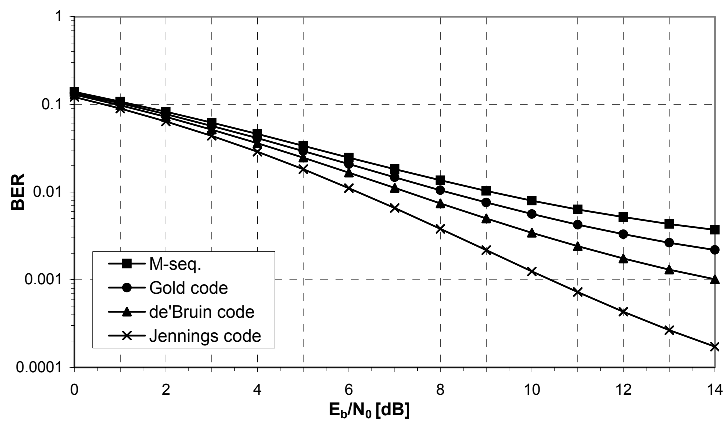

Figure 3. Simulation results for various codes, K=10, N=31

Figure 3 shows the simulation results for sequences length N=63 (64) and N=511(512) for K=10 users. Numbers in round brackets concern de'Bruin and Jennings sequences.

4.2.3 Access-nodes location using graph colouring algorithm

Projecting the spatial radio-access network, the initial location of BS can be found during optimisation procedure which is performed as long as the system coverage area achieves maximal value by the assumed constraint, e.g. assumed value of common area is covered by two cells ΔS_p^k. From the beginning, the very large list (set) L of possible sites of base stations is generated. The optimal selection of BS sites can be considered as coloured graph problem that was solved by using the method called the Maximal Independent Set (MIS). Base stations connections are generated according to the following procedure (Fig.4):

- each element of set L is considered as a node,
- area covered by BS is calculated using an appropriate propagation model for each node
- common area covered by each two neighbouring cells is estimated,
- an edge is created for two nodes for which the above calculated area exceeds the assumed value.

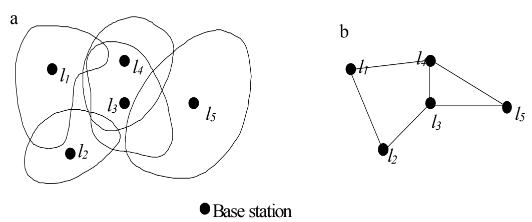

Figure 4. An example of graph creation

In the next step, the nodes are selected by iterative procedure which rejects these nodes that have the maximal value of connections in comparison with the other nodes. The vector W enabling nodes with minimal connections during each iterative loop is considered as the maximal independent set creating final optimal solution.

Figures 5 and 6 show intermediate and final results of MIS algorithm. The light points show the drown location of BS. To simplify, it is assumed that covered areas are defined by circles.

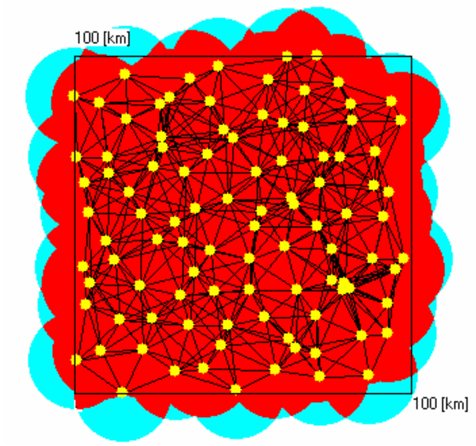

Figure 5. The intermediate result - an example of graph

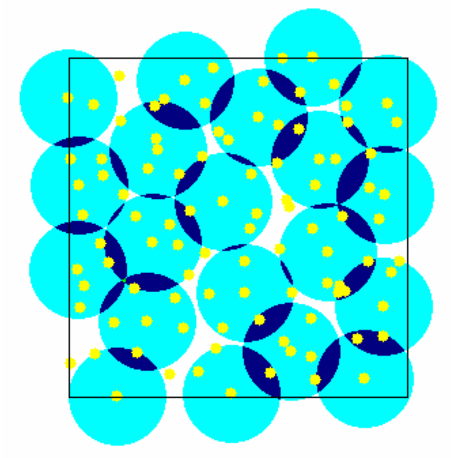

Figure 6. The final result - area coverage with chosen locations of access points

4.2.4 Access-nodes power distribution using Box's algorithm

The non-linear mathematical programming method of Box' Complex was used for optimisation of the power distribution of the radio-stations. The emitted power optimisation procedure is equivalent to minimisation of common area of cells. In order to limit the possible solutions, two additional constraints should be introduced, e.g. deployment area should be fully covered and intra-system electromagnetic compatibility criteria should be fulfilled (Fig.7).

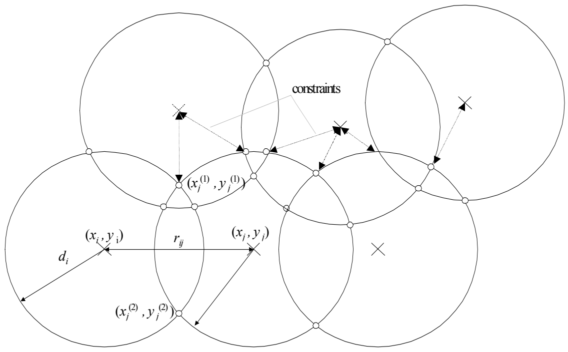

Figure 7. The constraints of global power optimisation procedure

This algorithm is realised in two main steps. In first step, nodes, that make up set of acceptable solution, are determined. Generation of co-ordinate individual nodes is described with following expression:

$$P_i = P_{\min} + \rho_i \left(P_{\max} - P_{\min}\right) \tag{5}$$

where: ρ_i – random numbers that are generated from range (0,1), P_i - power of i-th base station (i-th co-ordinate of individual nodes).

The essential number of vertexes that allows to realise optimisation process is equal $2N$. The complex is produced on the basis of generated point set. In this way we obtain the point set which meet all limitations of analysis optimisation problem. If one of points does not meet all limitations then we modify its location. To this end we determine new point that meets all limitations. This point arises on the basis of so-called centroid, which is created with points that fulfil all limitations. The centroid is described by following expression:

$$\boldsymbol{P}_c = \frac{1}{M} \sum_{\Omega} \boldsymbol{P}_\omega \tag{6}$$

where: M – number of all points that meet limitations, P_ω – the points (the vertexes of the complex) that meet all the limitations, Ω – the set of the point index.

Next we choose a location of new point that is halfway between the centroid and eliminated vertex. This procedure is repeated as long as all limitations will be met.

The second phase of optimisation is realised till optimal complex is obtained. In this step, we choose the vertex that gives the maximum value of the cost function. Then next centroid is determined. It is a basis of next complex of vertexes location. We repeat this procedure till met the criterion of stop.

Figure 8 shows results of this stage of optimization method.

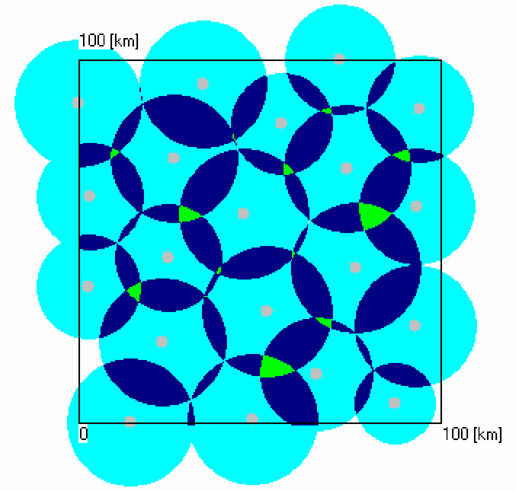

Figure 8. The final result of global power optimisation

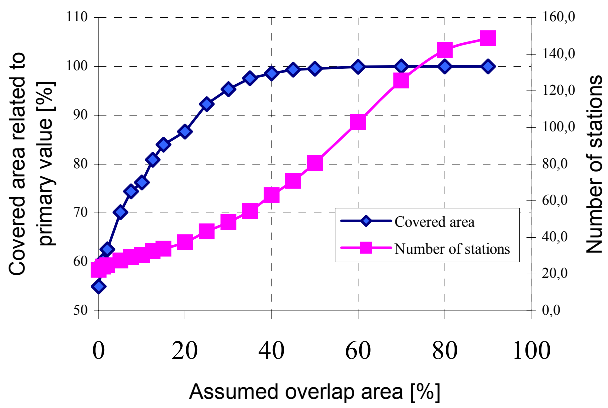

Figure 9. The coverage area and number of BS vs. areas overlapping

The percentage covered area and final number of stations versus δS common area assumed for radio-network system is shown in Figure 9. The best results were obtained for δS equals 30-40%. For δS>40%, the covered area increases insignificantly. It means that some redundancy in access points locations in final solution is achieved .

5.0 CONCLUSIONS

More and more common usage of commercial equipment and systems for military applications, of modern spread-spectrum technologies implementation, selection of new and higher frequency bands create the specific conditions for wireless systems engineering development. The necessity of fulfilling the requirements for coexistence of several wireless systems within the military forces deployment area calls for new and effective tools for military mobile system planning. The adequate models of wireless system engineering for military applications have to be developed and examined. It also requires a precise definition and estimation of effectiveness measures for particular models and procedures evaluation.

The methodology of wireless systems engineering presented in the paper as well as methods of network topology optimisation and radio resource management give the opportunity to solve the basic question of spectral-spatial optimisation of mobile systems for military applications. Already obtained results confirm the effectiveness of proposed procedures. This creates a good starting point for developing an effective computer tool for military wireless system optimisation.

Resources management requires taking all set of radio interface parameters into account. So, resources management for military radio-networks should be integrated and it should include all radio and network resources. Optimization methods assure an effective usage of radio resources in mobile military radio systems. The optimal methods should be used both on planning and on operational stages in range of QoS management. In military wireless systems, the specific solutions in RRM range should be elaborated taking the specific properties of future systems into consideration.

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