RFID network scheduling using an improved bat algorithm

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Abstract. The performance of RFID networks can be optimized by RFID reader scheduling. This paper proposed a novel approach using an improved bat algorithm (IBA), which can optimize RFID networks. The IBA algorithm includes 2 improved mechanisms. In the proposed approach, all RFID readers are scheduled to work in appropriate sequence, which can greatly reduce RFID collisions. Experiments on two different RFID networks have been carried out to evaluate the effectiveness. Simulation results show that the proposed approach using IBA has better optimization precision than control algorithms.

1. Introduction
Radio frequency identification (RFID) has been used widely in many types of industries including supply chain management, localization, medical monitoring and smart home, etc. Furthermore, it is counted as a foundation technology in the field of internet of things.

RFID network scheduling, which can be called as RNS, is an important research orientation to optimize large-scale RFID network performance. The RNS problem was firstly raised by Chen et al. [1]. Generally, since RFID has limited communication region, multiple readers are necessary to monitor tags in operation states. Firstly, in practical aspect of numerous applications, it is unnecessary to monitor tags in the entire region. For example, RFID tags should be communicated if they are located in exits and entrances of library. The region of exits and entrances are usually perspicuous. Secondly, from the aspect of optimizing economic benefits, it is uneconomic to use RFID readers work with maximum power all the time. Thus, the reader work parameters should be fully considered to void wasting resources. Thirdly, RFID system cannot work if there is collision occurred between RFID readers and tags.

Recently, swarm intelligence (SI) algorithms have been applied to solve RNS problem mentioned in this paper. Among those approaches, Particle swarm optimization (PSO) is easy to implement using few parameters. However, particles cluster rapidly will give rise to premature convergence, which makes PSOs always drop into local optimum [2]. Genetic algorithm (GA) is good at reaching a near optimal solution [3].However, they have trouble in finding an exact solution because previous knowledge will be destroyed while genetic population changes [4].On the basis of the above research, an RFID network scheduling model is proposed in this paper, which can be solved by using the improved IBA algorithm.
2. Related work

2.1 RFID network scheduling model
RFID reader scheduling model demonstrates RFID reader collisions in terms of graph theory. For a given RFID network including readers and tags, $G=(V,E)$, each reader is a vertex $v \in V$, there will be an edge $e \in E$ between two vertexes if the two readers can work simultaneously, that is to say, there are no collisions between them. The reader scheduling model is defined in Eq. (1).

$$
\begin{aligned}
\min F &= \frac{1}{w_1 \times N + w_2 \times T + w_3 \times W + w_4 \times C - P} \\
\text{s.t.} &\quad w_i > 0, \quad i = 1, 2, 3, 4 \\
&\quad \sum_{i=1}^{4} w_i = 1
\end{aligned}
$$

(1)

where $N$ is working readers in the current time slot, and the cumulative time of working readers is $T$. $W$ is the average working time, $C$ is the entire non-working readers. That is to say, readers in $C$ have collisions with readers in $N$. $P$ would be maximum if working readers cannot meet constraints, otherwise $P=0$. That is to say, $P$ is a penalty function. $w_i$ are weighted coefficients, $w_2 \geq w_1 \geq w_4 \geq w_3$.

2.2 Optimization algorithms in RNS
Chen et al. [1] firstly raised the RFID reader scheduling (RNS) problem. They proposed an approach of node scheduling, which makes the RNS problem transform to a problem of graph partitioning. The proposed model minimizes the entire working time in RFID networks, meanwhile to reduce reader collisions by scheduling working time slot of readers. A multi-swarm cooperative particle optimization (MCPSO) algorithm was proposed by Niu et al. [5]. An approach using improved GA was presented by Chiu et al. [6]. Tang used a hybrid binary PSO to solve the model [7]. A variant of PSO called PSOPC to find reader optimum configuration [8].

3. Improved bat algorithm

3.1 The text of your paper should be formatted as follows:
Inspired by bats’ echolocation behaviour, Yang et al. proposed the original bat algorithm (BA) [9]. The proposed IBA algorithm includes 2 improved mechanisms. In the original BA algorithm, with increment of iterations, individual bats will gather around the optimal individuals at the later stage. The bat group is difficult to escape from the local optimal region, while the optimal individuals are the local optimal value. Then it is necessary to change the status of the bat group in order to improve global the search capability. Therefore, according to the overall changes of individual fitness of all bats in the bat group can track and judge the location of the whole bat group, so as to avoid individual bats premature. The whole bat group standard deviation threshold can be extracted using Eq. (2).

$$
T = \text{std}(f(x_1), f(x_2), \ldots, f(x_N))
$$

(2)

In the course of flight migration, the bat population will evolve and adjust its position continuously. According to the standard deviation formula of biological population based on Chaos and differential evolution, the standard deviation of bat group flight can be predicted. It is shown in Eq. (3).

$$
\text{std} = \frac{1}{N} \sum_{i=1}^{N} \frac{P_i - P_{\text{avg}}}{P}
$$

(3)

where $\text{std}$ is standard deviation in evolutionary process, $P_i$ is the location of each individual bats, $P$ is limiting factor, and the limiting factor restricts the increase of variance $\text{std}$, $\max(|P_i - P_{\text{avg}}|/P) < 1$. The value of $P_{\text{avg}}$ is shown in Eq. (4).

$$
P_{\text{avg}} = \frac{1}{N} \sum_{i=1}^{N} P_i
$$

(4)
If $\text{std} < T$, the group conforms to the early maturity mechanism, and the whole bat group needs to be readjustment. The variances of group fitness reflect the aggregation degree of the individuals in bat group. Among them, bigger fitness variance would result in greater diversity of bat group, and better global optimization performance can be obtained. If the value of $\text{std}$ is smaller, the greater aggregation degree of the bat group, the diversity of bat group will be worse and it will easily get trapped in a local optimal solution.

### 3.2 Mutation mechanism

Mutation mechanism is proposed to make bat group break away from local optimal aggregation. The mutation mechanism aims to produce oscillatory mutation for the early maturity of bat group. On the one hand, we can enhance the diversity of bat group itself and avoid it trapped in local optimal solution and further global search; on the other hand, it enhances the vitality of individual bats make it produce more advantageous individual bats to avoid the algorithm converges too fast, and further improve the accuracy of algorithm results. The mutation factor $F$ is shown in Eqs. (5)-(6).

$$Na = \exp\left(\frac{1-N_{\text{gen}}}{1+N_{\text{gen}}-N}\right) \tag{5}$$

$$F = F_m \times 2^{Na} \tag{6}$$

where $N_{\text{gen}}$ is maximum number of iterations, $N$ is the number of iterations for the current iteration, $F_m$ is mutation rate and $F_m = 0.5$.

Introduce the mutation factor into iterations, and deeply oscillate the aggregated bat individuals in order to make them more energetic and search again, as shown in Eq. (7).

$$V_{iD}(i+1) = w\times x_{iD}(i) + c_1 \times \text{rand} \times [x_{\text{best}}(i) - x_{iD}(i)] + c_2 \times F \times [x_i(i) - x_s(i)] \tag{7}$$

where $w$ is inertia weight, $c_1$ and $c_2$ are acceleration factor, $F$ is variation factor, $k\neq s\neq i$, $k$ and $s$ express 2 individuals of non-bat individual. $[x_{\text{best}}(i) - x_{iD}(i)]$ can speed up the convergence rate and find the best result. $[x_i(i) - x_s(i)]$ combination with variant factor $F$ is advantageous to improve the probability of biological variation of bat particle population, avoiding the bat group are trapped in local optimum. Variation of bat group is advantageous to improve bat particle optimizing ability.

Figure 1 demonstrates the flow chart of the proposed approach using IBA.

### 4. Experimental results

#### 4.1 Simulation environment

The experiment has been carried on in this paper. The platform is Intel Core i7-7500U @ 2.70 GHz, RAM 8.0 GB, and MATLAB R2016b. Two different RFID network topologies are used.

**Network I:** The experimental area is 40×40 unit length (UL). There are 10 readers deployed randomly in the experimental area. The maximum interrogation region of readers (MIR) is set as 15 UL. The reader working time is randomly generated in [5, 20] seconds, as shown in Table 1. Figure 2 demonstrates the situation of reader collisions in the experimental area. Thus, two readers cannot work simultaneously if they don’t have an edge between them.

**Network II:** The experimental area is 50×50UL. There are 16 readers deployed randomly in the experimental area. The MIR is set as 15 UL. The reader working time is randomly generated in [5, 20] seconds, as shown in Table 2. Figure 3 demonstrates the situation of reader collisions in the experimental area. Thus, two readers cannot work simultaneously if they don’t have an edge between them.
Figure 1. The flow chart of the proposed approach using IBA algorithm

![Flow Chart]

Figure 2. RFID reader collisions (Network I)  
Figure 3. RFID reader collisions (Network II)

Table 1. Reader working time (Network I).

| Reader number | 1   | 2   | 3   | 4   | 5   |
|---------------|-----|-----|-----|-----|-----|
| Working time/s| 6.03| 18.93| 5.98| 7.15| 17.45|

| Reader number | 6   | 7   | 8   | 9   | 10  |
|---------------|-----|-----|-----|-----|-----|
| Working time/s| 6.12| 5.23| 17.03| 6.32| 19.90|

Table 2. Reader working time (Network II).

| Reader number | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   |
|---------------|-----|-----|-----|-----|-----|-----|-----|-----|
| Working time/s| 6.03| 18.93| 5.98| 7.15| 17.45| 13.34| 19.57| 5.87|

| Reader number | 9   | 10  | 11  | 12  | 13  | 14  | 15  | 16  |
|---------------|-----|-----|-----|-----|-----|-----|-----|-----|
| Working time/s| 6.12| 5.23| 17.03| 6.32| 19.90| 15.22| 17.14| 5.34|
The proposed approach has been compared with 4 other control algorithms: BA [9], PSO [10], guaranteed convergence PSO (GCPSO) [11], and binary GA [12]. Algorithm parameters are set as the same in original papers. For the IBA, frequency weight coefficients $\alpha = 0.9$ and $\gamma = -0.9$; $w = 0.8$, $F = 0.5$; $c_1$ and $c_2$ are set to 2.

4.2 Simulation results
Experimental results of Network I are shown in Table 3. Table 4 presents experimental results of Network II. In this section, all experimental data (average entire working time and average time slot number of readers) are obtained in 1000 sample runs.

In Table 3 - 4, the proposed approach using IBA algorithm can get better results in comparison to other control algorithms in solving the RNS problem. So the proposed approach has better performance than control algorithms in solving the proposed reader scheduling model, that is to say, less working time and fewer time slot number will be used to monitor the entire RFID network through using the proposed approach.

What’s more, although GA has a bad result in Table 4, the success rate is 100%. However, the other algorithms have certain failure probability in solving RNS problem. Actually, this situation may be caused by weighted coefficients in the model, which makes these algorithms to get trapped in a local optimum. Results accord with the deduction stated in section 1 that GAs are the best algorithms at reaching a near optimal solution, however, they have trouble finding an exact solution. As to IBA algorithm used in this paper, although it has the best results comparing to other control algorithms, the global search ability still needs further improved.

Table 3. Experimental results (Network I).

| Algorithms | Average time/s | Average slots | success rate % |
|------------|----------------|---------------|----------------|
| IBA        | 71.73          | 6.00          | 100            |
| BA         | 71.92          | 6.01          | 100            |
| GCPSO      | 71.88          | 6.01          | 100            |
| PSO        | 72.27          | 6.00          | 100            |
| GA         | 83.35          | 6.24          | 100            |

Table 4. Experimental results (Network II).

| Algorithms | Average time/s | Average slots | success rate % |
|------------|----------------|---------------|----------------|
| IBA        | 134.63         | 10.62         | 92.36          |
| BA         | 136.55         | 10.78         | 85.67          |
| GCPSO      | 135.99         | 10.73         | 87.00          |
| PSO        | 137.59         | 10.82         | 82.70          |
| GA         | 152.18         | 11.59         | 100            |

5. Conclusions
An efficient approach in the field of RFID network scheduling is presented. The proposed approach employs IBA algorithm. The advantage of IBA algorithm is that it does not require external parameters. The experimental results based on two different RFID networks proved that the proposed approach using IBA algorithm has better optimization precision than the compared control algorithms. In next work, the global search ability of IBA algorithm shall be further improved to enhance its performance.
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References
[1] H.N. Chen, Y.L. Zhu, K Hu, et al. Application of a multi-species optimizer in ubiquitous computing for RFID networks scheduling. In: Proc. of 3rd International Conference on Natural Computation (ICNC 2007). IEEE, 2007, pp.420-425.
[2] H.N. Chen, Y.L. Zhu, K.Y. Hu. Multi-colony Bacteria Foraging Optimization with cell-to-cell communication for RFID Network Planning. Applied Soft Computing, 2010, vol.10(2), pp.539-547.
[3] M. Settles, T. Soule. Breeding swarms: a GA/PSO hybrid. In: Proc. of 2005 conference on Genetic and evolutionary computation. ACM, 2005, pp.161-168.
[4] C.F. Juang. A hybrid of genetic algorithm and particle swarm optimization for recurrent network design. IEEE Transactions on Systems, Man, and Cybernetics, Part B: Cybernetics, 2004, vol.34(2), pp.997-1006.
[5] B Niu, E.C. Wong, Y Chai, et al. RFID Network Planning Based on MCPSO Algorithm. In: Proc. of Second International Symposium on Information Science and Engineering (ISISE). IEEE, 2009, pp.8-12.
[6] Chui-Yu Chiu, Cheng-Hsin K, Chen K Y. Optimal RFID networks scheduling using genetic algorithm and swarm intelligence. In: Proc. of IEEE International Conference on Systems, Man and Cybernetics (SMC 2009). IEEE, 2009, pp.1201-1208.
[7] J. Tang. Solving RFID Networks Scheduling Problems Using Hybrid Binary Particle Swarm Optimization Algorithm. Applied Mechanics and Materials, 2010, vol.29, pp.966-972.
[8] W. Liu, H.X. Chen, H.N. Chen, et al. Improved Particle Swarm Optimizer for RFID Network Planning. Journal of Jilin University (Information Science Edition), 2011, vol.29(2), pp.121-127.
[9] Yang X S. A new metaheuristic bat-inspired algorithm. Nature inspired cooperative strategies for optimization (NICSO 2010). Springer, Berlin, Heidelberg, 2010: 65-74.
[10] Y. Shi, R. C. Eberhart. Empirical Study of Particle Swarm Optimization. In: Proc. of 1999 Congress on Evolutionary Computing, 1999, pp.1945-1950.
[11] F.Vanden Bergh, A. P. Engelbrecht. A New Locally Convergent Particle Swarm Optimizer. In: Proc. of IEEE Conference on System, Man and Cybernetics, 2002.
[12] S.H. Cha, C. Tappert. A genetic algorithm for constructing compact binary decision trees. Journal of pattern recognition research, 2009, vol.4(1), pp.1-13.