Using Meta-Heuristic Algorithms for Minimizing the Costs of Access-Point Location

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***Abstract* — Cost and quality are important issues in the network design. This paper presents an approach to wireless network cost optimization. The suggested model aims at determining optimal locations of access points which could provide service for receivers. The target service area would be determined by distribution of receivers and the access points would provide service coverage to serve prospective user-traffic demand in the selected area. Two created algorithms for location of access points are described and investigated with the designed experimentation system. It may be observed that using these algorithms in designing wireless network may result in reduced costs for telecommunication companies.**

Keywords -- cost optimization; wireless network; access point, heuristic algorithm; experimentation system.

I. INTRODUCTION

Nowadays the wireless network technology has a great impact on our life. It could carry broadband internet access to humans in the remote area network. We deal with wireless communication networks in the level of single user (PAN), local area (LAN), metropolitan area (MAN) and wide area network (WAN). In this paper, we focus on metropolitan area networks and consider the issue of optimal access point (AP) usage. The equivalent term for AP is transmitter. One of the most important parameters of the access point is its range of service. The range of an AP is related to its cost. Here, we assume that access points provide service with IEEE standards: 802.11a, 802.11b, and 802.11g. In this paper, the objective is to select and allocate the APs in a way to minimize the total cost of their distribution.

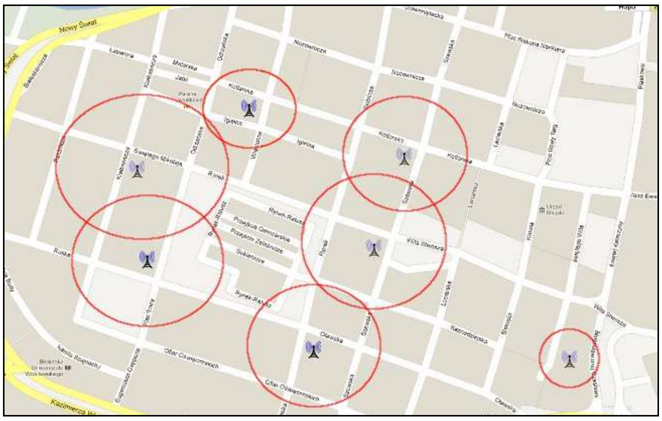

Figure 1. Example of access-points (APs) distribution.

Fig. 1 shows an example of the access point distribution that could provide network coverage inside the circles.

There are many related works in which the improvement of network design by taking into account costs of APs is discussed. Prommak and Wechtaison [1] proposed the WiMAX network design for the cost minimization and access data rate using mulit-hop relay stations. Regula and others [2] proposed algorithms for AP location, including the algorithm that uses term ‘center of mass’ and greedy approach. Kraimeche and Chang [3] suggested an approach for the optimization of a wireless access network based on a simple exhaustive search algorithm. Calegari and others [4] described optimisation algorithms for radio network planning, including a greedy algorithm and genetic approach. In this work, two meta-heuristic algorithms based on simulated annealing and genetic ideas are presented. The properties of these algorithms are tested with the designed and implemented experimentation system.

This paper is organized as follows. In Section II, we provide the formulation of the considered problem. The created meta-heuristic algorithms are presented in Section III. The experimentation system for testing these algorithms is described in Section IV. In Section V, the results of investigations made with this system are discussed. Section VI sums up the work and Section VII concerns further research in the area.

II. STATEMENT OF COST MINIMIZATION PROBLEM

The goal is to minimize the total cost of distribution access points over a given area. We express our objective function as:

$$Minimize\ \ f = min \sum_a z_a g_{ab} c_b \qquad (1)$$

where:

- a = 1, 2,…, A denotes a set of candidate APs locations,
- b = 1, 2,…, B denotes a set of APs types,
- c = 1, 2,…, C_b denotes a set of APs types’ costs (for each b an access point installation cost is defined),
- g_{ab} is binary variable; it is equal to 1, if AP is installed in location a and is of b type; it is 0, otherwise,
- z_a is also binary variable; it is equal to 1, if AP is installed in location a, it is 0, otherwise.
- t = 1, 2,…, T denotes a set of TP (receiver, test point), i.e., potential users of network facilities,

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- x_{at} is a binary variable, it is equal to 1 if TP is assigned to AP installed in location a; it is 0, otherwise
- $s = 1, 2,\ldots, S_b$ denotes a set of ranges for every b type of AP,
- $i = 1, 2,\ldots, I_a$ denotes a set of access point types assigned for each a,
- $m = 1, 2,\ldots, M_b$ denotes a set of maximum numbers of TPs possible to serve by b type AP.

Moreover, the following assumptions are taken into consideration: (*i*) the coverage of the AP is a circle (other propagation models are not considered here); (*ii*) the following constraints (2) – (7) have to be satisfied:

- The TP can be assigned only to an installed AP (i.e., $z_a = 1$) :

$$x_{at} \le z_a, \quad a = 1, 2,\ldots, A \quad t = 1, 2,\ldots,T \tag{2}$$

- It is a limit m_a for each a on maximum number of serving TP

$$\textstyle\sum_t x_{at} \le m_a, \quad a = 1, 2,\ldots, A \quad t = 1, 2,\ldots, T \tag{3}$$

- Each TP can be assigned to maximum one AP:

$$\textstyle\sum_a x_{at} \le 1, \quad a = 1, 2,\ldots, A \quad t = 1, 2,\ldots, T \tag{4}$$

$$x_{at} \le z_a, \quad a = 1, 2,\ldots, A \quad t = 1,2,\ldots, T \tag{5}$$

$$\textstyle\sum_a x_{at} \le 1, \; a = 1, 2,\ldots, A \quad t = 1, 2,\ldots, T \tag{6}$$

$$\textstyle\sum_t x_{at} \le m_a, \; a = 1, 2,\ldots, A. \tag{7}$$

III. META-HEURISTIC ALGORITHMS

Meta-heuristic approach is very often used in optimization. Formulation of the problem shows that we have to find the solution in huge discrete search-space. In this section, we present meta-heuristic algorithms to solve the problem. Firstly, we present basic procedures; next, we describe the way of adaptation of intelligent methods to creation of the algorithms.

A. Basic procedures

In the considered problem, the cost optimization is possible due to minimizing redundancy for transmitters' coverage. To achieve this goal we base on MIS (Maximum Independent Set) model used in [4]. The classical scheme for MIS extraction can be found in [5]. The concept of solving problem considered in this paper is lying in creating possible independent sets of receivers and then matching to them the cheapest possible transmitters. Firstly, for all receivers has to be created neighbourhood table (NT). NT consists of neighbourhood lists (NL). Each receiver has its own NL. Such list stores all neighbours of particular receiver. Neighbourhood is defined on the basis of largest range from set s. It means that for a given receiver all TP in distance less than S_{max} are its neighbours.

The procedure of creating complete neighbourhood table (CNT) for all receivers in t can be described as follows:

1. Find a largest range S_{max} in set s.
2. For each receiver from set t check whether distance between a given receiver T_t and the rest of TPs in set t is less than S_{max}.
3. If yes, add indices of these receivers to list of neighbours for a given receiver T_t.

The procedure of creating releasing neighbourhood table (RNT) can be described as follows:

1. Choose NL from NT for processing.
2. Match the cheapest transmitter that can support all receivers on the list.
3. Delete receivers from processed NL (do it for whole NT)
4. If NT is not empty go to step 1

As the result of this approach, an independent sets of receivers can be acquired. Next, AP is placed in the candidate AP location nearest the centre of set of receivers given in NL. Note that the chosen transmitters (APs) differ in dependence of order of processing the NL. The cost is a sum of installation costs c for types of AP selected in RNT.

The sequence of mentioned here procedures ends with calculated final cost and it is taken as a criterion function. In contrast to other AP distribution optimization methods, we do not take as a search space set of candidate AP locations but processing order for NL. And this sequence is a discrete search-space searched for the optimal solution in two implemented meta-heuristic algorithms.

B. Algorithm based on Simulated Annealing (SA)

The idea of simulated annealing method was used because of simplicity and efficiency [5]. In this method, as the criterion cost function the system energy is interpreted. The system state can be understood as the processing order of NL internal parameters of SA. In our implementation, internal parameters of SA were discovered experimentally. Entering perturbation (EP) is done in the following way:

1. Choose two random NL in NT
2. Reverse order between chosen NLs

The presented form of EP allows eliminating weakness of classic simple replacement of two chosen NL. Such classic replacement does not cause big change in search space.

C. Algorithm based on Genetic Algorithms

We applied the population-based model [6] that uses selection and recombination operators to generate new feasible solution. The roulette wheel selection is used to evaluate the fitness value associated with each individual (chromosome): the

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higher the fitness value of an individual, more likely it is to be selected. In our approach, chromosomes can be defined as processing order for neighbours' lists. Crossover is a combination of two chosen individuals and mutation is a random disturbance in this individual. The program execution stops when the predefined number of iteration steps has been run through [4]. Outline of the algorithm is presented as below.

1. Choosing random population of *n* chromosomes (feasible solutions for the problem).
2. Evaluate fitness (cost function computed) of each individual chromosome *x* in the population.
3. Repeat the steps below until the new population is created.
   3.1. Select pairs of chromosomes from a population according to their fitness ranking.
   3.2. According to crossover probability cross over pairs of chromosomes to form a new offspring.
   3.3. Apply mutation operation within a new offspring.
   3.4. Put new offspring in a new population.
4. Replace an old population by the new generated one.
5. Check whether the stop condition is satisfied. If yes, then stop. Return the best solution.
6. Go to step 2.

IV. EXPERIMENTATION SYSTEM

The model of the experimentation system is shown in Fig. 2. The idea of the system proposed in [7] was applied in order to allow testing properties of the created algorithms.

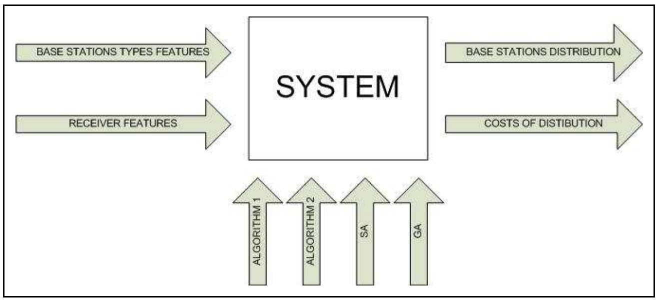

Figure 2. Experimentation system.

Input parameters of the system (simulator) are:
- AP types features
- Receivers features

Output parameters of the system (simulator) are:
- AP distribution
- Cost of distribution

The simulator was implemented in .NET C# in Visual Studio 2008 IDE. Simulator has graphical user interface (see Fig. 3), which allows choosing configuration options (design of experiment). Algorithms were tested under Microsoft Windows 64-bit OS, CPU of 1 GHz and 2 GB of RAM. Recently, the implemented simulator gives possibilities for observing effects of using four algorithms to finding location of APs (denoted as base stations in Fig. 2), including two created algorithms:
- Algorithm based on Simulated Annealing (SA),
- Algorithm based on Genetic Ideas (GA),

and two algorithms described in [2] [7] :
- Algorithm 1 (Alg. 1) - It is based on the physic's term – center of mass. The set of possible receivers is divided into the subsets. The subset's center of mass is considered as the location of the AP. Details are given in [7].
- Algorithm 2 (Alg. 2) - It is a greedy algorithm, which uses a particular graph model in order to implement adjacency matrix. This matrix is being checked in order to find the cheapest AP that supports receivers in nearby area [7].

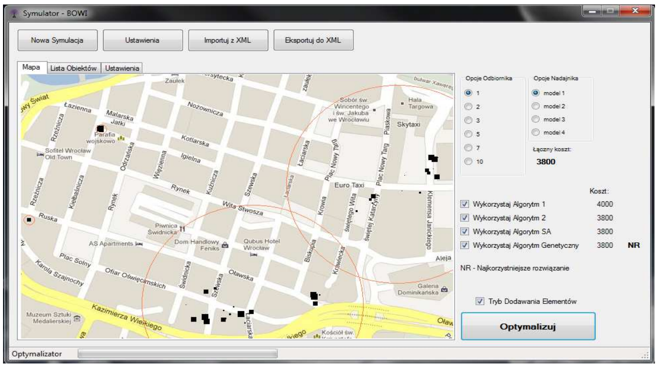

Figure 3. Simulator interface - working environment.

V. INVESTIGATIONS

The aim of the investigations was comparing efficiency of different methods for solving problem of location APs (access point's distribution) concerning minimization of the cost defined by (1) with assumptions expressed by (2) – (7).

Due to the fact that in real life receivers are distributed in many different ways, we provided differentiated benchmarks. To realize this task we created and implemented a module of experimentation system for generating different types of distribution. It allows testing algorithms in various conditions. Benchmark generator ensures 4 types of distribution. The user of experimentation system can set parameters such as the total number of receivers and the introduced distribution type:
- Regular – receivers are distributed regularly on the map, distances between points on the map are equal and in each point the total number of receivers is equal too;
- Regular with randomness – philosophy of this distribution is almost the same like in the regular distribution, but numbers of receivers differ – they are chosen at random;
- Irregular – locations of receivers are chosen randomly, but constraints arising from set parameters are held;
- Grouped – locations of receivers are grouped; groups are confined by surface of random circle shape.

A. Costs

For each series of experiments the total number of receivers was different – in range from 100 to 1000 with step 100. The obtained results are shown in Fig 4, Fig. 5, Fig. 6, and Fig. 7.

Experiment 1 – Regular distribution

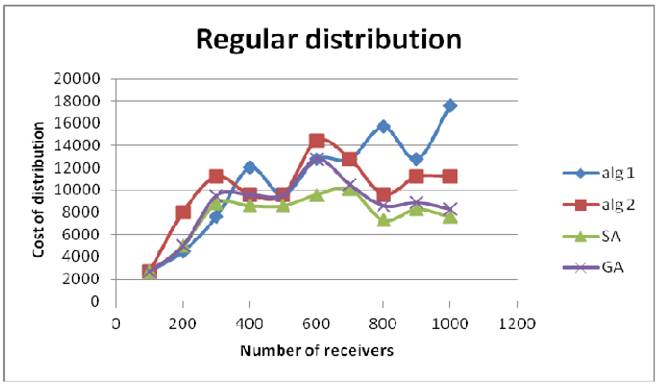

Figure 4. Regular distribution - cost in relation to the number of receivers.

Experiment 2 – Regular distribution with randomness

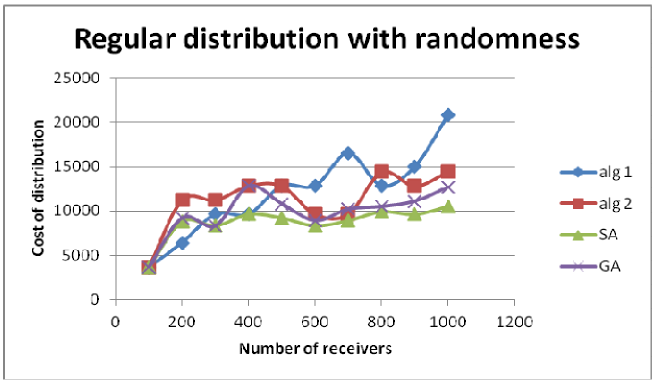

Figure 5. Regular distribution with randomness - cost in relation to the number of receivers.

Experiment 3 – Irregular distribution

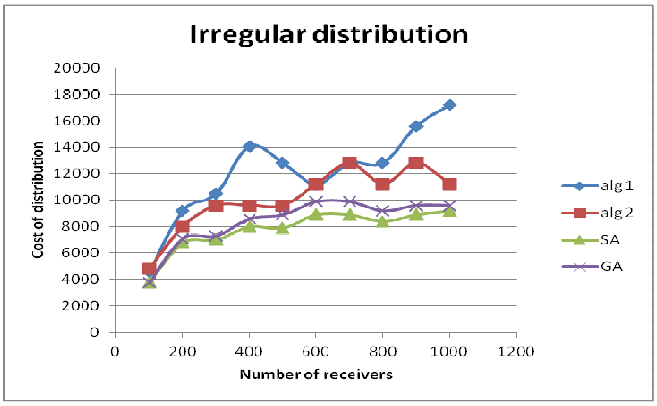

Figure 6. Irregular distribution - cost in relation to the number of receivers.

Experiment 4 - Grouped distribution

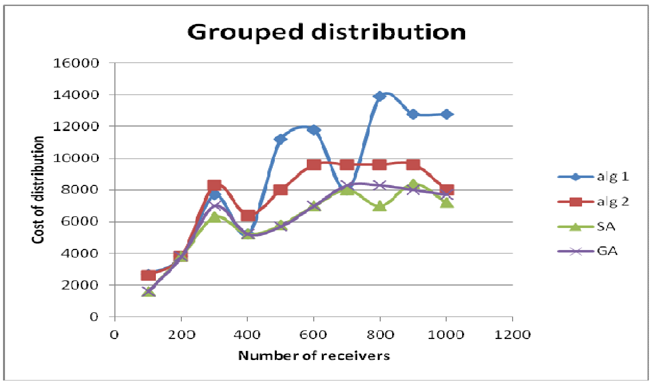

Figure 7. Grouped distribution - cost in relation to the number of receivers.

It may be observed that almost for every tested distribution type, the newly implemented algorithms decreased distribution cost. It is worth to be noticed that SA performed a little bit better than GA, especially in the case of irregular distribution – the most common distribution in the real world. Observing the shapes of graphs for SA and GA, one may conclude that they are quite similar to those 'produced' by Algorithm 2.

B. Execution time

The execution time for the both developed heuristic algorithms significantly increased in comparison with heuristic Algorithm 1 and Algorithm 2. The scale of this increase is visible in Fig. 8 and in Table I. Using meta-heuristic algorithms requires about 100 times longer execution time (in average). Notwithstanding to this fact, the execution time is still short – the longest was of about 1 sec. However, the obtained cost profits are worth this increment. One should remember that this paper deals with optimization of base station distribution cost – making decision about location of APs (distribution of base stations) is long-term designing process and it is worth to devote more computation time to obtain better solution to the considered problem.

Figure 8. Comparison of the averaged execution times for different distributions.

TABLE I. AVERAGE EXECUTION TIME

The averaged execution time [ms]					
		Alg 1	Alg 2	SA	GA
Distribution type	Regular	5.75	3.22	594.9	578.5
	Regular with randomness	6.85	5.61	369.0	580.2
	Irregular	10.37	10.60	460.3	490.6
	Grouped	12.17	13.58	617.2	473.3

C. Improvement

To show the obtained improvement while using the proposed approach (meta-heuristic algorithms), we present the results of comparison between algorithms.

Comparison to Algorithm 1. In comparison with Algorithm 1, the remarkable dependency between improvement and the number of receivers can be observed (see Fig. 9 and Fig. 10). This relationship can be expressed as follows: the larger number of receivers, the bigger improvement is obtained. It goes up to 60%. Such improvement can bring huge financial benefit.

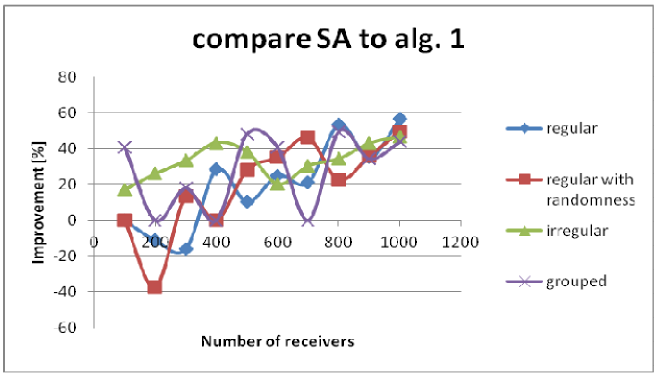

Figure 9. Improvement for SA and Alg. 1.

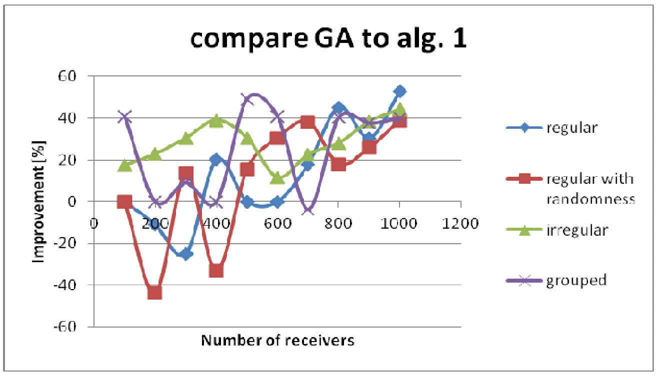

Figure 10. Improvement for GA and Alg.1.

Comparison to Algorithm 2. In comparison to Algorithm 2, such clearly relation like in comparison to Algorithm 1 is not visible (see Fig. 11 and Fig. 12). The improvement is unstable and does not depend on the number of receivers but in most of cases is positive and up to 40%.

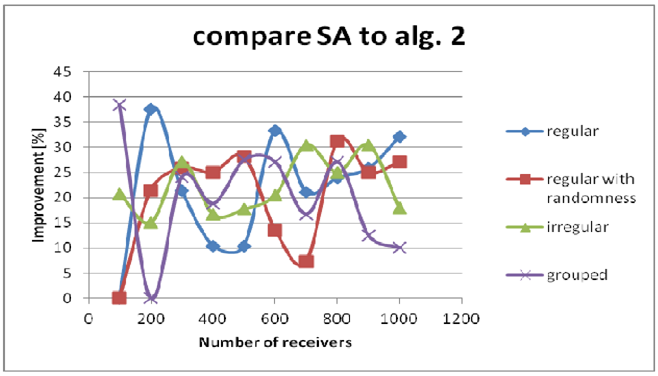

Figure 11. Improvement for SA and Alg. 2.

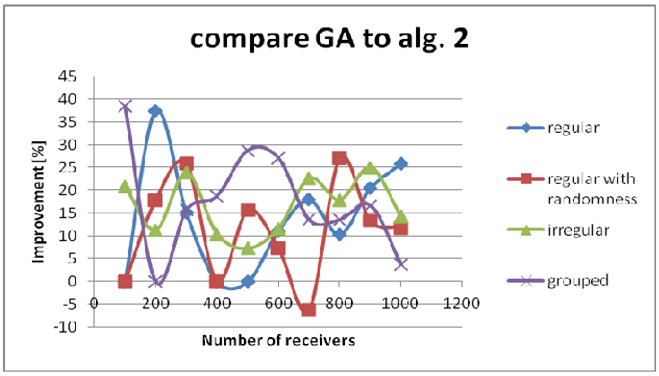

Figure 12. Improvement for GA and Alg. 2.

In Table II, the comparison of general (over all distribution types) improvements is presented. In columns, the created meta-heuristic algorithms applied to the problem and in rows, previously used Algorithm 1 and Algorithm 2, are specified. In the intersections, are improvement percentages between them, e.g., in the intersection between SA and Algorithm 1 is result 25%, it means that SA improved average distribution cost in comparison to Algorithm 1 by 25%.

TABLE II. COMPARISON BETWEEN THE IMPLEMENTED ALGORITHMS

	General average improvement of algorithms	
	SA	GA
Algorithm 1	25%	19%
Algorithm 2	21%	15%

Observing results shown in Table II, we may conclude that the average improvement may be estimated as around 20%.

VI. CONCLUSION

The aims of conducted investigations - presented in this paper - were achieved. We shown the advantage of the proposed approach – using of the created meta-heuristic algorithms ensured that the average improvement was of around 20%. It may be interpreted as a big advancement. The obtained results show that use of meta-heuristic algorithms in presented problem is profitable. Rising the execution time is the fact, but it can not be not acceptable when does not exceed 1 sec.

The weak points of investigation presented in this paper are lying in: taking into consideration a simple model and focusing only on cost optimization; algorithms were tested only on artificial generated benchmarks (basing on simulation experiments) – it would be more reliable to use real data.

VII. FUTURE WORK

The experimentation system can be developed in many ways as an incremental approach to aiding optimization of AP location problem. The system can be improved by including modules giving possibilities of aiding process of solving more complicated problem with propagation model applied [8] and quality indicators taken into consideration.

We believe also that results obtained by heuristics algorithms could be improved in some cases by two stage approach [9], including adjustment of internal parameters [10] of the meta-heuristic algorithms at the first stage. The efficiency of the Algorithm based on Simulated Annealing, largely depends on three internal parameters: cooling factor, start temperature and end temperature. The similar situation concerns the Algorithm based on Genetic Algorithm. Thus, we plan making more experiments with changing the number of iterations in which this algorithm creates new population and also more experiments which results could give hints how to match the size of chromosome's population. Finding optimal internal (input) parameters for both algorithms could be time-consuming; however, it may result in further minimization of the cost of the designed location of the base stations.

Moreover, some improvements in application are planned, e.g., the input map of simulator could be downloaded through Google Maps Api. It would improve the usability of graphical interface; maps would be created dynamically, either. It is also desirable to have such possibilities as saving all experimentation results in data base and generating charts in 'automatic way'.

The experimentation system with the simulator as a core is an aiding tool in teaching process at the Faculty of Electronics, Wroclaw University of Technology.

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