ISSN : 0974 - 7435 Volume 10 Issue 13

2014

BioTechnology

An Indian Journal

FULL PAPER

BTAIJ, 10(13), 2014 [7032-7044]

A novel intelligent anti-collision algorithm for radio frequency identification devices

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ABSTRACT

A radio frequency identification reader anti-collision optimization model is studied for Internet of things, which considers minimizing reader conflicting and total processing time. Based on the standard particle swarm algorithm, we propose a new anti-collision model on account of biological symbiosis theory of the nature. It defines the information communication mechanism of cooperation in single species and collaboration between species, so that symbiotic strategy in ecological system is established. It has better diversity keeping ability and searching performance. The simulation result shows that our proposed algorithm can effectively solve reader collision problem in intensive reader environment and optimize the efficiency of the whole reader network.

KEYWORDS

RFID; Anti-collision; Particle swarm optimization; Symbiotic strategy.

INTRODUCTION

Under the background of national strategy digital convergence and sensing China, Internet of things has received great attention from the government, industry, stock and etc. RFID technology as the main driving technology of Internet of things, which is considered one of the top ten important technologies in this century[1-5]. At present, the applications of RFID system form a small scale market in the logistics, transportation, retail and etc. However, the automation, intelligence, and coordination of the RFID system are still in low level. There are a lot of key problems of fundamental application technical researches to solve. Among them, the RFID system optimization technique[6,7,8], as the basis to ensure the RFID system stable, reliable and safe operation, has become important issues in the RFID technology research and application.

In RFID systems, there is a reading device called a reader, which is typically a powerful device with ample memory and computational resources. And there are more tags. Tags are different in their computational capabilities. Tags respond only at reader commands, to smart active tags, which have an onboard microcontroller, transceiver, memory, and power supply.

Among kinds of tags, passive tags can be a suitable choice for large scale deployments because of their low cost. Collision because of simultaneous tag responses is one of the important issues in RFID systems. Collision results in a waste of bandwidth, energy, and increases identification delays. In order to minimize collisions, RFID readers must use an anti-collision algorithm. Up to now, there are two kinds of anti-collision algorithms. In[19], the paper reviews Aloha variants only, which lacks coverage of dynamic FSA protocols using a tag estimation function to derive the optimal frame size for use in each round, especially those published after the year 2004. In the second paper,[20]only refers to four Aloha and nine tree variants. Binary tree based deterministic algorithm builds a tree with tag identifiers expressed in binary bits and identify tags by browsing through the nodes in the tree. In the ALOHA algorithm, every tag within a reader's identification area selects one of the given N slots to transmit its identifier.

The transmitted and received signals by the readers and the tags are in a specific frequency. Some kinds of problems arise when a lot of RFID readers are placed close to each other, which form a dense covered area[9-12]. Two readers can interfere each other even though these readers' interrogation zones do not overlap[13,4]. Due to the RFID system optimization generally being nonlinear, multi-objective, and large scale complex problems, this thesis uses the characteristics that the intelligent optimization algorithms have more advantages than the traditional mathematical optimization algorithms in accuracy, convergence, initial value sensitivity, robustness and adaptability of solutions, and etc, for solving this kind of problems. On basis of the review of biological heuristic calculation researches, RFID system optimization models[15-18] and intelligent algorithms based on biological behaviors are proposed. Through in-depth studying general and extensible RFID system optimization model, and designing a set of efficient and reliable intelligent optimization algorithms based on biological behaviors, the research fruits can mainly solve the optimization problems related to RFID reader scheduling, network loading balance, labels coverage, and multi-reader data fusion, and etc[21-25], which improve the operation efficiency and service quality of the RFID system.

In the next section, we introduce read write device confliction analysis and mathematical model. In Section3 we propose a RFID read write device anti-collision algorithm based on improved particle swarm optimization. In Section 4, in order to test the performance of proposed scheme, we design an experiment. In Section 5 we conclude the paper and give some remarks.

READ WRITE DEVICE CONFLICTION ANALYSIS AND MATHEMATICAL MODEL

Radio frequency identification RFID system is composed of RFID label and network RFID read-write device. Each link of the supply chain often appears disorder. No matter which link items lies in the supply chain, RFID read-write device must make at least one RFID tag of the object can communicate with tag read/write device[. All the read/write device around them has a limited space, and in this space they can communicate with the label. This space is called Interrogation Zone of the read-write device. In a supply chain, a read/write device cover will exist read/write device redundancy in many parts of the space. There are multiple read/write device read areas of the intersection. Read/write device read area intersection would result in interference between read/write devices, and two interference devices can not read any label in the reading area. Intensive reading and writing device network usually realizes all-round coverage of label in the physical environment, so overlapping situation of some Interrogation Zone will occur. When two read write devices uses the same signal frequency, and the distance between them is close, signal interference between the read write devices is easy to occur, resulting in read/write device confliction. This interference is caused by using communication radio frequencies, which is similar to interference of the cellular phone system.

For confliction problem, R represents read write device set, $R_i \in R$ represents read write device i. $f(R_i, t)$ represents that a serial of frequency are assigned to R_i according to assignment rule within time t. A feasible frequency allocation must meet certain frequency range and interference restraint. In RFID system, spectrum F is divided into k number of independent subinterval c_i.

$$F = \{c_1, c_2, \ldots, c_k\}, c_i \cap c_j = \varnothing, c_1 \cup \ldots \cup c_k = F. \quad \mathbf{(1)}$$

$i, j = 1, 2, \ldots, k, i \neq j$. For receiver, we can only define interference. For transmission, the RFID tag is just a simple receiver, rather than an emitter. For a RFID system, interference which can be controlled is a function of frequency and distance. There are two types of interference including frequency interference between multiple read/write devices and the interference between the tags and multiple read/write devices.

Two or more read write devices are used for communication under the condition of the same time and the same frequency. A read/write device sending strong power signal will lead to the near read/write devices receive the signal. This signal is equivalent to noise for near read/write device. When its power is more than the specific value, it blocks the normal communication. The area is a spherical area taking read write device as the center.

There are k number of read write devices. The minimal distance that frequency interference between two read write devices does not occur is d. When $i \neq j$, $D(R_i, R_j)$ is space distance between R_i and R_j. If $D(R_i, R_j) < d$ and $f(R_i, t) = f(R_j, t)$, frequency interference between R_i and R_j will occur. When one or more tags is in the read area of two or more than two read/write devices, and there are multiple read/write devices trying to communicate with them at the same time, label interference will produce at this time. In this case the actual situation is multiple read/write devices communicating with it at the same time. And due to limited function of the label itself, it can not identify the different read and write device signal, which can lead to labels can't respond to any identification request of read and write device. D_i is the maximum distance of Interrogation Zone of read write device R_i. $D(R_i, R_j)$ is space distance of device R_i and device R_j. If $D(R_i, R_j) < D_i + D_j$, it is possible t9hat label interference of overlapping area of Interrogation Zone between R_i and R_j occurs when R_i and R_j operate at the same time.

Confliction between the large-scale RFID network nodes can't use the traditional anti-collision algorithm to solve. So this paper investigates mathematical optimization model of RFID read write device anti-collision to optimize time slot allocation and total processing time, which can allocate working time and frequency reasonably. RFID network G has n number of read write devices. $V(g) = \{v_1, v_2, \ldots, v_n\}$ is vertex set. $E(g) = \{e_1, e_2, \ldots, e_n\}$ is edge set, and $A(g) = (a_{ij})_{p \times p}$ is adjacency matrix of G.

$$a_{ij}=\begin{cases}1 & v_i,v_j\in E(g)\\ 0 & otherwise\end{cases}. \quad (2)$$

Build system optimization balance objective function, considering channel number, total processing time and time slot allocation, which can be expressed as (3).

$$C=w_1\cdot N+w_2\cdot T+w_3\cdot W+w_4\cdot H-p\cdot N. \quad (3)$$

$$f=\frac{1}{C}. \quad (4)$$

w_1, w_2, w_3, w_4 is weight value of sub-objective function. N is number of read write device in each time slot. T is processing time of read write device when using the same channel.

$$T=\max(t_i). \quad (5)$$

W is weight value of read write device group when using the same channel.

$$W=\frac{1}{N}\sum t_i. \quad (6)$$

H is number of collision of read write device in other channels. p is penalty function. Objective function expresses RFID read-write device network scheduling efficiency cost and the entire network running time cost, which should be minimal when meeting collision constraint of network read write device. RFID read write device network scheduling model considers the confliction of read write device, signal frequency and time slot allocation as well as the system total processing time and it can be applied to actual large-scale RFID network deployment and operations.

A NOVEL SCHEME FOR RFID READ WRITE DEVICE ANTI-COLLISION

A novel intelligent compuation scheme based on biological symbiosis

Particle swarm optimization is an evolutionary computation technology based on swarm intelligence, which is characterized by fast convergence, simple calculation and so on in the process of dynamic optimization.

The i-th particle of particle swarm optimization in the D dimension space is marked as $X_i=(x_{i1},x_{i2},\ldots,x_{iD})$. The experienced best position is marked as p_{best}. In the swarm the best position experienced by all particles is marked as g_{best}. The speed of particle i is marked as $v_i=(v_{i1},v_{i2},\ldots,v_{iD})$. Particle coordinate and speed adjustment equation are (7) and (8) respectively.

$$\begin{aligned}v_{id}^{k}=&wv_{id}^{k-1}+c_1rand_1(p_{id}-x_{id}^{k-1})\\&+c_2rand_2(p_{gd}-x_{id}^{k-1}).\end{aligned} \quad (7)$$

$$x_{id}^{k}=x_{id}^{k-1}+v_{id}^{k-1}. \quad (8)$$

c_1 and c_2 are constant. w is inertia weight, $rand_1$ are $rand_2$ random numbers belonging to $[0,1]$. $i = 1,2,\ldots,M$, M is the number of particle in the swarm. x_{id}^k the d-th dimension component of position vector for particle i in the k-th iteration and v_{id}^k is the d-th dimension component of speed vector for particle i in the k-th iteration. p_{id} is the d-th dimension component of individual best position p_{best} of particle i. p_{gd} is the d-th dimension component of individual best position g_{best} of particle i.

Basic PSO algorithm has some shortcomings. The basic PSO algorithm only considers the collaboration between single species, without taking into account the symbiotic relationship between different species. Standard PSO couldn't reflect population diversity in the nature and that is why standard PSO is easy to fall into the premature convergence. For these reasons, this paper draws on biological symbiotic mechanism in the nature, by defining a collaboration between single species, mutualism between species and extinction mechanism. In the proposed algorithm, the whole group is divided into N number of subpopulation containing M number of individuals. This algorithm IPSO can be defined as an array of ten elements and its flow chart is shown in Figure 1.

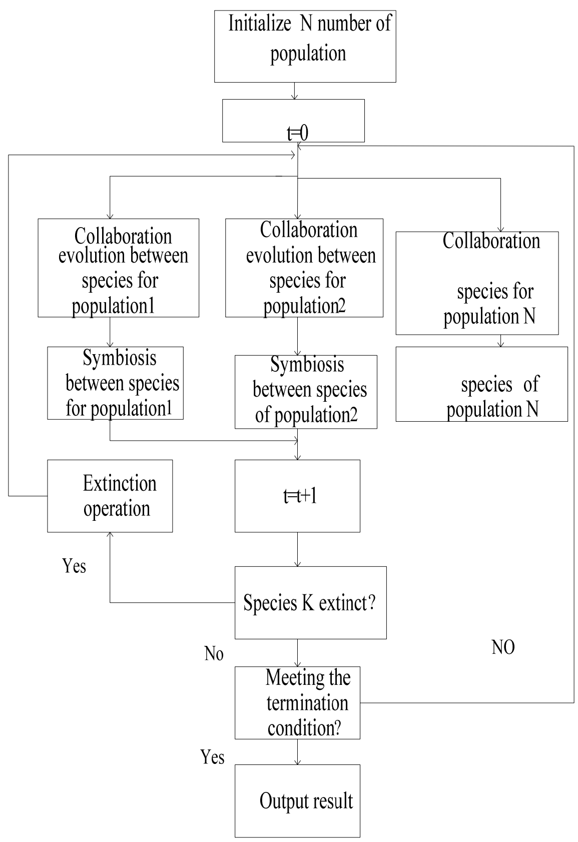

Figure1: flow chart of our proposed scheme.

$SMPSO = (S, C, E, F, PO, M, N, V, X, T)$.

S is evolution mode within species and C is evolution mode between species. E is extinction operation of population and F is fitness function of individual. PO is initial subpopulation and N is the number of population. M is population size. V is speed update operator and X is position update operator. T is termination condition of the algorithm. Firstly each population runs basic particle swarm optimization to evolve independently in the iteration process.

$$a_i^k = c_1 r_1 (p_i^k - x_i^k) + c_2 r_2 (p_g^k - x_i^k)\,. \quad \textbf{(9)}$$

All populations share the best individual information with other symbiotic populations. Each population updates there states according to experience of the best individual in other populations.

$$a_i^{k+1} = a_i^k + c_3 r_3 (p_s^l - x_i^k)\,. \quad \textbf{(10)}$$

At last, choose partial species e to do species extinction operation randomly and generate new species randomly to increase biology diversity of the whole population in evolution process of each population.

$$if\,(k \in e), x_i^k = r \cdot (ub - lb) + ub\,. \quad \textbf{(11)}$$

$$else \quad v_i^k = \chi(v_i^k + a_i^k), x_i^k = x_i^k + v_i^k \quad \textbf{(12)}$$

r_1, r_2 and r_3 are random numbers belonging to [0,1]. c_1, c_2 and c_3 are learning factors and $c_1 + c_2 + c_3 = 4.1$. χ is compression factor and can be calculated by (13).

$$\chi = 2 / \left| 2 - \varphi - \sqrt{\varphi^2 - 4\varphi} \right| \quad \textbf{(13)}$$

$c_1 + c_2 + c_3 = \varphi$. p_i^k is the best position of individual i in the population k. p_g^k is the best position of all individuals in the population k. p_s^l is the best position of the whole population. In the macro theory evolution, symbiotic mechanism between species is the driving force of biological evolution in nature. It is completed under interaction of different populations.

Anti-collision algorithm based on proposed intelligent compuation

The process of RFID network read write device anti-collision algorithm is as follows.

Step1. This paper designs a dynamic binary encoding scheme combining construction character of scheduling problem of RFID read write device network. Encoding scheme of RFID network made up of six read write devices is shown in Figure 2.

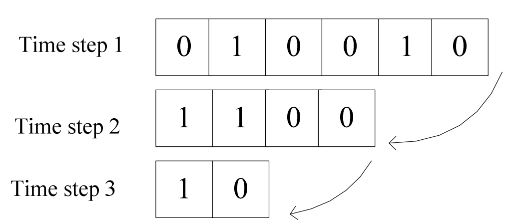

Figure 2 : Note how the caption is centered in the column.

The dimension of individual of IPSO can be adjusted dynamically in different time slot. The size of dimension is equal to the number of RFID read write device in current time slot. Particle [0 1 0 0 1 0] of Time step 1 represents the current time slot is assigned to the second and the fifth read write device.

Step2. Initialize RFID read write device network

$D = (d_{ij})_{n \times n}$ is defined as read write device confliction relation matrix, which depicts whether there is confliction between read write devices in the network. When r_i and r_j have confliction relation, $d_{ij}=0$. When r_i and r_j have no confliction relation, $d_{ij}=1$. So matrix D is a symmetric matrix. Read write device confliction relation matrix made up of ten read write devices is shown as (14).

$$d=\begin{bmatrix} 0&1&0&0&1&1&0&0&0&0\\ 1&0&1&0&0&1&0&0&0&0\\ 0&1&0&1&0&1&0&0&0&0\\ 0&0&1&0&0&0&1&0&0&0\\ 1&0&0&0&0&1&0&1&0&0\\ 1&1&1&0&1&0&1&1&1&0\\ 0&0&0&1&0&1&0&0&1&1\\ 0&0&0&0&1&1&0&0&1&0\\ 0&0&0&0&0&1&1&1&0&1\\ 0&0&0&0&0&0&1&0&1&0 \end{bmatrix}. \qquad \textbf{(14)}$$

Initialize processing time $T(g)=\{t_1,t_2,\ldots,t_n\}$.

Step3. Population scale is S. Lower limit of the search space is L_d and upper limit of the search space is U_d. The maximum iteration time is $T_{\max}$. The maximum speed is $v_{\max}$ and the minimal speed is $v_{\min}$. Learning factors are c_1, c_2 and c_3. Initialize the position and speed of the particle.

Step4. Calculate fitness function of each particle according to (3).

Step5. According to (9) and (10) update individual speed of each population. Update individual discrete location according to (15) and (16).

$$f(rand()<S(v_{id}))then\,x_{id}=1;else \quad x_{id}=0. \qquad \textbf{(15)}$$

$$S(v_{id})=\frac{1}{1+\exp(-v_{id})}. \qquad \textbf{(16)}$$

If current iteration time arrives predefined maximum time $T_{\max}$, turn to step 2. Otherwise stop iteration and output the optimal solution.

tep6. Delete read write nodes being assigned time slot from network G and update network G. Initialize relation matrix D again. If all the read write devices in the network have time slots, iteration stops and output scheduling result. Otherwise turn to step 3.

SIMULATION TEST

his paper chooses five common function to test the performance of our proposed algorithm and compare it with standard particle swarm optimization. Two functions are modal function and three functions are multimodal function, which are shown in TABLE I. For these five functions, the value of $v_{\max}$ is 5.12, 30, 5.12, 600, 5.12 and $v_{\min}=-v_{\max}$. Parameter of test function is shown in TABLE 2 The population size is 50. In the proposed algorithm, $c_1=c_2=c_3=1.3667$, $\chi=0.729$ and the number of population is $m=5$. Population extinction parameter is $a=10$. In particle swarm optimization $c_1=c_2=2$. Inertia weight is set to decrease from 0.9 to 0.4 linearly. Each algorithm runs 50 times.

xperiment results are shown in TABLE 3 which gives optimal value, the worst value, average value and variance. It can be seen that average value of fitness is better than standard particle swarm optimization. Variance of our proposed algorithm is smaller than that of standard particle swarm optimization and it is more stable than standard particle swarm optimization. In order to analysis biological symbiosis PSO evolution process more clearly, Figure 3 to Figure 7 give evolution curve of five kinds of test functions in the iteration respectively. Each curve is related to three kinds of biological symbiosis PSO-SMPSO and PSO. The horizon axis represents generations and the vertical axis represents fitness value. RFID network anti-collision algorithm based on our improved particle swarm optimization is applied to four different RFID read write networks, the size of which is 30, 60, 120 and 200. Processing time of each read write device is randomly generated between 0 and 20. It can be seen that convergence speed of SMPSO is faster and final solution is better than PSO algorithm. It has better performance on Sphere, Griwenk and Weierstrass function. PSO algorithm almost has no progress, after it converges to local optimum. Almost convergence curve of SMPSO algorithm decreases until it finds the global optimal solution. Above all, SMPSO algorithm is better than particle swarm optimization in convergence speed, accuracy of the results and robustness.

TABLE 1 : Test function

Sphere	$f_1(x)=\sum_{i=1}^{D} x_i^2$
Rosenbrock	$f_2(x)=\sum_{i=1}^{D} 100\cdot(x_{i+1}-x_i^2)^2 +(1-x_i)^2$
Rastrigrin	$f_3(x)=\sum_{i=1}^{D}(x_i^2-10\cos(2\pi x_i)) +10D$
Griewank	$f_4(x)=\frac{1}{4000}\sum_{i=1}^{D} x_i^2-\prod_{i=1}^{D}\cos\left(\frac{x_i}{\sqrt{i}}\right) +1$
Arckly	$f_5(x)=-20\exp(-0.2\sqrt{\frac{1}{n}\sum_{i=1}^{n} x_i^2}) -\exp(\frac{1}{n}\sum_{i=1}^{n}\cos 2\pi x_i)+20+e$

TABLE 2 : parameter of test function

Test problem	Dim	Population size	Initial Hypercube
Sphere	30	40	$[2.56,5.12]^n$
Rosenbrock	30	40	$[15,30]^n$
Rastrigrin	30	40	$[2.56,5.12]^n$
Griewank	30	40	$[300,600]^n$
Arckly	30	40	$[2.56,5.12]^n$

TABLE 3: parameter of test function

Func.(dim.30)		IPSO	PSO
f_1	best	7.7789e-118	4.2513e-092
	worst	2.5403e-051	2.0333e-082
	mean	10.3401e-053	1.2045e-083
	std	6.9442e-052	4.5752e-083
f_2	best	0.1021	0.0360
	worst	3.2458	15.2582
	mean	0.4123	7.3954
	std	0.2344	4.7577
f_3	best	10.3341	31.8386
	worst	29.8247	67.6571
	mean	20.3603	51.7378
	std	4.8200	11.2427
f_4	best	0	0
	worst	0	0.0467
	mean	0	0.0136
	std	0	0.0143

f_5	best	2.4431e	015
	worst	6.1943e-015	1.3210
	mean	3.0213e-015	0.0439
	std	1.1251e-015	0.3065

TABLE 4: Network scheduling performance comparison of SMPSO and PSO

SMPSO		PSO	
T_s	T_a	T_s	T_a
30 readers RFID network			
11	132.5277	13	160.6200
60 readers RFID network			
19	211.0975	20	227.1393
120 readers RFID network			
28	333.9301	32	412.8158
200 readers RFID network			
41	506.7990	51	683.9016

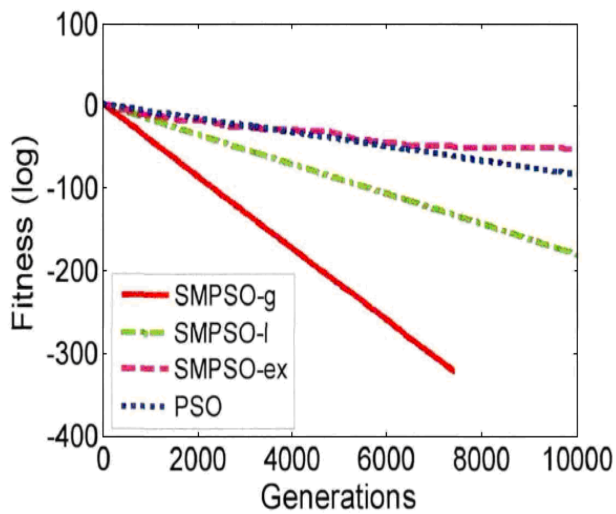

Figure 3 : Cnvergence curve comparison of Sphere function

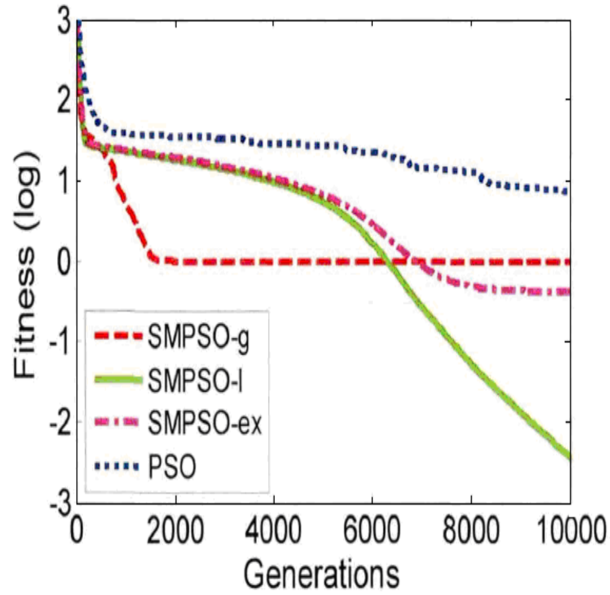

Figure 4 : Convergence curve comparison Rosenborock function

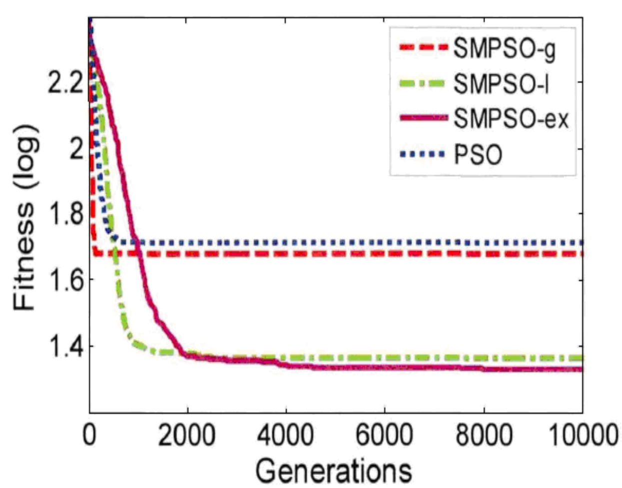

Figure 5 : Convergence curve comparison of Rastrigrin function.

When using proposed algorithm-IPSO, population size is 100 and the number of population is 10, meaning each population contains 10 number of particles. $c_1 = c_2 = c_3 = 2.0$. Population size of PSO is 100 and $c_1 = c_2 = 2.0$. The maximum iteration times of two algorithms is 30, 60, 120 and 200. Network scheduling performance comparison of IPSO and PSO is shown in TABLE IV. T_s is the number of time slot of RFID network. T_a is total processing time that network scans once. When a network containing 30 readers uses our proposed algorithm-SMPSO, T_s is 11 and T_a is 132.5277. When a network containing 60 readers uses our proposed algorithm-SMPSO, T_s is 19 and T_a is 211.0975. When a network containing 120 readers uses our proposed algorithm-SMPSO, T_s is 28 and T_a is 333.9301. When a network containing 200 readers uses our proposed algorithm-SMPSO, T_s is 41 and T_a is 506.7990. When a network containing 30 readers uses PSO algorithm, T_s is 13 and T_a is 160.6200. It can be seen that solution of IPSO is better than PSO. Especially when network scale is big, ISPO makes each RFID read write device has less scanning interval time. So efficiency of RFID network using ISPO is better than basic PSO.

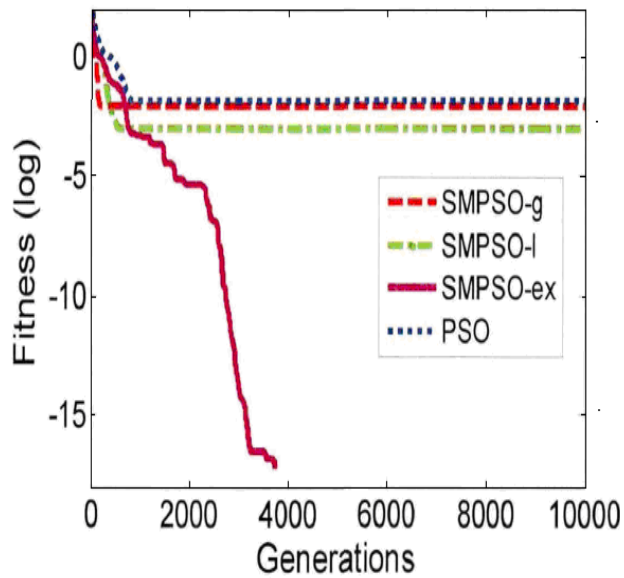

Figure 6 : Convergence curve comparison of Griewank function.

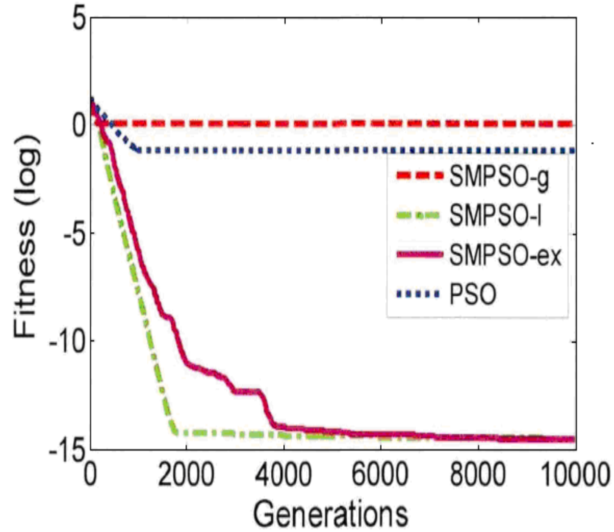

Figure 7 : Convergence curve comparison of Weierstrass function

CONCLUSIONS

The internet of things is considered to be the next step in the revolution of internet. People are expecting to be able to quickly connect between objects existed all the time no matter where. This requirement not only propels rapid development of internet of things technology and wide acceptance of RFID devices, but also deviates the traditional computing style to smart internet of things computing. Compared to hardware and network support in pervasive computing, the reliability of sensors software for internet of things, which in return, limited the application and deployment of internet of things to some extents. Unlike the traditional distributed computing software running in stable environments with rich resources, sensor nodes in internet of things runs in unforeseen wireless network environments, limited resources and continuously altered context. These put a great deal of demands on the dynamic software, resource configuration and energy maintenance technology.

The RFID reader anti-collision problems are studied by symbiotic multi-species particle swarm optimization. Through analysis of the RFID reader collision and conflicting model, a RFID reader anti-collision optimization model is studied, which considers minimizing reader conflicting and total processing time. Based on the standard particle swarm algorithm, the IPSO algorithm, on account of biological symbiosis theory of the nature is presented. By defining the information communication mechanism of cooperation in single species and collaboration between species, symbiotic strategy in ecological system is established, which has better diversity keeping ability and later searching performance. The simulation result shows that our proposed algorithm can effectively solve reader collision problem in intensive reader environment, and optimize the efficiency of the whole reader network.

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