Optimization of RFID Network Planning Using MDB-FA Method

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***Abstract*— Topology network design in RFID Network Planning (RNP) is the most important factor in hard optimization problems of network planning. Reader distribution is highly impacted by topological tags distribution. The integration of RFID multi-objective network planning with the network topology design results in better capability of reader distribution. Thus, this paper evaluates the impact of topological network design to support the RFID reader's distribution system. Monte Carlo simulation (MCS) is used to generate tag distribution based on network topology design modules as a method to evaluate the deterministic indicators in NP-hard problems. The generated data are utilized as an input representation to apply into firefly algorithm based on Density-Based Algorithm (DBSCAN) to find the optimal network solution. Experimental results show the effectiveness of the method in L-Shape RNP, and show that the proposed algorithm is capable of achieving high coverage and use of fewer readers in actual conditions of warehouse design.**

***Index Terms*— DBSCAN; Firefly Algorithm; MCS; MDB-FA; RFID Networks Planning.**

I. INTRODUCTION

RFID Network Planning (RNP) strategy depends on the functional parameters. It assigns frequencies, transmitter locations and parameters for a wireless communication system [1]. Most studies investigate the use of RFID to find the optimal evaluation of objective functions in NP hard problem. These objective functions mainly involve minimum number of readers needed to cover an entire region, the interference between two or more RF readers' fields that may overlap and interfere with each other, and signal propagation that represents the minimum power required at a RFID tag antenna [2]. However, the structure of the network is strictly related to the topography of the environment and effective geometrical parameters. Therefore, Network design is noticeably affected by RFID at the edge effects and deployment of the storage area network (SAN) solution [3].

Giampaolo et al. [4] place the reader's antennas on two side walls and apply the Particle Swarm Optimization PSO algorithm for planning in L shape environment system. Kim et al. [5] deploy the RFID systems in terms of tracking coverage by dividing the area into equal rectangles and specify the reader position in the center of each such rectangle. Bhattacharya and Roy [6] find that the possible positions of the readers depending on physical distribution of the items. Based on the above, they used Particle Swarm Optimization (PSO) to find optimal RFID network reader placement. Botero and Hakima [7][8] propose a software tool to assist in the topology design based on rectangular region with circler interrogation. They obtain optimal solutions for RFID multi-objective functions by applying Genetic Algorithms. Ting et al. [9] present a feasibility study of RFID positioning system using grid cells. Al-Naima and Hussein [10] developed a GUI software tool based on the parameters and the number and locations of tags as an input. This planning strategy applies the PSO algorithm successfully in RFID network planning. Gong et al. [11] present a novel local topology. In this method, the adaptive small-world network model correlated with PSO algorithm (ASWPSO). The probability of randomization and the size of neighborhood are used to adjust based on the convergence state of the swarm. Chun et al. [12] used the K-means model as a cluster algorithm correlated with fuzzy-ART to optimize the Simplified Swarm Optimization (SSO) algorithm in order to find the best RFID network planning design strategy.

Thus, related studies concentrate on the use of RFID technology based on Topology Network Planning to present a novel view of RFID reader placement in RFID networks. The Monte Carlo simulation method is used to generate the tags distribution based on warehouse design condition to find a solution that ensures the complete coverage of an entire facility (e.g., a warehouse), which allows an RFID network to support real-time inventory tracking and localization that can minimize shrinkage and prevent theft [13]. Both traditional and non-traditional layout designs are considered independent warehouse models in this paper. Discussion concerns data generator and optimal RFID network planning, process of warehouse design based on RFID readers' employment, the objective functions correlated with DBSCAN technique, and the firefly algorithm as a method to find the optimal solution [14].

II. NETWORK DESIGN MODEL

Modeling is the process of producing a representation of some system of interest. It aims to describe the different aspects of the real world, their interaction, and their dynamics through mathematics. In RNP problems, the mathematical model must be able to address universal concepts in order to obtain a successful numerical simulation [15]. The method for the development of engineering models can be planned in the framework below:

Step1: Identify the topological model, which involves specifying the working dimensions, input representation and the internal topological design.

Step2: Identify the RFID model, which involves specifying the propagation range of the tags threshold and the reader threshold.

Step3: Identify the optimization algorithm, which involves specifying the RFID rules, the input features based on DBSCAN technique, limitations and finally the working condition.

A. Topological Model

Topological model is a model of the system functionality in mathematical modeling languages [8]. It can be specified as a metric topological space with finite set of functional features. In this study, the mathematical formula of Topological Model considered a warehouse design. The selection of the type of warehouse system design based on long-term impact is a highly complex task. Warehousing, along with transportation and inventory carrying, is one of the three major drivers of logistics costs. Dukic and Opetuk (2012) provide the layout of storage area as parallel pallet racks and aisle-based pallet floor storage as having the same characteristics as the pallet rack storage. The independent dimensions of the layout can be considered as 1 m for Storage location width (b1) and Storage location front (l1), 2 m for aisle width (b2). Aisle length (Lr) and aisle width (Br) percentage is (1:2). Ideally, observation of warehouse design should be tapped from real environment. Monte-Carlo simulation approach was applied for generating synthetic data [16] as the following:

Step 1: Generate random normal values for tags position in each storage length that are identically and independently distributed using the formula:

$$x = B_r + r \tag{1}$$

$$y = L_r + r \tag{2}$$

where *Br* is warehouse width, *Lr* is the aisle length as a centerline of storage position, *r* = random condition within [-0.5, +0.5] based on Storage location width.

Step 2: Generate random data series for tags layout distribution in the warehouse as the formula:

$$X_n = \sum x_i \tag{3}$$

$$Y_n = \sum y_i \tag{4}$$

Step 3: Store the set of tags position for transfer to the firefly algorithm to find the optimal readers position based on the RFID objective function.

$$\Lambda = (Xn, Yn) \tag{5}$$

B. RFID Model

This section presents the mathematical definition of the RFID network-planning problem that was also used recently by Hasnan [17]. One of the most important objectives employed in this model is optimal tag coverage (C) that enables the ability to detect and obtain the IDs of all of the deployed tags 8. 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[17]:

$$C_{\min} = \sum_{\mathbf{i=1}}^{N_T} (P_{tagi} - P_{req}) \tag{6}$$

P*tagi*= Actual received power at each tag
P*req*= required threshold power
N_T=Number of tags in working area

The Friis transmission equation power at each tag can be calculated by the following equation:

$$P_r = (P_t . G_t . G_r) / (4\pi \frac{d}{\lambda})^2 \tag{7}$$

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. The problem of interference can be solved by separating the reader's interrogation ranges and varying the radiated power of readers. Due to changing the positions of readers away from each other and variation of radiated power, the interference is formulated as:

$$\text{int.} = \sum_{i=1}^{N-1} \sum_{(j=i+1)}^{N_{max}} [d_t(R_i, R_j) - (r_i + r_j)] \tag{8}$$

where Nmax represents the total number of readers, "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. The set of present objective functions will be applied in the firefly algorithm to find the optimum level of network planning.

C. 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 18. 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 the present definitions [18].

Definition 1: (Eps-neighborhood)

The Epsneighborhood of a point Ƥs is defined by the cluster region Nr that represents the space of propagation range radiated from the RFID reader.

NEps (Ƥs) = {Ƥtag ϵ d |dist(Ƥs, Ƥtag) < dmax} (9)

Definition 2: (Density-reachable)

Density-reachable is the tag point Ƥtag that can be reached by propagation based on chain of points such as in Figure 1. The summation of Ƥtag represents the recorded tags positions in the area of propagation range as in the formula below:

$$\sum Ƥtag \in NEps(Ƥs) \quad (10)$$

Definition 3: (cluster)

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

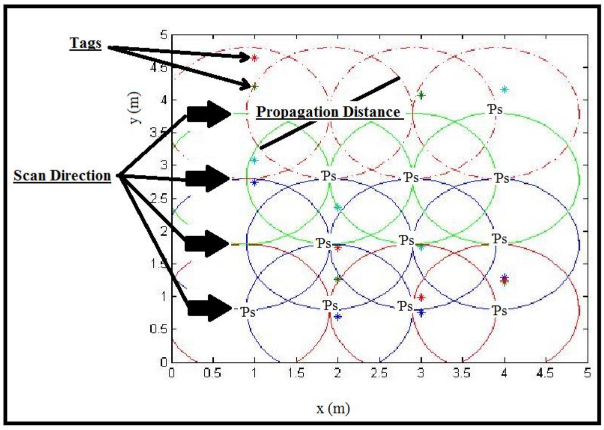

Figure 1: The cluster Density-Based region

III. Optimization Algorithm

Firefly is the selected optimization algorithm. This algorithm, developed by Xin-She Yang in late 2007 and 2008 at Cambridge University, is a type of swarm intelligence algorithm based on the reaction of a firefly to the light of other fireflies [19].The main variables in firefly algorithm are light intensity and attractiveness. Attractiveness is dependent upon the light intensity; therefore, the light intensity follows the inverse square law as the following equation [19]:

$$I_{(r)} = \frac{I_O}{1+\gamma r^2} \quad (11)$$

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 expressed in the following equation:

$$\beta_{(r)} = \frac{\beta_o}{1+\gamma r^2} \quad (12)$$

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:

$$r_{i,j} = \left\| x_i - x_j \right\| = \sqrt{\sum_{k=1}^{F} (x_{i,k} - x_{j.k}} \quad (13)$$

where F is the number of problem parameters.

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

$$x_i(t) = x_i(t) + \beta_o r^{-\gamma r^2_{i,j}} (x_j - x_i) + \alpha(rand - 0.5) \quad (14)$$

where β_o is considered attractiveness at $r = 0$, α is randomization parameter, rand represents random number uniformly distributed between 0 and 1, r(i;j) is distance between fireflies i and j. 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 firefly algorithm so that it can efficiently solve large-scale PNP network planning problems.

IV. Hybridization Procedure

Three 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 [20]. The present approach used a form of collaborative hybrid. This hybrid type has a three-sequence structure. The first algorithm is Monte Carlo Simulation which generates the require data. The second 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 third 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 meet the best objective functions. The step-by-step operating procedure of hybrid firefly with DBSCAN algorithm based on Monte Carlo Simulation is described as follows [21] [22]:

Step1. Generate tags position using Monte Carlo Simulation based on the warehouse design conditions as in equations (1), (2), (3), (4), and (5).

Step2. Specify the Eps-neighborhood domain by calculating the radiated power of reader (r) from equation (3).

Step3. Initialize number of readers "N" and position Ƥs of each reader by applying the DBSCAN algorithm.

Step4. Transfer the DBSCAN algorithm results in FIREFLY algorithm.

Step5. Evaluate the fitness of each reader based on equations (6), (7) and (8).

Step6. Update the position of all readers. Re-evaluate the fitness of each reader. The independent value of position and velocity will be specified based on the best fitness.

Step7. If the fitness value achieved so far is the global best position, then stop operation.

V. EXPERIMENTAL RESULTS

The present method (MDB-FA) results are obtained through applying FA algorithms based on Monte Carlo simulation that observe good solutions to the multi-objective optimization RNP problem. The circler model of the read region has been evaluated in two cases. The first case is L shaped environment scenario in order to perform a comparative analysis with PSO result of optimization planning presented by Giampaolo (2010)4.

The parameters considered for this case are the adjustable readers power not exceeding [31dBm] (1.3 watts) and maximum gain Gr=8dB. Monte Carlo simulations in lattice form are generated to the same topological boundary layer presented by Giampaolo. The plotted tags are denoted as blue dote sign ".", the coordinates of readers are shown as red star "*", and their interrogation range as red dashed line circle. Figure 2 shows the experimental results. It can be seen that our proposed FA based Monte Carlo approach achieves 100% tag coverage with the least interference.

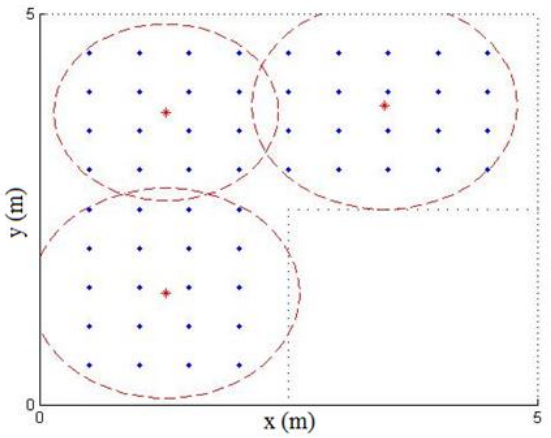

Figure 2: L-shaped network environment

The proposed method guided the search to a good solution with the use of circler propagation as reported in Table 1 for L shape topologies that present better results from PSO (Giampaolo) in circler propagation condition.

Table 1
Experimental results of L shape

Algorithm	Radiation pattern	Coverage	Reader N	Power
MDB-FA	circle	100%	3	0.3
PSO (Giampaolo)	circle	95%	3	0.3

The second case in the experiments is the actual warehouse design based on the warehouse design model presented by Dukic and Opetuk (2012). The specific parameters of the RFID network planning (RNP) problem were adjusted to improve the quality of the solutions. The specific values of these parameters are shown in Table 2.

Table 2
RFID parameters

Parameters	Values
RFID Reader Frequency	915 MHz
Transmitting power range	[20; 33]Dbm
Sensitivity thresholds of tags	-14 dBm
Sensitivity thresholds of Readers	-80 dBm
RFID Reader Antenna Gain (Gr)	6.7 dBi
RFID Tag Antenna Gain (Gt)	3.7 dBi
Wave length (λ)	0.328m

The scenario of the working area was set as 26m x 48m. 130 tags are randomly distributed in working space with 10 tags in each aisle length (Lr=26m) based on the width of area (Br=48m) for given dimensions of storage location (l1=1m, b1=1m).

The Monte Carlo Simulation MCS in large real warehouse samples provide 10 distributed tags randomly in each aisle as shown in Figure 3 below. The generated tags are trapped in the aisle similar to real store environment and each tag identifies in (x,y) position and are collected as a group. The set of tags transferred to the second algorithm to be clustered by DBSCAN algorithm provide the initial number of readers required and the initial position of each reader as mentioned before. The DBSCAN results observe four readers as initial number of readers required. Each part contains a certain amount of tags representing the density group. In addition, the algorithm provides the initial readers' positions.

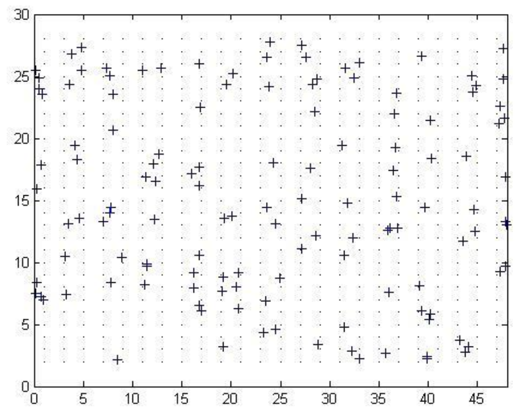

Figure 3: Large warehouse MCS result

The gained information from the MCS and DBSCAN will be tested in the firefly algorithm.

The first test is by direct insertion of the MCS set of data into the firefly algorithm, the second test is by insertion of the BSCAN results in the same algorithm in order to investigate the effect using DBSCAN. Figure 4 observes the firefly plot result based on MCS set of tags position, while Figure 5 observes the firefly plot result based on DBSCAN data

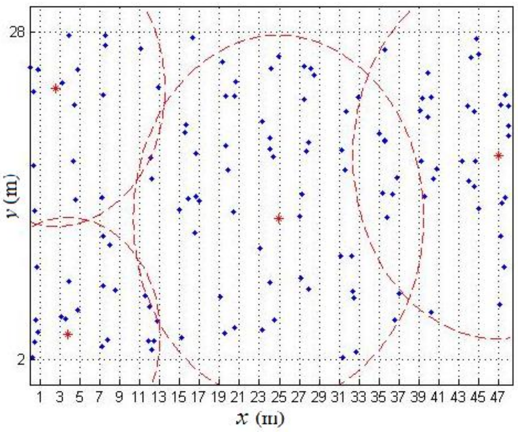

Figure 4: Large warehouse firefly result base on MCS

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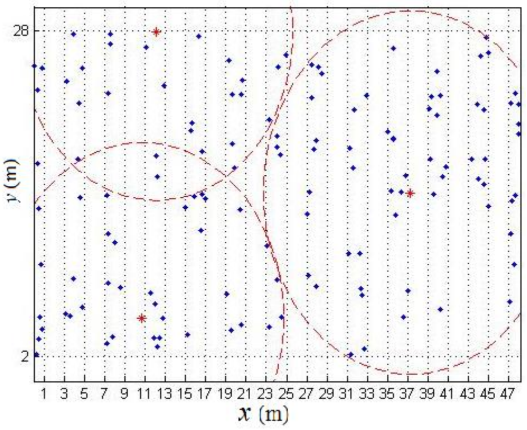

Figure 5: Large warehouse MDB-FA results

Table 3 summarizes the results for the MDB-FA algorithm and FA algorithm for large area scenario. The results indicate that MDB-FA method able to reduce the number of readers and the overlapped Tags with same tags coverage quantity.

Table 3
Large warehouse results summary

	FA	MDB-FA
Number of readers	4	3
Total Number Of Generated Tags	130	130
Total Number Of Covered Tags	129	129
Total Number Of Overlapped Tags	6	2

The simulation results show that the present method was able to achieve full coverage of the network based on the 130-tag density. Generally, the proposed method guided the search to a good solution with the use of actual topology cases and the pre-process operation using DBSCAN. The present method enables to find the RNP network planning solutions in both the existing warehouse design and in conceptual stage of warehouse design based on complicated topologies RFID network planning. Table 4 shows the numerical experimental results. It is clear that the positions of the readers in this method will be in ceiling condition, which is more flexible in practical usage of other RNP cases.

Table 4
Experimental Results

		Best Results		
Algorithm	Coverage	Reader N	Interfer.	Power
MDB-FA	99.2 %	3	0.030	25.56

The RFID Network Planning (RNP) serves the complex applications in the Islamic Structured Warehouse Finance (inventory finance) field. It is one of the Islamic tools used by International Islamic Trade Finance Corporation ITFC to develop the markets and trading capacities and providing additional finance to the Organization of Islamic Cooperation OIC member countries. The financial system based on warehouse involves the smooth running, efficiency and organization in the warehouse. The present MDB-FA scheme can represent a helpful tool to solve the traditional warehouse problems such as specify the Insufficient Warehouse Space, detect and monitor both Slow Picking Processes and Stock Discrepancies and finally, highlight the warehouse Slotting Problems14.

VI. CONCLUSIONS

The impact of topological network design based on multi-objective RFID network planning was developed and tested using firefly algorithm correlated with Monte Carlo simulation and DBSCAN technique. The proposed method was tested against L shape environment problem and applied on actual warehouse design example. It exhibited better capability in topological network design based on clustering data of different boundary conditions during the optimization process. This algorithm can be used in large and complex environments with different shapes of indoor working areas based on topological network design that represent one of the challenges to RFID network planning. The present MDB-FA method can be applied in conceptual design stage to specify the warehouse design and material organization. Trucking and monitoring different types of materials in the warehouses pave the way to Internet of Things (IoT) marketing, which represents a major destination for Islamic investment.

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