Multi objective optimization of Indoor UHF RFID Network Based on Gradient - Cuckoo search

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Abstract. : Network design, in general is a critical concept due to its effect on efficiency, cost and other significant factors. In recent years, RFID is widely applied for RNP Network design. The large -area network design process requires a significant number of interrogating antennas based on the reader-tag range communication. RFID technology uses a huge number of tags communicate with a small number of the reader, from thus point of view, the challenges of large scale RNP problems include high computational cost due to the time consumption of RFID readers placement error, as a result, these challenges reduce the effectiveness of the RFID system. In this study, a model of multi-objective function for RFID reader placement was conducted on various large -area condition to evaluate the impact of network design expansion. A comparative analysis was performed with (GBCS algorithm) Gradient-Based Cuckoo Search. The dataset was performed for the area of 80m x 80m and 150m x 150m. Simulation results exhibited that the performance of (GBCS) Gradient-Based Cuckoo presented a minimum number of deployed readers with maximum RFID tags coverage and was superior in solving large scale RFID-NP problems. Simulation results not only explained that the present algorithm is strong and workable but also showed excellent approximation abilities even in the high scale-area. Consequently, the authors recommend if the area bigger than (80m²), there is a need to divide the area into separate regions and deal with each region separately to be sure that the objective function can work efficiently.

1. Introduction
Radio frequency identification system (RFID) as a modern inventory monitoring technology has accomplished significant development in many industrial domains. Many real -applications of an RFID system such as toll collection, warehouse, supply chain management, transportation and manufacturing more and more readers are deployed to provide full coverage of all the RFID tags in the given working area.[1] This case leads to the problem of finding the readability of UHF RFID tags based on the limited domain of the tag-to-reader telecommunication [2] therfore, the RFID network planning aims to improve a set of objectives involving the coverage of RFID tags, cost of installation, avoid interference between RFID readers and economic efficiency, by adjusting control variables of the system, such as the required number of the readers, location of the readers, and the parameters of antenna. In RFID technology, the optimization method was very beneficial in solving problems of high complexity, large search area, and searching ill-structured areas. For these reasons alone, Nature
Inspired techniques have been applied in this field. Optimization methods used to improve the values of chosen parameters of relevant RFID objective functions. The design for optimization begins with the design of objective function. The parameter relationships are formulated by the mathematical model [3]. There are many methods are applied for optimization, with Swarm Intelligence technique is one of the optimization methods that gather the multi- systems. This method includes an efficient technique to solve real-difficult problems [4]. Nowadays, a group of RFID Network design optimization has been developed involving five basic techniques [5]. These techniques are (PSO algorithm) Particle swarm optimization, (ABC algorithm) Artificial Bee- Colony, (BFO algorithm) Bacterial Foraging Optimization, (ACO algorithm) Ant Colony Optimization, and (FA algorithm) Firefly Algorithm. The cuckoo algorithm was newly developed to use in the wide domain such as engineering optimization and to solve difficult optimization problems [7]. All of these methods were developed to enhance their performance to solve RFID-NP problems. (PSO algorithm) Particle Swarm Optimization was improved by Hasnan et al. [5] using (MC-GPSO algorithm) Multi-Colony Global Particle Swarm Optimization to cluster the working space into regions and apply the algorithm in each region separately. Elewe et al. [8] developed the (FA algorithm) Firefly Algorithm by applying (DBSCAN method) density base technique to scan and investigate the topology of the area. This method called (DBSCAN-FA) represents the result of hybridization between (FA) Firefly algorithm and Density-Based Clustering technique (DBSCAN). The contribution of this method (DBSCAN-FA) is the classification of the RFID tags based on their density and specify the optimum reader numbers and primary reader locations. Finally, the (CS) cuckoo algorithm was developed by Fateen and Bonilla, [9] by utilizing (GBCS algorithm) Gradient-Based Cuckoo Search algorithm. The gradient improves numerical performance and enhances the search method. All these techniques (GBCS and DBSCAN-FA) will be examined in this work to evaluate their performance in the large area RFID Network design. The aim of this work is to evaluate the impact of extended network planning based on the RFID objective function in order to be able to choose the superior method to apply in the real application of large-area IoT field.

2. PNR mathematical model

The mathematical model of RNP in this study was construct based on the circular propagation area of RFID readers. The objective function of the RFID-NP Network Planning was developed to enhance the (QOS) quality of solution. The propagation domain of the reader can be calculated by Friis transformation equation The Friis transformation is applied to find the power received from one antenna (with gain $G_T$), when transmitted from another antenna (with gain $G_R$), based on distance $r_{max}$ between antennas, and operating at frequency $f$ as in (1) [10].

$$P_R = P_T \times G_T \times G_R \times \left(\frac{\lambda}{4\pi}\right)^2 \times \frac{1}{r_{max}^n}$$  \hspace{1cm} (1)

The difference between the power transmitted and received is known as (PL) path loss. From this formula, the PL is higher for higher frequencies and energy transferred at lower frequencies will be highest. The functional parameters that affect the optimization process are identified in Table 1 below [8;10]:
Table 1. UHF-RFID parameters.

| Symbols       | UHF RFID Parameters                  |
|---------------|--------------------------------------|
| $P_R$         | Power input at tag antenna           |
| $T_R$         | Power Sensitivity- thresholds of reader |
| $T_T$         | Power Sensitivity- thresholds of tag  |
| $n$           | Path loss exponent (free-space)      |
| $f$           | Operating Frequency                   |
| $G_R$         | Receiving tag antenna Gain           |
| $G_T$         | Receiving reader antenna Gain        |
| $C$           | Speed of light                        |

| Value |                      |
|-------|-----------------------|
|       | [0.1 - 2] watts       |
|       | -70 dbm               |
|       | -12 dbm               |
|       | 2                     |
|       | 915 MHZ               |
|       | 2                     |
|       | 2                     |
|       | (299792458 m/s)       |

In Free-Space, the path loss exponent ($n$) is set at 2, but in a cluttered environments such as (Urban area. Suburban – area, pipes and tunnels, etc.) PL exponent ($n$) may vary of 1 to 4 [11]. The propagation domain of the RFID reader can be determined in equation (2) – (4) [12].

\[
L_{dB} = P_T + G_T + G_R + P_R
\]

\[
L_m = 10^{\frac{L_{dB}}{10}}
\]

\[
\tau_{max} = \frac{\sqrt{L_m \times \lambda}}{4 \times \pi} \quad \text{where} \quad \lambda = \frac{C}{f} = \frac{299792458}{915}
\]

The relationship between the propagation range of the reader and tag threshold power sensitivity with tag antenna gain which are specified in Table1. given by equation (4) and plotted in Figure 1 and Figure 2.

![Chip power sensitivity (dBm)](image1)

![Tag antenna gain (dBi)](image2)

Figure 1. Relationship between the propagation range $\tau_{max}$ of the reader and tag threshold power sensitivity $T_T$

Figure 2. Relationship between the propagation range $\tau_{max}$ of the reader and tag antenna $G_R$

Therefore, by using equation (4) we can note from figure (1) and figure (2) the propagation area is dependent on RFID tag antenna gain and tag threshold power sensitivity. Accordingly the maximum propagation area ($\tau_{max}$) not exceed 29ft when tag threshold power sensitivity is set at (-12dbm) theoretically, presently, the maximum range of UHF RFID technology is restricted by tag threshold power sensitivity. However, when the tag threshold power sensitivity is high, such as in the case of semi-passive tags, the range becomes restricted by the reader sensitivity. Note that tag range in UHF RFID can also be affected by various kinds of overlapping, like reader-to-tag, tag-to-tag, and reader-
to reader. The propagation range is calculated in the above formula in equation (4) Is subject to the boundary conditions [6]

\[ r_{\text{max}} \geq r_{td} \]  

(5)

The distance between tag and reader in working space can be calculated by the following expression:

\[ r_{td} = \sqrt{(x - x_t)^2 - (y - y_t)^2} \]  

(6)

Where \( y, x \) are Coordinate of reader and \( x_t, y_t \) are Coordinate of tag.

To calculate the optimal number of RFID readers and its location first the next formula is utilized [11]

\[ COV_i = \sum_{t=RS}^{\text{max}} (r_{\text{max}} - r_{td}) \]  

(7)

The tags coverage rate(cov) in the specified area, which represents a quite significant and important objective function of RFID technology is determined as:

\[ f(cov) = \sum_{t=TS}^{\text{MAX}} \frac{\text{detected tag}}{\text{total tags}} \]  

(8)

The overlapping between RFID readers can be reduced by the next mathematical equation [12-14]

\[ I_{\text{min}} = \sum_{i=1}^{N-1} \sum_{j=(i+1)}^{N} (r_i + r_j) - \text{dis}(R_i,R_j) \]  

(9)

Where \((r_i, r_j)\)are Interference rang and \((R_i, R_j)\) are Position of reader

\[ f(I) = \frac{\sum_{i,j} \text{cov}_i \cap \text{cov}_j}{Nt} \]  

(10)

Based on the presented set of formulas, a RFID-network design performance comparison was made in various RNP cases in order to examine the algorithm accuracy in large - scale situations

### 3. Result and Discussion

The Gradient Based Cuckoo Algorithm operates by creating cuckoo species based on the parameters specified in Table 2. The main idea is to lay the cuckoo eggs as a host. In other words, the search will apply the RFID objective function as host. Each selected egg represents a new solution in the algorithm (i.e. new reader positions based on the maximum tags coverage). The best solution will be presented by the best egg by throwing out the weak solutions. The main formulas are shown in equation (11) to equation (15) below:
The new solution of $x_i(t+1)$ for the $i$th cuckoo will use the following Lévy flight equation (11) below:

$$x_i(t + 1) = x_i(t) + \alpha (\oplus)\text{levy}(\lambda)$$

(11)

The Lévy flight in above equation is considered as step-lengths based on the following probability distribution in equation. (12) Below:

$$\text{levy } u = t - 1 \quad 1 < \lambda < 3$$

(12)

The modification presented by Petriciolet in 2014 applied the random walk based on the fraction $(1-pa)$ of the replaced nests, $(1-pa)$ of the nest selected at random is abandoned and changed by new ones at new positions via local random walks. The local random walk can be written as equation (13) below:

$$x_i^{t+1} = x_i^t + \alpha (x_i^t - x_i^k)$$

(13)

To modify the present algorithm, the researcher resaved the randomness of the magnitude of the step. However, direction is calculated based on the gradient sign of the objective function. When the gradient is negative, the direction of step will be positive. If the gradient is positive, the direction of step will be negative. Based on the present sequence, new nests will be generated randomly from the worst nests but in the direction of the minimum number of old nests. The simple modification of the original cuckoo search algorithm was done to enhance the numerical performance of stochastic optimization methods particularly the precision and quality of global optimum solution. Thus, equation (11) is replaced by equation (14);

$$x_i^{t+1} = x_i^t + \text{step}_i \oplus \text{sign} \left( \frac{-\text{step}_i}{df_i} \right)$$

(14)

$$\text{step}_i = \alpha (x_i^t - x_i^k)$$

(15)

Where sign function involves the sign of its argument and $df_i$ is the objective function gradient at each variable, which is $\partial f/\partial i$. The results of this method show an improvement in fitness function effect based on the coverage efficiency and also specified the optimum installation reader positions [9; 11].

**Table 2. The GBCS parameters.**

| Symbols | Parameters | Symbols | Parameters |
|---------|------------|---------|------------|
| $(\oplus)$ | The multiplications of entry-wise | $p_a$ | The nest fraction |
| $x_{kt}$ and $x_{it}$ | Two different solutions | $\alpha$ | Random number intended by the uniform distribution |
| $d_{fi}$ | The objective function gradient | $\partial f_i/\partial i$ | The process variables |

GBCS operates in the following steps:

The step by step operating procedure of gradient cuckoo algorithm based on the specified parameters of RFID is explain as follows:

1- Randomly deploy the number of nests in working space, the nests must be equal to number of initial RFID readers.
2. Evaluate the fitness value of each RFID reader based on the (OF) objective functions used in the equations (1 to 10), then record the “Best Solution” of each reader.

3. Update the gradient position of all readers by using equation (14).

4. Evaluate the fitness value of each RFID reader then compare the results with the previous best fitness position.

5. If the achieved fitness value so far is global best with optimal reader position and the iteration has to be completed, then go to the end.

4. Simulation results

The simulation results were conducted with the selected Gradient Based Cuckoo Algorithm presented in Figure 4 and Figure 3. Figure 3 presents the scenarios of (80m²) working space. The RFID tags distribution were 100, 50 and 30. Figure 4 presents the scenarios of (150m²) working space. The tags distribution were also 50, and 30. All the results were based on the specific parameters of UHF RFID Network objective function presented in previous segment. Two kinds of Network Planning instance were conducted in this work, the clustered kind which is indicated by C100, C50, C30, and the random kind which is indicated by R100, R50, and R30. The run was conducted by MATLAB program 2018 with 12000 iterations and 40 independent. The readers denoted by red star as a coordinate center and the RFID tags are denoted by plus sign in blue color. With red dashed line circle for indicate interrogation range of RFID reader. The plotted results observed the RFID readers were distributed in two different areas in which id detected and covered the tags based on different probability. The results are compared with DB-FA algorithm results presented by Adel Elewe et al., 2017, [13-15]. He simulated the 30, 50 and 100 tags in the area of (80m²) and obtained the results presented in Table 3:

Table 3. Comparative Analysis of the Best Results of (80m X 80m) working space.

| Tags Number | Algorithm | Reader Number | Interference | Coverage |
|-------------|-----------|---------------|--------------|----------|
| C30         | GBCS      | 5             | 0            | 100 %    |
| C30         | DB-FA     | 5             | 0            | 100 %    |
| C50         | GBCS      | 5             | 0            | 100 %    |
| C50         | DB-FA     | 5             | 0            | 100 %    |
| C100        | GBCS      | 5             | 0            | 100 %    |
| C100        | DB-FA     | 6             | 0            | 100 %    |
| R30         | GBCS      | 6             | 0.005        | 92.5 %   |
| R30         | DB-FA     | 7             | 0.006        | 92 %     |
| R50         | GBCS      | 7             | 0.009        | 94 %     |
| R50         | DB-FA     | 8             | 0.002        | 98 %     |
| R100        | GBCS      | 6             | 0.009        | 94.5 %   |
| R100        | DB-FA     | 8             | 0.007        | 97 %     |

The results observe an enhancement in the objective function in all cases when using GBCS algorithm. And Comparative analysis observes the weakness in tag coverage in cases R50 and R100 in cases R50 and R100 the GBCS algorithm was able to achieve 94% and 94.5% coverage respectively, while DB-FA covered 98% and 97%. This is due to the DB-FA algorithm is working effectively in random data because using either uniform distributions or Gaussian distributions to generate novel explorative moves. As well as, they utilize exhaustive tuning; these two points make DB-FA algorithm working high efficiently with random data only.

The same scenario has been used on the larger region in order to explore the impact of the large-area such as warehouse, railway stations. The selected algorithm is GBC due to it presents good ability with large-scale cases. The results are shown in Table 4. It is seen that when the working space is enlarged, the domain of RFID tags coverage is reduced Another observation is the impact of random
tags distribution. Which weaken the capability of the GBCS algorithm to discover the tags as well as specify optimum RFID reader to each group of tags. The major reasons for that are the limited propagation range against the larger space between RFID tags and a large number of possibilities in the large area induce many obstacles to reach the best solution as observes that from the time of each run. The times of running in the second instances were five times the first instances in this paper. thus, as a solution to achieve good results for RFID Network design when it is needed to apply the algorithm in this size of working space, there is a necessity to divide the working space into small regions to deal with each region separately to be sure that the RFID objective function can work better. Therefore the authors recommend, that for areas larger than 80m x 80m, to cluster the area into regions and apply the algorithm in each region separately, a solution that will gives better results. Also the run was conducted by MATLAB 2018 with 12000 iterations. The number of iteration is few if compared with state-of-the-arts swarm intelligence iterations. Therefore few numbers of iterations mean reduce (time, effort and cost and fast convergence to find global best solutions) also the GBCS achieved a minimum number of the RFID reader in all cases also means (Reduce purchase and installation costs). Therefore GBCS improves the performance in terms of convergence rate, computation time, and cost.

**Table 4.** Comparative Results of (150m x 150m) working space.

| Tags Number | Algorithm | Reader Number | Interference | Coverage |
|-------------|-----------|---------------|--------------|----------|
| C30         | GBCS      | 6             | 0.01         | 85.3%    |
| C50         | GBCS      | 8             | 0.01         | 76%      |
| R30         | GBCS      | 6             | 0            | 71%      |
| R50         | GBCS      | 7             | 0            | 67%      |
Figure 3: Simulation results of (80×80) m2 scenarios

The clustered kind denoted by C100, C50, C30, and random kind denoted by R100, R50, and R30.
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5. Conclusion
A survey into best nature inspire algorithms in large scale Radio frequency identification technology Network design is crucial when it is necessary to apply them in real application such as supply chain management or controlling train stations by using RFID system. In this paper, we have compared two state-of-the-arts swarm intelligence based multi objective algorithms, namely, (GBCS) and (DB-FA) for that the researchers tested and compared these methods in large scale area $(80 \times 80m^2)$, then enlarged the area to $(150 \times 150)m^2$ to investigate the response of the used algorithm. The aim of the present work is to measure the weakness of applying the search algorithm in abnormally large area and select the best method to use in real case of large scale IoT field. The results show that GBCS was the best algorithm for detecting large number of tags and minimum number of readers as well as minimization of reader interference. The benchmark tests also observe that GBCS improves the performance in terms of convergence rate, computation time, and cost. Results guide the researchers to apply the same algorithm with larger area based on the same condition of dataset. The results demonstrate weakness in the algorithm operation due to large distance between the tag positions. The main reason for that is the limited propagation range against larger distance between tags Therefore, the authors recommend that if the area is bigger than $80m \times 80m$, to cluster the area into regions and apply the algorithm in each region separately. This solution will give better results.
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