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EFFECT OF PARAMETERS VARIATION ON THE PERFORMANCE OF PARTICLE SWARM OPTIMIZATION ALGORITHM FOR TAG COVERAGE PROBLEM OF RADIO FREQUENCY IDENTIFICATION NETWORK

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ABSTRACT
Optimal tag coverage is the most crucial aspect for deploying RFID (Radio Frequency Identification) system in a large scale. From the literature, optimal tag coverage can be considered as a high dimensional optimization problem and often solved using nature-inspired algorithms. In this paper, PSO (Particle Swarm Optimization) algorithm is used to optimize the tag coverage problem. This paper also investigates the effect of varying two parameters of PSO (swarm size and iteration number) to the performance of the algorithm. During the simulation sessions, both parameters are set at 50, 100, 150 and 200. Next, sets of comparison were made. From the experiment, the best set of results is generated when the swarm size is set at 200 and the iteration number is at 50. This is very encouraging because for the iteration number at 50, the runtime is much less (4.9s) compared to the higher iteration numbers (100, 150 and 200). The percentages for additional runtimes for iteration number set at 100, 150 and 200 are 103%, 204% and 341% respectively.

Keywords: RFID system, tag coverage, particle swarm optimization.

BRIEF INTRODUCTION OF RFID SYSTEM

An RFID system utilizes radio waves for the purpose of communication. This system consists of RFID tags or transponders, an RFID reader or interrogator and a data processing system which also known as middleware [1-4]. The main components of an RFID system are shown in Figure-1.

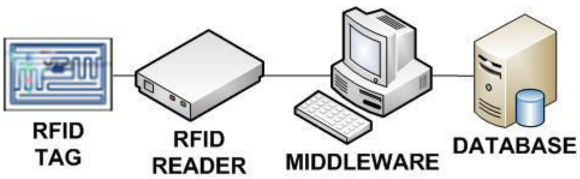

Figure-1. Main components of an RFID system [5].

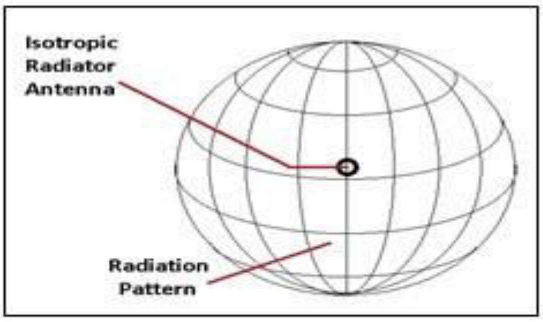

Figure-2. Radiation pattern of an isotropic radiator. RFID tag is used for storing unique ID and this tag is located or attached on the object to be identified.

RFID tags can be divided into two main categories (active tags and passive tags). The main difference between these two types of tags is the battery availability [2-3]. An active tag needs a battery while a passive tag does not need any. On the other hand, an RFID reader is a device that transmits electromagnetic waves as a medium of communication [3]. RFID reader will read the information stored in the tag and transfer the information to the middleware. In addition, the reader also capable of writing new information into the tag memory [1].

Low-cost RFID tag is capable of reading or writing information of an entity without contact physically, while it possesses a fast recognition speed, and has a relatively greater storing ability compared with bar-code [6-9]. Data-on-tag can also be modified for information updating purpose [10]. Additionally, RFID label or tag can be scanned from a greater distance and this will eliminate the need for Line of Sight [8, 11-13].

RFID NETWORK PLANNING (RNP)

RFID system reached its mature point nowadays and this system is often being deployed in a large scale for the purpose of tracking and managing assets. As the size of an RFID system goes bigger, the complexity of the system is also increasing. From there, various challenges come to surface such as achieving the optimal tag coverage, avoiding readers' collisions, obtaining a cost efficient RFID system and maintaining a good load balance between readers [14-19]. These challenges formed a new optimization branch known as RFID Network Planning (RNP).

RNP acts as the main requirement for deploying an RFID system. As the RFID system becomes larger, RNP importance will be deemed as more significant. This is due to the level of complexity of an RFID system is directly proportionate to its size [14]. A good RNP will produce an RFID system with an acceptable Quality of Service (QoS). This means that the particular system has the most optimum tags coverage, acceptable level of readers' interference and cost efficient (suitable number of

ARPN Journal of Engineering and Applied Sciences

readers). In order to control RNP, several parameters will be taken into consideration (location of readers, number of readers and antenna parameters) [18]. RFID readers come with various detection ranges but these ranges have their own limits. With the limited range of tag detection, a proper number of readers are needed to cover the whole working area. If the number of readers is not sufficient, there will be RFID tags that are not detected. In addition, an RFID system with more readers than needed will cost more to setup and there will be a chance of signal interference between readers. From here, it can be concluded that as an RFID system goes bigger, the complexity of the system will follow suit. This paper focuses on the optimal tag coverage of the RFID system because it is very crucial [14].

OPTIMAL TAG COVERAGE

In order to solve RNP, literature suggest the use of Nature Inspired Algorithm such as Genetic Algorithm (GA) [1-2], Particle Swarm Optimization (PSO) [2-4], Bacteria Foraging Optimization (BFO) [5], Evolution Strategy (ES) [2] and others. In this paper, PSO algorithm is used for optimizing the optimal tag coverage problem. The mathematical model for optimal tag coverage is taken directly from [17-19] due to its flexibility and a good establishment. This mathematical model can be elaborated to suit the complexity of the RFID system (refer Equation (1)).

$$\text{Minimize } C = \sum_{i=1}^{N_T}(P_i^r - P_d) \tag{1}$$

From Equation (1), P_i^r is the power receives at tag and P_d is the threshold power (minimum power to initiate communication between a reader and a tag). This equation focuses on minimizing the differences between the powers receive at tag and the threshold power. In addition, this equation tends to move readers to the areas with higher densities of tags. For the areas with fewer tags, a higher radiate power will be used.

In the optimal tag coverage problem optimization, three system parameters will be considered: 1) x-coordinates of readers, 2) y-coordinates of readers and 3) the readers' powers. From Equation (1), the correlation between these parameters is not available. As a result, before Equation (1) can be used for optimization, it must be elaborated for the purpose of exposing the correlation between Equation (1) and system parameters (x and y coordinates and readers' powers). In order to simplify the model, this paper utilizes isotropic radiator antennas (refer Figure-2). The radiation pattern of an isotropic radiator is like a sphere shape as it radiates in omni-direction [20]. For the power received at tag, P^r, the formula is taken from [21] (refer Equation (2)).

$$P^r = P^t \frac{A_e}{4\pi r^2} \tag{2}$$

Notation				
	P^r	: Power received at tag	A_e	: Effective aperture
	P^t	: Power transmitted from reader	r	: Distance between tag and reader

To calculate the effective aperture, A_e, another method from [21] is followed (refer Equation (2)):

$$A_e = \frac{\lambda^2}{4\pi} \approx 86cm^2 @915\,MHz \tag{3}$$

In Equation (3), λ is defined as the wavelength (meter). In addition, $\lambda = \frac{c}{f}$ where c is the speed of light (299792458 m/s) and f is the UHF frequency [21-22].

It is also worth to note that in Equation (1), the value of P_d is set at -10 dBm. For that reason, Equation (2) should be made compatible with the dBm unit. The formula for converting P^r from mW to dBm is as follow [23] (Equation (4)):

$$P^r_{dBm} = \log_{10}(P^r_{mW}) \times 10 \tag{4}$$

Embedding Equation (4) into Equation (2) will result as follow:

$$P^r_{dBm} = \log_{10}(P^t\left(\frac{A_e}{4\pi r^2}\right) \times 1000) \times 10 \tag{5}$$

Next, Equation (5) need to be embedded into Equation (1) in order to form the objective function

$$\text{Minimize} \quad C = \sum_{i=1}^{N_T}(\left(\log_{10}(P^t\left(\frac{A_e}{4\pi r^2}\right) \times 1000) \times 10\right) - (-10)) \tag{6}$$

In Equation (6), one parameter of RNP (power of reader, P^t) is available. The other two parameters of RNP (x and y coordinates of reader) is still not available. For that reason, the relation of the reader coordinates to the optimal tag coverage objective function (Equation (6)) needs to be derived.

A further exploration in Equation (6) can reveal that the relation between the coordinates of reader and tag is embedded under the variable, r which represents the distance between the transmitter (reader) and the receiver (tag). The formula of r is presented in Equation (7) [24-25]. Given that, *(x,y)* is the coordinate of a reader and *(a,b)* is the coordinate of a tag. The distance between a reader and a tag:

$$r = \sqrt{(x-a)^2 + (y-b)^2} \tag{7}$$

Embedding Equation (7) into Equation (6) will yield an objective function that shows the direct relation to

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ARPN Journal of Engineering and Applied Sciences

the three parameters of RNP: coordinates and power of reader (refer Equation (8)).

$$\text{Minimize}$$
$$C = \sum_{i=1}^{NT}\left(\left(\log_{10}\left(P^t\left(\frac{A_e}{4\pi((x-a)^2+(y-b)^2)}\right) \times 1000\right) \times 10\right) - (-10)\right) \tag{8}$$

Equation (8) can be used directly in PSO optimization. Before that, it is worth to note that there are 10 readers used in this paper. As a result, there will be10 values for each RNP parameters which make the dimension of each PSO solution is equal to 30. In short, the formula for determining the number of dimensions for each solution is *3M* [17-19]. *M* is equal to the number of readers in the system. In the *3M* formula, the first 2*M* s represent the x and y coordinates of reader while the other one *M* is for the power of reader. If the number of readers is 3, the number of dimensions for each PSO solution is 3x3=9 dimensions (refer Equation (9)).

$$D = 3M = 3 \times 3 = 9\ dimensions$$
$$D = (x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9) \tag{9}$$

Each x is equal to one dimension of PSO solution. Each x has its own representation (refer Table-1) [26].

Table-1. Representation of PSO solution.

Name of RFID reader	x coordinate (meter)	y coordinate (meter)	Power of reader (watt)
Reader 1	x_1	x_2	x_7
Reader 2	x_3	x_4	x_8
Reader 3	x_5	x_6	x_9

PARTICLE SWARM OPTIMIZATION (PSO) ALGORITHM

PSO algorithm is an optimization technique that is based on population system. This algorithm is inspired by the movement of birds and fishes in their own groups [27]. PSO operates in multi-dimensional metric and it uses real number values. In addition, PSO is also inspired by the concept of Evolutionary Computation [28]. PSO has a strong relation to Genetic Algorithm (GA) and Evolutionary Computing (EC). PSO and GA are almost similar except PSO does not apply Mutation and Crossover operations [27].

Mathematically, PSO utilizes the concept of particle's location and velocity. Before beginning each search for best solution, some values need to be taken into account such as the best known locations found by a particle, its neighbor (informants) and any particle in the swarm [29]. To use PSO, ones must understand the standard formula of PSO [27, 30-31].

$$v(t+1) = wv(t) + R(c_1)\big(p(t) - x(t)\big) + R(c_2)\big(g(t) - x(t)\big) \tag{10}$$

$$x(t+1) = x(t) + v(t+1) \tag{11}$$

Notation					
$v(t+1)$	:	New velocity	$p(t)$	:	Personal best known position
w	:	Inertia weight	$x(t)$	:	Current position
$v(t)$	:	Current velocity	c_2	:	Social weight
R	:	Random variable (0 to 1)	$g(t)$	:	Global best known position
c_1	:	Cognitive weight	$x(t+1)$	:	New position

Equation (10) is for updating the velocity of particle. The new velocity is represented by $v(t+1)$ and there are three (3) terms that contribute to the new velocity. The first term is $wv(t)$ and this is where the current velocity, v and the inertia weight, w takes place. The inertia weight, w is used to control the velocity of each particle [32]. The second term which consists $R(c_1)\big(p(t) - x(t)\big)$ is for the movement of particle based on the particle's best known solution. This term also related to the cognitive part of the particle because it contains $p(t)$ which represents the best location found so far and $x(t)$, the current location of particle [33]. In the second term, R is random variable in the range of 0 to 1 while c_1 is known as cognitive weight. The third term of basic PSO equation is devoted to the social behavior of each particle. The factor that contributes the social effect is g(t) which represents the best location so far found by any particle in the swarm. In this social behavior, all particles in the swarm do communicate with each other in order to share information about the best location. The R variable in the third term is same to the one in the second term. To control the movement of particle in its social behavior, the variable c_2, social weight is used [34].

In PSO calculations, there are three main aspects need to be considered: velocity of a particle in interest, the best position found by the particle and any best position found so far by any particle in the swarm. These elements can be obviously seen in the standard PSO formula (refer Equation (10)).

For the purpose of updating the location of each particle, Equation (11) is used. This equation formed by summing the new velocity value with the value particle's current location.

COMPUTATIONAL EXPERIMENT

In this paper, the working area is a 30m x 30m square area with 100 randomly scattered tags and 10 readers need to be located according to optimal tag coverage objective function. As mentioned before, the locations of RFID readers must satisfy the needs of the mentioned objective function. In this paper, the number of readers in used is 10. As a result, the calculation for dimension of each particle is as follows:

$$\text{Number of reader, } M = 10$$
$$\text{Dimension of each particle,} \tag{12}$$

From Equation (12), the number of particle's dimension is 30. The coordinates for the ten readers are represented by x_1 to x_{20} while x_{21} to x_{30} represent the power of Reader 1 to Reader 10. All numbers in the particle's dimension will be embedded into the objective function. As mentioned before, the objective function is the optimal tag coverage (refer Equation (1)).

The main purpose of this paper is to minimize the value of the objective function (Equation (1)). For that reason, the lower the value of the objective function, the result is considered much better. The iteration number is set at 50, 100, 150 and 200. The same level applies to the number of swarm. The variables for this experiment are iteration number and number of swarm. As there are 4 levels for each variable, the number of experiment settings can be calculated using 2^4=16. For each setting, 10 simulation runs are completed. The average value for the objective function can be seen in Table-2. From here, the setting of iteration number set at 50 and number of swarm is set at 200 (iter=50, swarm=200), shows the best result.

In order to get a more precise result, the minimum values generated in each setting are recorded (refer Table-3). From the table, the best result (lowest value) is for the setting of iter=50 and swarm=200.

Table-3 seems to strengthen the position of the setting of iter=50 and swarm=200 to be the best setting. Besides the value of the objective function, this paper also takes into account the time needed for completing each simulation run. The average time needed (in seconds) can be seen in Table-4. From here, it is worth to note that, for the setting of iter=50 and swarm=200, the running time is only 4.86 s. For the other settings with the swarm number of 200, the percentages for additional runtimes for iteration number set at 100, 150 and 200 are 103%, 204% and 341% respectively. In addition, these settings (iter=100,150 and 200), do not yield the minimum value for the objective function. This is a good sign because, although the setting of iter=50 and swarm=200 only needs a short runtime period, this setting produces good results.

Table-2. Average value for the objective function.

Objective Function Value (Average)				
Iteration Number	Number of Swarm			
	50	100	150	200
50	12261.93	11895.57	11882.23	**11455.27**
100	12398.34	12447.42	11873.67	11914.57
150	12459.45	12531.18	12047.65	12108.86
200	12765.78	11838.71	12118.47	11773.77

Table-3. Minimum value generated in each setting.

Objective Function Value (Minimum)				
Iteration Number	Number of Swarm			
	50	100	150	200
50	11728.08	10734.67	11026.48	**10558.78**
100	11577.31	11172.81	10765.33	10626.07
150	11190.78	11892.26	10941.58	11647.23
200	11662.56	10616.91	10807.20	10951.16

Table-4. Average time needed for each simulation run.

Runtime (Seconds)				
Iteration Number	Number of Swarm			
	50	100	150	200
50	1.27	2.52	3.73	**4.86**
100	2.48	4.94	7.46	9.86
150	3.84	7.69	11.45	14.78
200	5.22	11.68	15.65	21.40

In order to visualize the effect of varying the iteration number to the performance of PSO, Figure-3 is constructed. In the figure, it can be seen that iter=50 produces the lowest value in most of the runs. It is also worth to note that the values are consistent for iter=100. Unfortunately, iter=100 does not produce the lowest value.

Figure-4 shows the performance of each swarm number in the group of iter=50. In this figure, swarm=200 seems to generate lowest values in most of the runs. This figure agrees with the claim that the setting at iter=50 and swarm=200 is the best. It is also obvious that swarm=50 produces a lot of highest values. Highest value is deemed as not a good result. One reason for this scenario is for swarm=50, the number of particles is only 50. For that reason, the size of communication network is small compared to when swarm=200. It will take a longer time for swarm=50 to find a good solution because the best values in the swarm come from only 50 particles.

ARPN Journal of Engineering and Applied Sciences

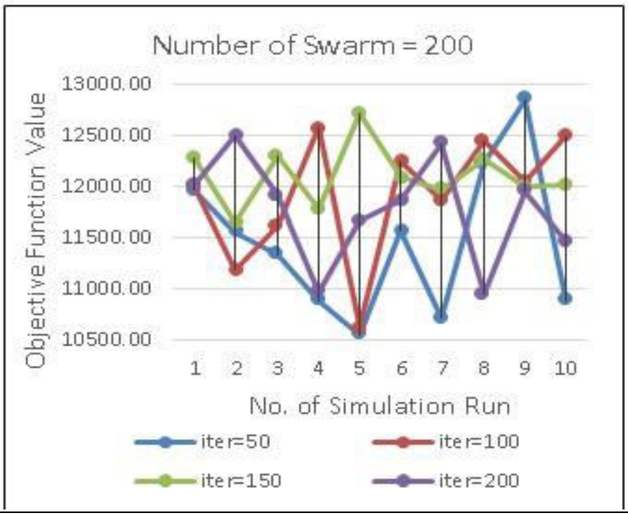

Figure-3. Behavior of each iteration number in the group of swarm 200.

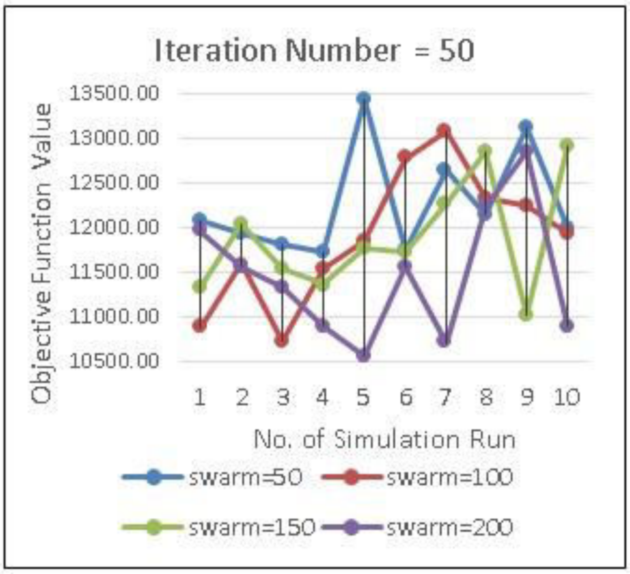

Figure-4. Behavior of each swarm number in the group of iteration set at 50.

CONCLUSIONS

From this paper, the best result is generated when the iteration number is set at 50 (iter=50) and swarm number is set at 200 (swarm=200). This setting seems to generate the lowest average values too. The time needed to run this setting is only 4.86s, which is much shorter compared to other settings in the swarm of 200. This is deemed as a good characteristic because for the iter=50 and swarm=200, good results can be generated in a short period of time. This characteristic will yield an excellent decision making tool for RFID Network Planner.

In the future, other types of antennas can be used (dipole antenna and directional antenna). These types of antennas exist in the real world thus the results generated are good for the RFID industry. In addition, there are more parameters of RNP can be investigated such as the number of readers, number of tags and working space dimension. The effects of varying these parameters are worth to be studied for the purpose of building a robust decision making tools. Other than that, researchers can study the effect of varying other PSO parameters such as the inertia weight (w), cognitive weight ($c1$) and social weight ($c2$). These parameters are worth to be studied because the objective function of RNP is a high dimensional and nonlinear optimization problem.

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