Biogeography Based Optimization Algorithm for Efficient RFID Reader Deployment

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***Abstract*— one of the major problems in Radio Frequency Identification (RFID) system is the RFID Reader Deployment Problem (RRDP). The solution to this problem is to find the optimal distribution (number, and position) of the RFID readers that guarantees the fulfillment of the deployment objectives. This paper proposes an efficient solution based on a Biogeography based Optimization (BBO) algorithm that has not been dealt before in solving the RRDP. Our motivation is to use the outstanding capability of the BBO algorithm (i.e. sharing the features among its solutions) for solving RRDP problem. The BBO based solution is developed to achieve a highly efficient placing and tracking system inside a building and to optimize the tracking performance for different passive RFID tags. This paper involves design of square grid RFID reader arrangement. The placement solution of RFID readers is offered via the square grid system, hence the optimal number of required readers and guaranteed coverage can be achieved. The proposed algorithm is compared to different evolutionary algorithms on small and large scale models. Simulation results verified the superiority of the proposed algorithm over the compared ones for solving the RRDP with satisfying the deployment objectives.**

Keywords—BBO, Collision, RFID and RRDP

I. INTRODUCTION

RFID is an automatic data capturing technology used to collect the data concerning objects. This data can be used to identify, track and specify the locations of tagged objects at distance using radio waves without a line of sight between communicating tags and readers. It works based on the radio frequency signals transmitted between tags and readers[1]. RFID system generally consists of tags, readers, and a middleware (host computer) as shown in Fig. 1. The tag is a transponder consists of a microelectronic chip used to store the data concerning the attached object and an antenna to receive signals from and send response to the reader. Tags are grouped according to their power supply into three types as[1]:

1. Active tags contain a battery as a power source, are of large size, high cost, long read range, and small life span due to the need for replacing batteries. These tags can initiate the communication with the reader.
2. Passive tags do not contain any power source and get the energy for activating the tag circuit from the received radio frequency signal from the reader. These tags are of small size, small read range, low cost, and long life span.
3. Semi-passive tags have a battery to energize the internal circuit but still wait for an activation signal from the reader to reveal themselves (send their response) to the reader.

Readers are devices (interrogators) used to identify tags in their interrogation zone (read range). The interrogation zone is defined as the area around the reader where it can correctly identify the tags. The middleware is software responsible for gathering, filtering, aggregating and integrating the data collected by the RFID readers then transforming them into meaningful information.

The great challenge in RFID systems deployment is to define the optimal placement (the number and the best distribution) of the readers in order to achieve maximum system efficiency.

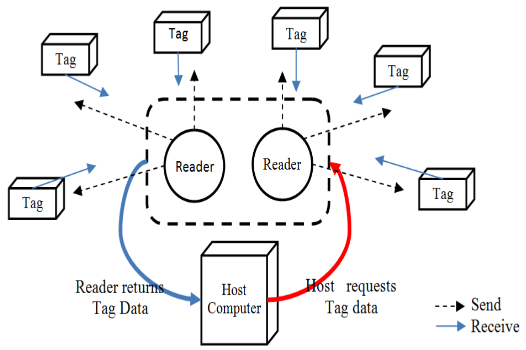


Fig. 1. Components of the RFID system.

This problem is referred to as RFID Reader Deployment Problem (RRDP) where there is an area needs to be covered by the RFID readers, and due to the limited interrogation zone (read range) of the readers one have to place multiple readers to achieve the deployment objectives. Accordingly, the positions of the RFID readers should be selected carefully in order to avoid the collision among the interrogation zones of reader where the RF signal from one reader tries to interrogate tags in vicinity of another reader and prevents the correct communication among tags and readers. This interference occurs in dense reader environment, degrades the reading process, and considered as waste of resources especially in allocating frequency to readers.

This paper presents a solution to the RRDP based on the Biogeography Based optimization (BBO) algorithm. The main feature of BBO algorithm that makes it suitable for solving RRDP problem, is its capability of sharing the features among its solutions. This allows poor solutions to benefit from the good ones, and helps the solutions to continue evolving until reaching the optimum solution. The coverage efficiency, reader collision and load balance are the objectives considered for solving the RRDP. The proposed scenario assumes that the tagged objects to be randomly distributed over the area of interest. The paper is organized as follows: section II presents some related work on optimizing the RRDP. Section III presents the proposed BBO based solution. Section IV introduces and discusses the simulation results. Section V concludes the obtained remarks. .

II. RELATED WORK

The definition of the Optimization process is the search for the best values of a set of parameters of a function in order to find the optimum solution of a complex problem. This function is known as the objective function, depends on the nature of the problem to be optimized [2]. The criteria that govern the objective function may be single or multiple. In single objective problems there is only one best solution as the global optimum. In multi-objective problems, there are many aspects (parameters) that need to be optimized together and the optimization with respect to a particular aspect may lead to results that may conflict with respect to another aspect. Therefore, there might be a tradeoff between all aspects to find the optimum solution. In this case the objective function needs to be constructed as a combination of all conflicting aspects to guarantee the satisfaction of all of them simultaneously. The use of bio-inspired algorithms for solving the complex problems has become an area of growing interest because of their iterative manner that leads the optimization algorithms to accurately solve the optimization problems [3]. Bio-inspired optimization algorithms are can be defined as algorithms that simulate the behavior of biological organisms such as, the Artificial Bees Colony (ABC) [4, 5], the Ant Colony optimization (ACO) algorithm [6-9], the Particle Swarm optimization (PSO) algorithm [10, 11], Ensemble particle swarm optimizer (EPSO) [12] and Biogeography Based optimization (BBO) algorithm [13, 14].
Concerning the RRDP, many researchers investigated the utilization of biological system features to find optimum solution. Ma et al. [15] proposed a hierarchical artificial bee colony (HABC) optimization for solving the RFID network planning problem. This optimization algorithm is extended from the single Artificial Bee Colony (ABC) algorithm in a multilevel manner. Zakaria et al [16] utilized the ant colony optimization for object localization and path optimization of mobile RFID readers. I. Bhattacharya [17] proposed a technique used for placement of readers in a store implementing an RFID network using the particle swarm optimization (PSO). Guan et al. [18] developed a genetic Algorithm for finding the optimum locations of RFID readers with the constraints of coverage of all read test points by readers, minimizing the number of readers, minimizing the level of interference among readers, and receiving the reflected signals from tags by readers. Gao et al [19] proposed a multi-objective estimation of distribution algorithm combined with PSO using a Pareto-based method for optimizing the RFID network. H. Chen et al. [20]presented the multi-objective Evolutionary Algorithms (EA) and Swarm Intelligence (SI) algorithms to find all the Pareto optimal solutions.

III. PROPOSED SOLUTION FOR OPTIMIZED RFID READER DEPLOYMENT

Biogeography-based optimization is a modern population based optimization technique that is based on the theory of studying the geographical distribution of biological organisms. It was developed by Simon [21]the idea behind biogeography is that biological classes such as animals or plants migrate from one island to another over the time. Islands that attract more classes are known to have a high Habitat Suitability Index (HSI), and those who have few classes are known to have a low HSI. Islands with high HIS have high immigration rate η while island with low HSI have high emigration rates λ. Each island has its immigration rate η and emigration rate λ that can be computed as [21]:

$$\eta = I\left(1 - \frac{C_K}{C}\right) \tag{1}$$

$$\lambda = E\left(\frac{C_K}{C}\right) \tag{2}$$

where I is the maximum immigration rate, C_K is the number of classes in the K^{th} island, C is the maximum number of classes, and E is the maximum emigration rate.
Each solution of the optimization problem is equivalent to an island. High HSI Island is equivalent to a good solution. Low HSI Island is equivalent to a bad solution. Each solution consists of a set of variables called Suitability Index Variables (SIV) that transferred among solutions using the migration operation. A mutation operation is performed after the migration process to modify the SIV and increase the diversity of the BBO solutions.

A. Model Description

The working area is divided into a finite number of grids and the readers can only be located at the corners of grids instead of any other place. The reader covers a circular area of radius r, this leads to squared gird with side length $r/\sqrt{2}$. Figure 2 shows a 4m x 4m working area which involves 36 grids with 49 available positions for deploying the readers represented by circles on the corners of the grids. A tag set, *TS* of 200 tags is distributed randomly on the working area and marked by stars.

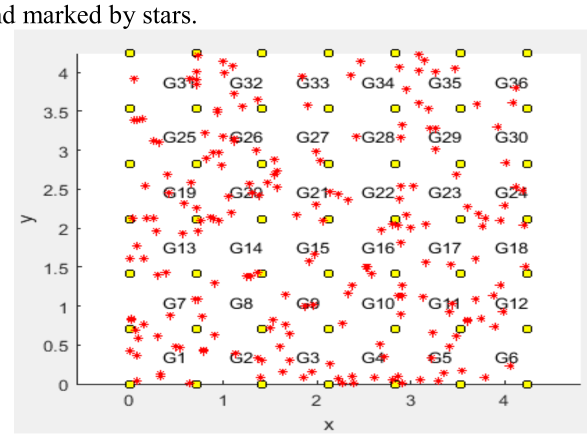


Fig. 2. A working area of 4m x 4m.

The task of solving the RRDP is to distribute several RFID readers in the working area in order to achieve certain five objectives. These objectives are the full coverage of the whole area of interest with minimum number of RFID readers, reducing the readers' collisions with load balancing over the deployed readers, balance the economic efficiency and in turn reducing the overall optimization cost.

B. Problem Formulation

Suppose that a given working area of dimension $(L \times W)$ is planned to be covered by a set of RFID readers of circular areas with radius (r). Hence, that working area is divided into N_G squared grids with total possible(N_R) readers defined as follows:

$$N_G = \left\lceil \frac{L}{r/\sqrt{2}} \right\rceil \times \left\lceil \frac{W}{r/\sqrt{2}} \right\rceil \tag{3}$$

$$R = \left(\left\lceil \frac{\sqrt{2}L}{r} \right\rceil + 1 \right) \times \left(\left\lceil \frac{\sqrt{2}W}{r} \right\rceil + 1 \right) \tag{4}$$

Therefore, the RRDP decision is whether to place a reader at a specific corner or not, which can be formulated in the category of binary programming, where the solution of the RRDP problem is depending on the fact "whether the reader at node z is placed $(x_z = 1)$ or not $(x_z = 0)$"as illustrated in Fig. 3.

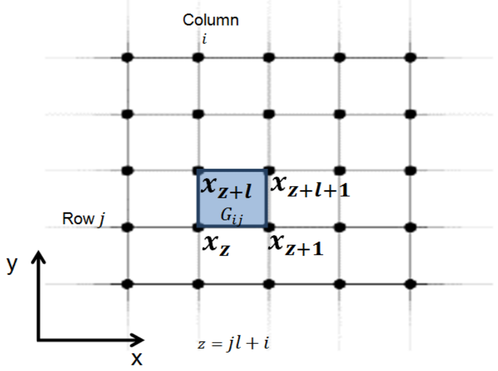


Fig. 3. The order of all readers that cover grid $\boldsymbol{G_{i,j}}$.

The RRDP problem can be formulated as:

- Maximizing the coverage by guaranteeing that each grid is covered by at least one reader. The number of covered grids N_{CG} is calculated as:

$$N_{CG} = \sum_{j=0}^{w-1} \sum_{i=0}^{l-1} (x_z \vee x_{z+1} \vee x_{z+l} \vee x_{z+l+1}), \qquad z = jl + i \tag{5}$$

- Minimizing the number of deployed readers N_R which is given by:

$$N_R = \sum_{z=0}^{N_R - 1} x_z \tag{6}$$

- And guarantee that all tags are able to answer the reader queries and identify themselves over time. This challenge requires the avoidance of the readers' collision which occurs when the readers are not well distributed and their interrogation zones intersect. This readers' collision can be represented by calculating the number of repeated covered grids N_{RCG} by the following equation

$$\begin{aligned} N_{RCG} = \sum_{j=0}^{w-1} \sum_{i=0}^{l-1} [&(x_z + x_{z+1} + x_{z+l} + x_{z+l+1}) \\ &- (x_z \vee x_{z+1} \vee x_{z+l} \vee x_{z+l+1})] \approx 0, \\ &z = jl + i \end{aligned} \tag{7}$$

Note that the operator '$\vee$' in the previous equations stands for the logical OR operation.

The readers need to be accurately configured in order to satisfy the problem objectives that can be defined as:

1) Coverage Efficiency

The coverage efficiency is the most important goal in the RRDP. In our model the coverage efficiency is defined as the ratio of the number of covered grids to the total number of grids as:

$$C_E = \frac{N_{CG}}{N_G} \tag{8}$$

2) Reader collision avoidance

The second important goal in designing the RFID Deployment is to minimize the collision among the deployed readers by minimizing the number of redundant readers. The reader collision R_C is defined as the ratio of the number of repeated covered to the total number of grids as:

$$R_C = \frac{N_{RCG}}{N_G} \tag{9}$$

3) Load Balance

Load balancing is the process of redistributing tags to readers, assignment of more RFID readers in areas of high tag capacity in order to reduce the over load on the set of deployed readers which in turn improves the coverage efficiency of the RFID system and maximizes the reading reliability. Since the presence of large number of tags in the reader interrogation zone results in large number of messages transmitted among the tags and the reader, there might be missing tag information. load balance guarantees that each tag is read by at least one reader. Load balance is defined [22]as:

$$L_B = \sum_{1}^{N_G} \frac{G_T}{G_R} \tag{10}$$

Where G_T is the number of tags within the grid, and G_R is the number of readers covering the grid.

Finally, the combined cost function F_C, by which the optimization algorithm must use to obtain the solution, is formulated as follow:

$$\begin{aligned} F_C = W_{RC} \times R_C + \frac{N_R \times W_R}{N_G} + W_{CE} \times Violation \\ + \frac{L_B \times W_L}{N_G} \end{aligned} \tag{11}$$

The weights; W_{RC} , $W_{CE,}$ W_R, and W_L are the weight factors for reader collision, coverage efficiency, and load balance respectively. These weights vary corresponding to which objective have to be more effective according to RRDP system priority. The violation represents how much the system away from the total coverage of all grids and is given by:

$$Violation = 1 - C_E \tag{12}$$

$$W_{RC} + W_{CE} + W_R + W_L = 1$$

The fitness cost function F_C is formulated in normalized form to guarantee minimum value is '0'. So the optimization algorithm will search for '0' cost value.

C. BBO based solution

After the RRDP problem formulation with the multi-optimization objectives, the RRDP problem can be solved as a typical problem of multi-objectives combined optimization and a meta-heuristic solution is designed based on BBO. The proposed algorithm starts with a number of individuals (habitats) are the agents of the population used in searching for the solution. The problem control-variable of the proposed BBO solution is the "habitat" and is assigned to the nodes locations for readers' Placements $(P.X, P.Y)$ and to the binary operator describe the existence of this reader (x_z). Therefore, the number of habitats $H(P,x)$ is equal to the maximum number of readers can be supported (R). The solution evaluation is performed using the cost function (fitness function). The cost function, which is given by equation (11)**Error! Reference source not found.**, returns a positive number (cost value) that indicates how good the solution is. The solution optimization goal is to reach zero cost value which satisfies the objectives. The pseudo code for BBO based solution procedures is shown in Fig. 4.

Define Habitat
$H(P,x) = \{(P_1.X, P_1.Y, x_1), \cdots (P_k.X, P_k.Y, x_k), \cdots (P_R.X, P_R.Y, x_R)\}$
Create and initialize R one-dimension habitats: H_i , $i \in [1, R]$
Repeat:
Choose H_i with probability proportional to η_i
if H_i is chosen ***then***
Calculate Emigration Probabilities
for $s = 1$ *to* R
Choose H_s with probability proportional to λ_s
if H_s is chosen ***then***
$H_i = \alpha H_i + (1 - \alpha) H_s$
end if
end for
end if
if rand $< \mu$
Update the mutation
$H_i = H_i + (\max(H_i) - min(H_i)) * rand$
end if
Evaluate solution
Until stopping condition is satisfied (size of population)

where $\alpha \equiv$ Blended migration operator = 0.9,
rand $\equiv$ any random integer between *0* and *1*

Fig. 4. The Pseudo code for the proposed BBO solution

IV. SIMULATION RESULTS AND DISCUSSIONS

The ACO, ABC, PSO, EPSO and BBO optimization algorithms were implemented for solving the RRDP. These algorithms are selected as they are recently used in the literature for solving the RRDP problem as discussed above in section II. The simulations were done at model sizes of (100, and 225 grids) each for 1000 iterations. The Tags set TS (total number of tags) is changed from 100 to 200 tags non-uniformly distributed over the area of interest. The tags distribution is kept fixed on the simulation of all algorithms. The cost curves are shown in Fig. 5- 8.

Simulation results show that the proposed BBO based solution achieves the lowest optimization cost (as it deploys the lowest number of readers that well distributed for fully covering the whole area, reducing the collisions, and in turn reducing the cost than the other compared algorithms). The superiority of the proposed BBO based solution attributes to the mutation process of the BBO algorithm that allows better diversity of solutions on the search space that enables the algorithm to reach the optimum solution. On the contrary, the ACO algorithm gets trap in a local minimum, and cannot provide the optimum solution as it does not improve its solutions and stuck in a poor solution over all the iterations). The results also show that the BBO algorithm picks the better solutions in a fewer number of iterations.

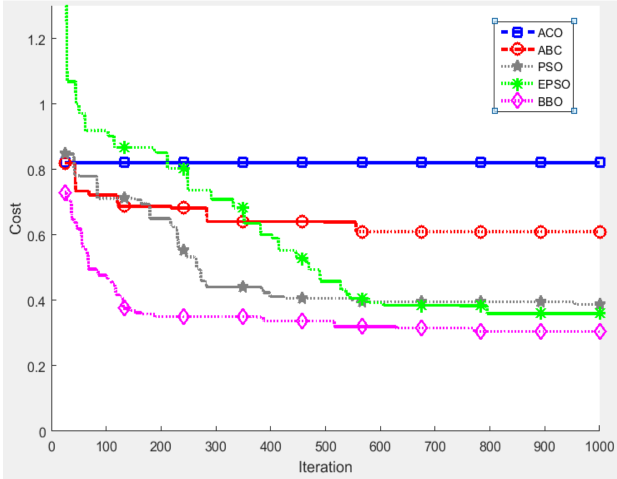


Fig. 5. Cost curves for a model of 100 grids with 100 tags.

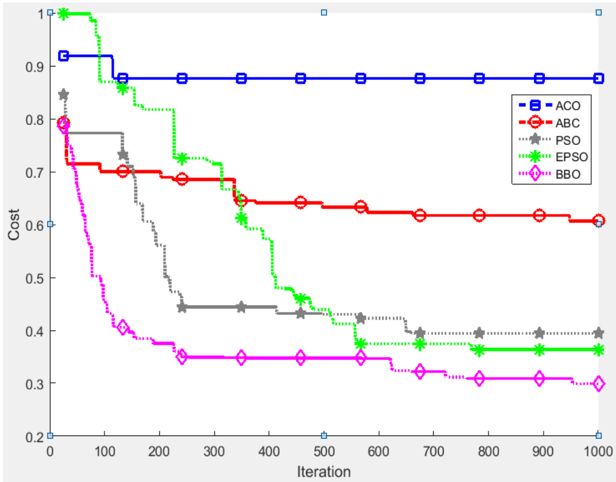


Fig. 6. Cost curves for a model of 100 grids with 200 tags.

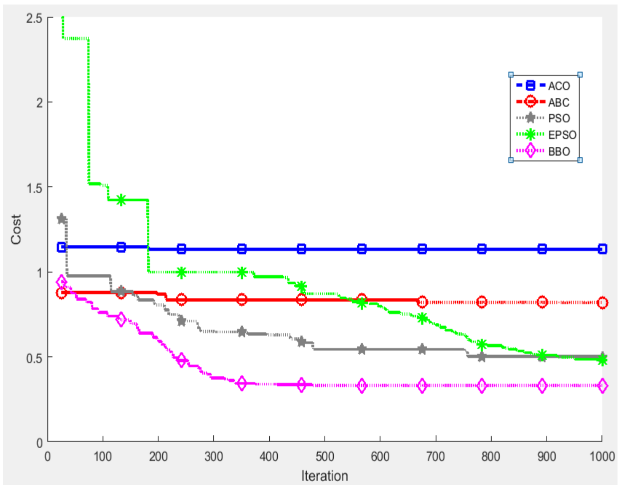


Fig. 7. Cost curves for a model of 225 grids with 100 tags

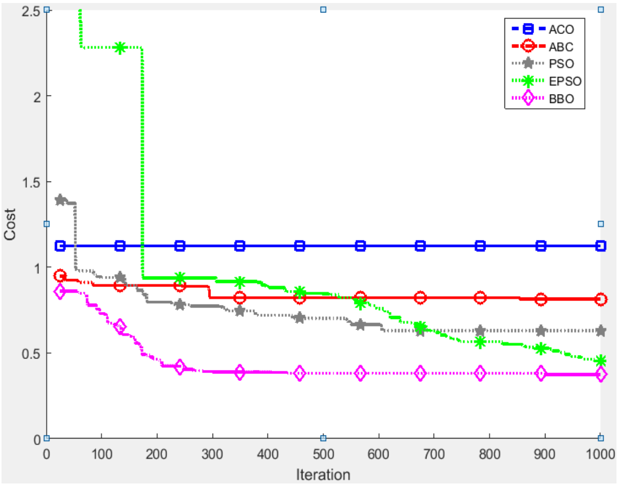


Fig. 8. Cost curves for a model of 225 grids with 200 tags.

For further illustrations, the numbers of used readers and the cost values that give full coverage of the deployment areas of size, 64, 100 and 225 grids for a tag set TS of 200 tags are listed in Table 1. Since the results of the optimization techniques depend on random variables, the presented results are averaged over 10 runs. It is clear from Table 1 that, the proposed BBO based solution achieves the optimal distribution of readers that leads to better performance in terms of the number of used readers, RS and the cost values, Cost than the other compared algorithms.

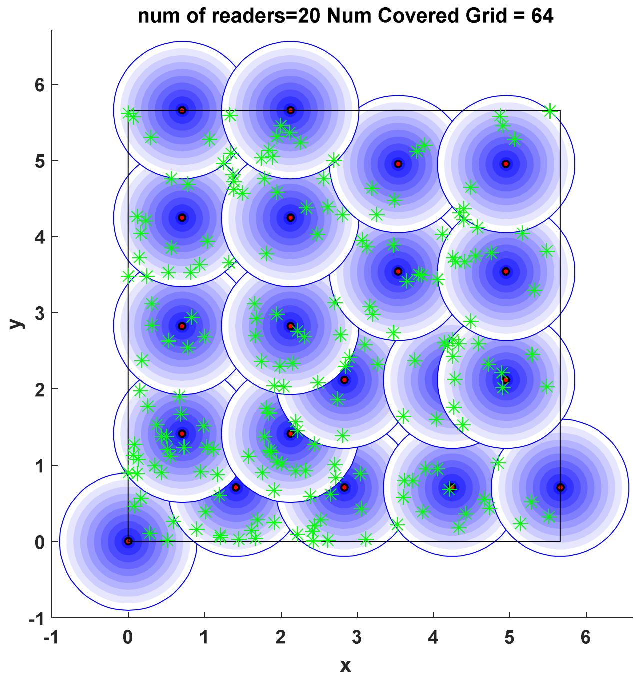
TABLE 1: THE RESULTS OF THE OPTIMIZATION ALGORITHMS ON SIMULATED AREA OF 64, 100AND 225 GRIDS OF TS OF 200 TAGS THAT ACHIEVE A FULL COVERAGE EFFICIENCY.

Optimization Algorithm	$N_G = 64$		$N_G = 100$		$N_G = 225$	
	RS	Cost	RS	Cost	RS	Cost
ACO	40	0.80	64	0.88	159	1.12
ABC	30	0.42	47	0.61	125	0.81
PSO	22	0.32	38	0.39	109	0.63
EPSO	23	0.33	36	0.36	86	0.45
BBO	20	0.28	34	0.29	73	0.31

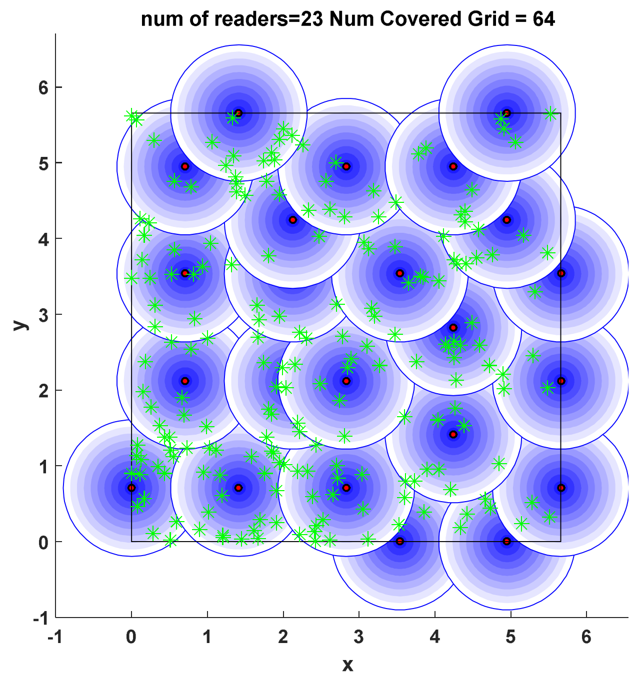
The coverage patterns of the proposed BBO based solution and the EPSO based solution for a working area $N_G = 64$ are shown in Fig. 9a and Fig. 9b respectively, which are the best two solutions obtained. It can be seen from the figure that the BBO based solution gives the best distribution of readers that achieves the full coverage of the area of interest with the lowest number of readers, the minimum collision, and in turn minimum cost which can be deduced also from table 1.

Besides, the BBO based solution reduces the power losses outside the working area. Considering that the reader radiates a power, P_r then the distribution of the readers on BBO based solution lose about $2.25P_r$ of their radiated power while the distribution of the readers on EPSO based solution lose about $4P_r$.

This reduction in the power losses attributes to the efficiency of the BBO based solution in distributing the readers and achieving 13 percent redundant reader reduction than the EPSO based solution.



(a) BBO coverage



(b) EPSO Coverage

Fig. 9 the area coverage of (a) the BBO based solution and (b) the EPSO based solution.

V. CONCLUSION

A meta-heuristic Biogeography based solution is proposed for solving the RRDP problem. The proposed algorithm restricts the immigration patterns of the habitats in the iteration process and provides better diversity of the BBO solutions. In order to emphasize the superiority of the proposed BBO solution, other bio-inspired algorithms (i.e. PSO, EPSO, ABC and ACO) are implemented and compared via MATLAB based simulations. A grid based model is presented to investigate the art of RFID reader positioning. The simulation results show that the proposed BBO solution outperforms the other simulated optimization algorithms in finding the optimal readers' distribution that achieves better solution to the RRDP. It can be also concluded that for large size areas, the proposed BBO-based algorithm outperforms the compared algorithms in terms of the number of deployed readers, the optimization cost, and the coverage efficiency which makes it suitable for optimizing the large scales RFID deployment. Besides, the BBO based solution reduces the power losses outside the working area by obtaining the best reader distribution. The BBO converge rapidly to the best solution than the other algorithms. In future, the performance of the BBO based algorithm could be improved to suit further real world applications. Besides, it is of interest to monitor the path of mobile tags in RFID large-scale deployments based on the implemented grid model.

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