VOL. 12, NO. 3, FEBRUARY 2017 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

HYBRIDIZED FIREFLY ALGORITHM FOR MULTI-OBJECTIVE RADIO FREQUENCY IDENTIFICATION (RFID) NETWORK PLANNING

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ABSTRACT

The RFID network planning (RNP) problem belongs to the large-scale multi-objective hard optimization problems. RNP aims to optimize the overall read region based on a set of objectives. A novel approach of hybrid firefly algorithm was developed for multi-objective RNP problem. The technique was combining the Density Based Clustering method (DBSCAN) and firefly algorithm. Empirical tests were conducted on six standard RFID benchmark sets with random and clustered topologies. A comparative analysis performed with other state-of-the-art algorithms based on the same test data.Simulation results exhibited uniformly better performance in achieving maximum coverage with smaller number of deployed readers and less transmitted power.

Keywords: RFID networks planning, firefly algorithm, BDSCAN.

INTRODUCTION

Development in manufacturing technology has enabled radio frequency identification (RFID) applications in various fields such as automatic detection and supply chain management. RFID system transmits data by small electronic chip, called a tag, while the RFID reader collects the data from tagged items and transmits to the middleware in electromagnetic wave environment (Hasnan*et al.* 2015). The central optimal RFID network parameters include tag coverage, interference, economic efficiency and load balance. All these parameters are related to two origins, the topological tag distribution and the limited range of RFID reader (Hasnan*et al.* 2015) (Lu and Yu 2014). Several algorithms have been developed to optimize RFID network planning. Particle Swarm Optimization (PSO) algorithm was the well-known optimization technique due to fast operation speeds, ease of implementation and fewer parameters that require adjustment (Elewe et al. 2016). The latest development for PSO algorithm was Multi Colony – Global Particle Swarm Optimization (MC-GPSO) (Hasnan*et al.* 2015). The state of art optimization-based approach includes many other recently proposed methods such as firefly algorithm (Bacanin/a *et al.* 2015), ABC algorithm (Bacanin/b et al. 2015), and fireworks algorithm (Tuba et al. 2015). The simulation results of these methods demonstrate the more efficient optimal solution of RFID Network Planning (RNP).

This paper presents the development of clustering strategy based on RFID circular reader range to specify the number readers that can cover all the tags distributed at two-dimensional planes as a pre-process operation in order to improve the RFID network planning performance. The proposed method discretized the distributed tag area based on the ability of reader coverage and clusters the tag into groups based on the Density-Based Algorithm.

The suggested model in this method used the DBSCAN algorithm (Density Based Spatial Clustering of Applications with Noise) which is designed to discover the clusters in a spatial database (Bäcklund*et al.* 2011). This method was used to specify the appropriate number of required readers and enhanced the operation of the system. The DBSCAN method is combined with firefly algorithm (FA) as a pre-process step to solve the RNP issues by deploying minimum number of readers to cover all tags with minimum interference between readers and requires less transmitted power.

MATHEMATICAL FORMULATION

This section presents the mathematical definition of the RFID network-planning problem that was also used recently by Hasnan in 2015. The RFID system is a Radio communication between tags and readers and involves writing/reading information between them. To deploy RFID network, three important questions must be answered (Chen *et al.* 2011): how many readers are needed, what is the optimal location for the readers, and how should readers' parameters be adjusted. The answer to these questions can be detected from the set of equations that are concerned with the objective functions of RNP problems.

The first and one of the most important objectives employed in this model is optimal tag coverage (C) which enables the ability to detect and obtain the IDs of all of the deployed tags (Botero and Chaouchi 2011). It can be considered the sum of the difference between the actual power received by each tag to the required power and is formulated as:

$$C\min = \sum_{i=1}^{N_T} (P_{tagi} - P_{req}) \quad (1)$$

Ptagi = Actual received power at each tag
Preq = required threshold power
NT =Number of tags in working area

The Friis transmission equation power at each tag can be calculated by the following equation (Hasnan *et al.* 2015):

$$Pr = (Pt.Gt.Gr)/(4\pi \frac{d}{\lambda})^2 \quad (2)$$

where λ is wavelength (m), Pr is power input at receiving antenna, Pt is Power output at transmitting antenna, d is distance between tag and reader, Gt is transmitting antenna gain, Gr is receiving antenna gain. The tags located inside the reading area will normally be detected, but collisions will occur if any other reader interferes. As a result, many tags cannot be identified in the working area of the readers (Botero and Chaouchi, 2011). The problem of interference can be solved by separating the reader's interrogation ranges and varying the radiated power of readers (Hasnan*et a*l. 2015). Due to changing the positions of readers away from each other and variation of radiated power (Elloumi*et al.* 2014), the interference formulated as:

$$\text{int.} = \sum_{i=1}^{N-1} \sum_{(j=i+1)}^{N_{max}} [d_t(R_i, R_j) - (r_i + r_j)] \quad (3)$$

whereNmax represents the total reader's number, "dt" represents the distance between readers, Ri represents the position of ith reader, Rj represents the position of jth reader, ri represents the interrogation range of ith reader and rj represents the interrogation range of jth reader (Hasnan*et al.* 2015) .

The present solution observes a number of effective readers in the tag detection and some extra readers that must be discarded from the optimal solutions using the formula as;

$$N_{req} = N_{max} = N_{extra} \quad (4)$$

whereNreq is the number of required readers, Nmax is the number of available readers and Nextra is the number of extra readers. The set of present objective functions will be applied in the firefly algorithm to find the optimum level of network planning (Hasnan*et al.* 2015).

Standard firefly algorithm

Firefly algorithm, developed by Xin-She Yang in late 2007 and 2008 at Cambridge University (Yang and Algorithms 2008), is a type of swarm intelligence algorithm based on the reaction of a firefly to the light of other fireflies (Ali *et al.* 2014). Firefly algorithm was one of the evolutionary computing models for solving multimodal optimization problems that have nonlinear and multi-dimensional components (Prakash and Aravindhababu 2015). This algorithm appears to be an effective tool due to the high potential powerful in solving optimization problems. It also seems to be a favorable optimization tool in part due to the effect of the attractiveness function (Pal *et al.* 2012).

There are three idealized rules combined into the Firefly algorithm (FA) operation (Johari*et al.* 2013):

i) All fireflies are unisex so that a firefly is attracted to all other fireflies

ii) There is a proportional attractiveness of firefly's brightness. The attracted one is the brighter, and if the firefly could not detect the brighter one, it moves randomly.

iii) The objective function value is proportional with the brightness of a firefly.

Light intensity and attractiveness are the main variables in firefly algorithm. Attractiveness is dependent upon the light intensity; therefore, the light intensity follows the inverse square law as the following equation (Bacanin*et al.* 2015) (Ali *et al.* 2014):

$$I_{(r)} = \frac{I_O}{1 + \gamma r^2} \quad (5)$$

where I(r) represents the light intensity, r is distance, I0 represents the light intensity at the source and γ is considered the light absorption coefficient. The attractiveness β of a firefly is proportional to its brightness as the following equation (Bacanin*et al.* 2015):

$$\beta_{(r)} = \frac{\beta_o}{1 + \gamma r^2} \quad (6)$$

where β0 represents the attractiveness at r = 0.The process of search space mainly depends on attractiveness. The distance between two fireflies can be defined using Cartesian distance (Bacanin*et al.* 2015):

$$r_{i,j} = \|x_i - x_j\| = \sqrt{\sum_{k=1}^{F} (x_{i,k} - x_{j.k}} \quad (7)$$

where F is the number of problem parameters.

Firefly i is attracted toward the more attractive firefly j, and the movement is defined as

$$x_i(t) = x_i(t) + \beta_o r^{-\gamma r^2_{i,j}} (x_j - x_i) + \alpha(rand - 0.5) \quad (8)$$

where β0 is considered attractiveness at r = 0, α is randomization parameter, rand represents random number uniformly distributed between 0 and 1, ri;j is distance between fireflies i and j. The pseudo-code of firefly is available in (Bacanin*et al.* 2015):

Our implementation of the firefly algorithm FA in this paper is based on RFID objective function that is applied in the Network Planning. In order to improve the fire fly algorithm so that it can efficiently solve large-scale PNP network planning problems, the researchers created a hybrid with Density-Based Algorithm (DBSCAN) as presented in the next section.

Density-based algorithm

Density-Based Algorithm (DBSCAN) is a data clustering algorithm proposed by Ester in 1996. It is a method of quick logical division by grouping a set of

points in a space that are closely packed together (Bäcklund*et al.* 2011). In this research, the DBSCAN algorithm is used to break the tag distribution area into smaller parts in order to discretize them into several small typical density points making them a discrete problem. The aim of using this method is to classify the tags into groups to find out the primary number of required readers that are needed to cover the tags and the primary position of each reader. The idea of using this information as an input representation to the firefly algorithm is to reduce the iteration process and increase the accuracy of results, especially with the large-scale RNP problems.

DBSCAN can categorize the tags' information positions into separate clusters that lie close to each other based on the reader propagation range by computing process of four definitions creating two lemmas (Bäcklund*et al.* 2011).

Definition 1: (Eps-neighborhood)

The Epsneighborhood of a point Ṗs, is defined by the cluster region Nr that represent the space that is distinct from the total distributed tags area. The Epsneighborhood has the existing tags. Each tag has a position Ṗtag that lies in propagation range distance d. It also has a center point that represents the propagation source Ṗs that is radiated from the RFID reader.

$$NEps(\dot{P}s) = \{\dot{P}tag \in d \mid dist(\dot{P}s, \dot{P}tag) < dmax\} \quad (9)$$

Definition 2: (directly density-reachable)

Directly density-reachable is the tag point Ṗtag which can be reached from propagation source Ṗs.
where

$$\sum \dot{P}tag \in NEps(\dot{P}s) \quad (10)$$

The border points which belong to the Eps-neighborhood will be a part of the cluster. In Figure-1 is shown the reachable tags in the Prop-neighborhood domain.

Definition 3: (Density-reachable)

Density-reachable is the tag point Ṗtag that can be reached by propagation if there is a chain of points such as in Figure-1.

Definition 4: (cluster)

In the present use of DBSCAN algorithm based on RFID reader propagation, consider each cluster Ċ is density-reachable with maximum rank of Ṗtag from point Ṗs.

hence:∀Ṗtag ϵ C is density-reachable from Ṗs with respect to Eps-neighborhood.

The required information from the present processes are the number of groups that are clustered in the working area to represent the number of required readers and the center position Ṗs of each clustered group to represent the reader position. This information will be used in firefly algorithm as an input data to investigate the optimal reader position correlated with the required propagation of each tags group. The present processes observe two lemmas:

Lemma 1: A cluster can be formed from only one core point Ṗs based on the reader propagation range. It has a group of tags ranked based on the maximum density of clustered group. The shape always will be circular as shown in Figure-1.

Lemma 2: The clustered group in Epsneighborhood will not be considered as density-reachable to any other group.

Figure-1 illustrates the quality of DBSCAN algorithm results by C30 benchmark example, where it is obvious that the proposed algorithm finds good primary solution of required readers and primary position of each reader. The scenario of the working area was set as 50m × 50m for all cases. It is clear from the cluster operation that for the upper left group, the black DBSCAN parts propose the higher rank of tags coverage, followed by the red and green DBSCAN parts. For the lower right group, one search condition was enough to specify the reader position because of the wide range of Eps-neighborhood as shown in blue circle.

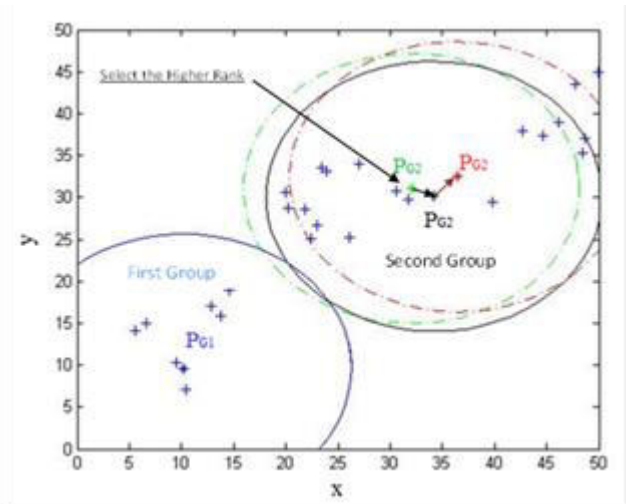

Figure-1. The cluster density-based region.

Hybridization procedure

Two different algorithms have been combined with the aim of enhancing the exploitation and exploration of the search domain to solve the multi-objective radio frequency identification (RFID) network planning problem efficiently. The solution process is to represent each firefly as a real vector with readers. The readers' positions are applied in the first two dimensions while the propagation range takes place the third dimension. The optimization technique is built based on changing the readers' positions to enhance the tag coverage, interference and transmitted power. The improvements of hybridization outcome can be denoted in terms of either computational speed or

accuracy (Ting *et al.* 2015). The present approach used a form of collaborative hybrid. This hybrid type has a two-sequence structure. The first algorithm is DBSCAN that acts as a pre-process to specify the primary "N" number of readers and initial position [xi, xj] for each reader, whereas the second algorithm firefly will apply the present "N" number of readers in "D" dimension based on initial position[xi, xj] in search space. At the initial stage, the switch on position represented by the availability of readers' number and position in the network carry out the objective functions. The operation will remain switched on until reaching the best position vectors that meets the best objective functions. The step by step operating procedure of hybrid firefly with DBSCAN algorithm is described as follows:

Step1: Specify the Eps-neighborhood domain by calculating the radiated power of reader (r) from equation (3).
Step2: Initialize number of readers "N" and position Ꝑs of each reader by applying the DBSCAN algorithm.
Step3: Transfer the DBSCAN algorithm results in FIREFLY algorithm.
Step4: Evaluate the fitness of each reader based on equations (3), (4) and (5).
Step5: Update the position of all readers. Re-evaluate the fitness of each reader. The independent value of position and velocity will be specify based on the best fitness.
Step6: If the fitness value achieved so far is the global best position, then stop operation.

EXPERIMENTAL RESULTS

The empirical tests were conducted by using six RNP instances: C30, C50, C100, R30, R50 and R100 with clustered and random topologies and 30, 50 and 100 tags, respectively, presented as a benchmark in URL: http://www.ai.sysu.edu.cn/GYJ/RFID/TII/. The same tests were performed in (Bacanin*et al.* 2015). All experiments were conducted with 50 independent runs with 10,000 iterations. Several factors of the RFID network planning (RNP) problem as well as specific parameters of each optimization technique were adjusted to improve the quality of the solutions. The specific values of these parameters are shown in Table-1.

Table-1. RFID parameters.

Parameters	Values
RFID Reader System Operating Frequency	UHF band: 915 MHz
RFID Reader adjustable Transmitting power range	[20; 33]Dbm 0.1 to 2 watts
Sensitivity thresholds of tags Tt	-14 dBm
Sensitivity thresholds of Readers are dBmTr	-80 dBm
RFID Reader Antenna Gain (Gr)	6.7 dBi
RFID Tag Antenna Gain (Gt)	3.7 dBi
Acceleration coefficients (c1 = c2)	2.0
Inertia weight (ω)	0.9 to 0.4
Wave length (λ)	0.328m

The present method (named DB-FA) results obtained through hybridization the DBSCAN and FA algorithms observe good solutions to the multi-objective optimization RNP problem. Comparative analysis results are shown in Table 2 and representative solutions are plotted in Figures 2-7. A comparative analysis was performed with two groups. The first group is PSO group including GPSO (traditional PSO with the global topology), VNPSO (traditional PSO with the von Neumann topology), and GPSO-RNP and VNPSO-RNP as corresponding algorithms with incorporated tentative reader elimination (TRE) and mutation (Gong *et al.* 2012). The second group is the state of art swarm intelligence methods including HFA (hierarchical Firefly algorithm), FWA (Fireworks Algorithm) and ABC (artificial bee colony algorithm hybridized with heuristic) (Bacanin/a *et al.* 2015) (Bacanin/b *et al.* 2015) (Tuba *et al.* 2015).

The plotted results shown in Figures 2-7 indicate that the RFID readers were distributed in order to cover all the tags denoted as blue plus sign "+". The coordinates of readers is shown as red star "∗", and their interrogation range as red dashed line circle. The observation in final network planning results shows that the algorithm was able to achieve full coverage of the network in all runs for the clustered topology benchmarks C30, C50 and C100. While it cannot provide full coverage in each run for random topology benchmarks R30, R50 and R100, it used a smaller number of readers and transmitted power in each run of random topologies benchmarks. The simulation results also show that while the present method was not able to completely eliminate interference in random topologies benchmarks, no other algorithm was able to do that. The proposed hybrid algorithm guided the search to a good solution with the use of less radiated power and readers as reported in Table 2 for large scale topologies benchmarks, which indicates that this method can be used successfully in large and complicated topologies RFID network planning.

VOL. 12, NO. 3, FEBRUARY 2017 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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Table-2. Experimental results.

	Algorithm	Mean				Best			
		Coverage	Reader N	Interfer.	Power	Coverage	Reader N	Interfer.	Power
benchmark C30	BD-FA	100.00 %	2	0.000	16.975	100.00 %	2	0.000	16.840
	FA	100.00 %	2	0.000	16.460	100.00 %	2	0.000	15.600
	FWA	100.00 %	2	0.000	16.806	100.00 %	2	0.000	15.881
	ABC	100.00 %	2	0.000	16.246	100.00 %	2	0.000	15.297
	GPSO	100.00 %	6	0.000	35.074	100.00 %	6	0.000	31.865
	VNPSO	100.00 %	6	0.000	34.762	100.00 %	6	0.000	31.951
	GPSO-RNP	100.00 %	3.18	0.000	35.511	100.00 %	3	0.000	33.948
	VNPSORNP	100.00 %	3.04	0.000	35.034	100.00 %	3	0.000	33.535
benchmark C50	BD-FA	100.00 %	4	0.000	24.423	100.00 %	4	0.000	18.760
	FA	100.00 %	4	0.000	27.191	100.00 %	4	0.000	20.871
	FWA	100.00 %	4	0.000	29.125	100.00 %	4	0.000	19.058
	ABC	100.00 %	4	0.000	26.246	100.00 %	4	0.000	23.800
	GPSO	95.60%	6	0.000	35.170	100.00 %	6	0.000	31.852
	VNPSO	99.20%	6	0.000	35.023	100.00 %	6	0.000	31.742
	GPSO-RNP	100.00 %	5.04	0.000	36.244	100.00 %	5	0.000	33.418
	VNPSORNP	100.00 %	5.06	0.000	36.565	100.00 %	5	0.000	34.522
benchmark C100	BD-FA	100.00 %	4	0.001	32.693	100.00 %	4	0.000	28.263
	FA	100.00 %	4	0.000	33.129	100.00 %	4	0.000	28.685
	FWA	100.00 %	4	0.000	33.676	100.00 %	4	0.000	29.563
	ABC	100.00 %	4	0.000	33.638	100.00 %	4	0.000	30.066
	GPSO	98.34%	6	0.002	38.652	100.00 %	6	0.000	37.374
	VNPSO	99.72%	6	0.000	38.167	100.00 %	6	0.000	36.803
	GPSO-RNP	100.00 %	5.16	0.000	38.800	100.00 %	5	0.000	37.513
	VNPSORNP	100.00 %	5.04	0.000	38.513	100.00 %	5	0.000	37.449
benchmark R30	BD-FA	96.70 %	4	0.000	37.331	96.70 %	4	0.000	31.581
	FA	100.00 %	5	0.000	39.841	100.00 %	5	0.000	33.894
	FWA	100.00 %	5	0.000	40.704	100.00 %	5	0.000	35.103
	ABC	100.00 %	5	0.000	37.475	100.00 %	5	0.000	32.747
	GPSO	92.13%	6	0.000	38.849	100.00 %	6	0.000	38.842
	VNPSO	94.53%	6	0.000	38.849	100.00 %	6	0.000	38.655
	GPSO-RNP	99.87%	7.46	0.002	39.821	100.00 %	6	0.000	39.265
	VNPSORNP	100.00 %	6.86	0.003	40.143	100.00 %	6	0.000	39.574
benchmark R50	BD-FA	96.00 %	4	0.004	37.548	96.00 %	4	0.001	35.081
	FA	100.00 %	5	0.004	43.285	100.00 %	5	0.000	37.097
	FWA	100.00 %	5	0.006	43.343	100.00 %	5	0.000	37.564
	ABC	100.00 %	5	0.006	41.273	100.00 %	5	0.000	39.017
	GPSO	92.52%	6	0.000	39.692	98.00 %	6	0.000	40.520
	VNPSO	93.96%	6	0.000	39.690	98.00 %	6	0.000	39.595
	GPSO-RNP	99.84%	8.26	0.012	40.652	100.00 %	7	0.000	40.315
	VNPSORNP	100.00 %	7.66	0.030	40.667	100.00 %	7	0.000	40.080
benchmark R100	BD-FA	98.00 %	4	0.006	38.492	98.00 %	4	0.001	36.181
	FA	100.00 %	5	0.016	44.987	100.00 %	5	0.006	42.249
	FWA	100.00 %	5	0.018	44.908	100.00 %	5	0.006	40.127
	ABC	100.00 %	5	0.015	44.721	100.00 %	5	0.006	40.011
	GPSO	91.18%	6	0.014	40.074	95.00 %	6	0.000	40.098
	VNPSO	94.14%	6	0.012	40.333	97.00 %	6	0.043	40.657
	GPSO-RNP	99.74%	9.24	0.118	41.505	100.00 %	8	0.000	40.925
	VNPSORNP	100.00 %	8.44	0.242	41.462	100.00 %	8	0.000	41.031

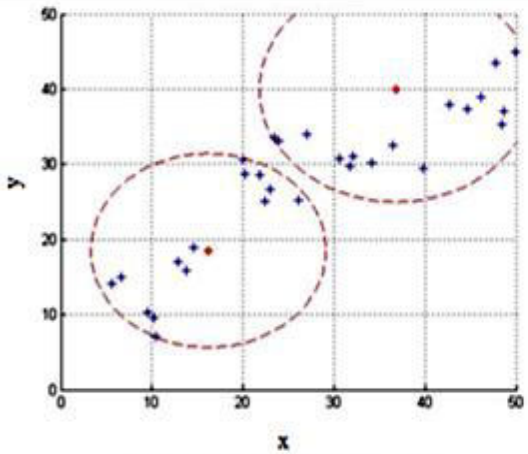

Fig. 2. Test on C30 benchmark

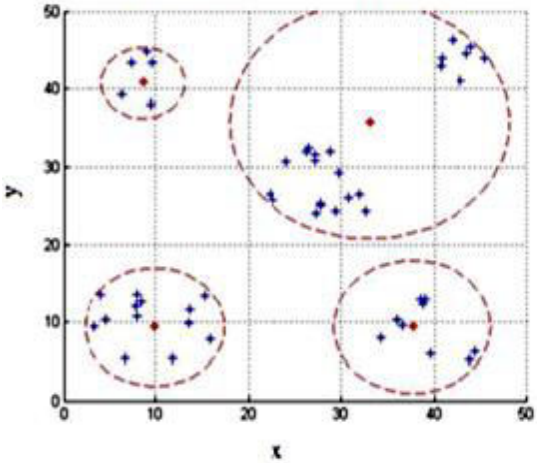

Fig. 3. Test on C50 benchmark

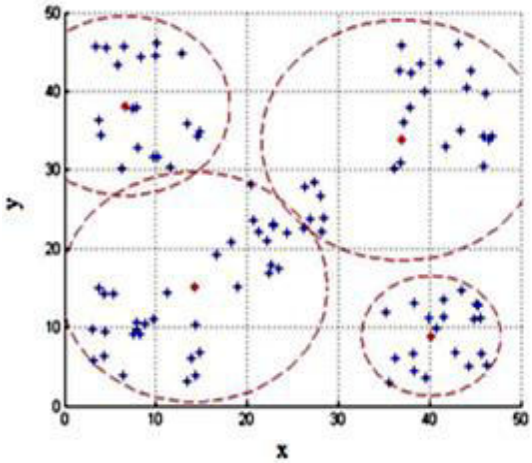

Fig. 4. Test on C100 benchmark

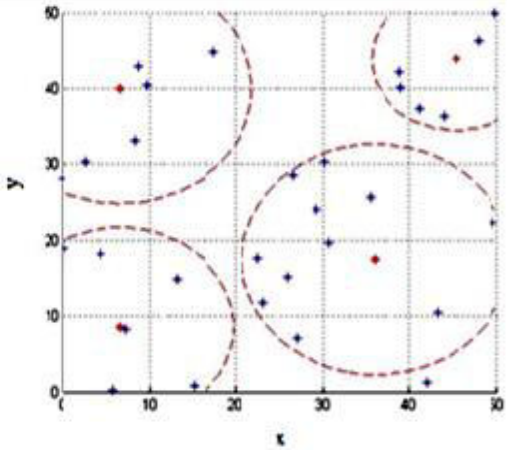

Fig. 5. Test on R30 benchmark

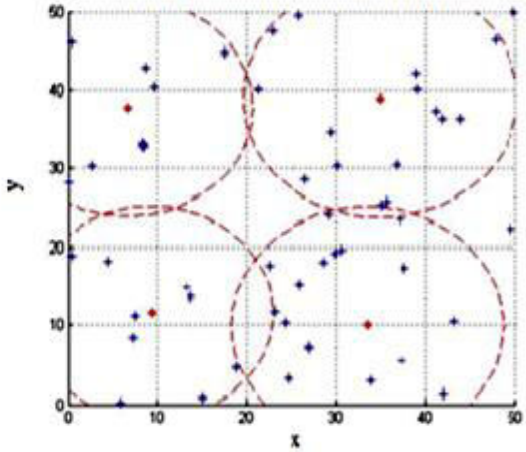

Fig. 6. Test on R50 benchmark

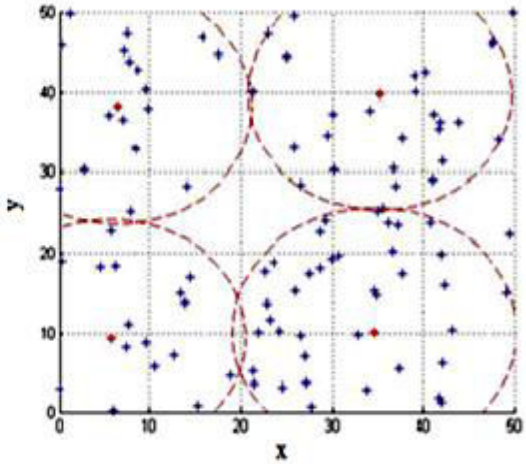

Fig. 7. Test on R100 benchmark

CONCLUSIONS

Hybridizing DBSCAN with firefly algorithm for optimizing multi-objective RFID network planning was developed and tested. The proposed method was tested against standard benchmark problems. It exhibited better capability in intelligent adjustment of the number of deployed readers during the optimization process. In addition, the algorithm proved the ability to run experiments with less iteration. The elimination of the redundant readers and the run iteration improve the cost-efficiency with suboptimal. This algorithm can be used in large and complex environments with different shapes of indoor working areas that represent one of the challenges to RFID network planning.

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