Application of hybrid ant colony algorithm in wireless sensor network coverage

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Received 1 June 2014, www.cmnt.lv

Abstract

The coverage control is a fundamental problem in the study of wireless sensor network. The network is required to have a certain quality of service and optimized through some technologies or protocols so as to achieve the maximization of the coverage and provide reliable monitoring data and target tracking service. Based on detailed analysis of advantages and disadvantages of ant colony algorithm and genetic algorithm, this article makes some improvement and proposes a hybrid ant colony algorithm, and such new algorithm combines the strong adaptivity of the ant colony algorithm and the high convergence of the genetic algorithm etc. The experimental results show that the presented algorithm in this article can effectively improve the use efficiency of network nodes and prolong the network lifetime to realize the optimization goal of a network coverage control with highly effective energy.

Keywords: Hybrid Ant Colony-Genetic Algorithm, Wireless Sensor Network, Coverage

1 Introduction

As one of basic problems in wireless sensor network research, with the aid of sensor's sensory ability, the coverage control technology uses the node perception to configure the node and monitor targets, thus achieving the goal of obtaining the required information completely and effectively. It fundamentally reflects the sensor network’s sensory ability to the physical world [1]. Different from the current Mobile Ad-hoc Networks and wireless networks, the wireless sensor network (hereinafter shorten as WSN) will face constraints from the node energy supply, communication capacity and computing capacity when the network coverage agreement is designed, and the sensor node deployment is large in number, wide in distribution and strong in network dynamic etc [2]. One important goal of network coverage protocol is to prolong the network lifetime, and prolonging the network lifetime can effectively save the cost in redeploying sensor nodes [3]. To sum up, coverage control technology is the precondition for nodes to obtain the physical world information, and also the most basic research issue in studying quality of service(QoS) of wireless sensor network [4].

As excellent artificial intelligence algorithms, ant colony algorithm and genetic algorithm have good global search capability, but these two algorithms also have their own defects. Because the multiple individual motion of ant colony is random, it costs a long search time to find out a better path in the early stage when the group scale is larger [5]. In optimization process, with the implicit parallel search feature, the genetic algorithm faces no constraint from the objective function and continuous differentiability of constraint conditions, but it is very sensitive to initial population, and the selection of the initial population often directly affects the quality of the solution and the algorithm efficiency. Thus the genetic algorithm and ant colony algorithm are complementary, and can overcome their own shortcomings and display their respective advantages when they two are organically combined together [6]. Based on the research on the basic ant colony algorithm and genetic algorithm and by adopting the strong ant colony algorithm adaptability and high genetic algorithm convergence, this paper proposes and applies a new hybrid ant colony-genetic algorithm to the wireless sensor network coverage. Simulation results show that this coverage control strategy can achieve higher coverage rate, maintain the stable network operation and prolong the network lifetime, thus obtaining the ideal optimization result.

2 Overview of wireless sensor network coverage

Wireless sensor network is composed of a large number of randomly distributed integrated small nodes of sensors, data processing units and communication modules. By means of self-organization, nodes compose the network which is a large-scale, unattended distribution system with strictly limited resources [7]. Various sensors embedded in the node measure surrounding environment parameters, collect data through the network and transmit in the network or through the upper network. Components of wireless sensor network node is shown in Figure 1.

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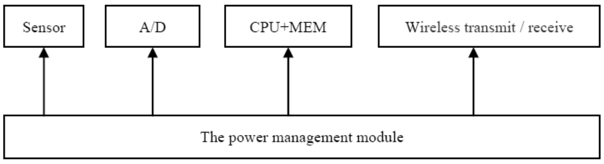


FIGURE 1 Components of wire1ess sensor network node

In traditional wireless sensor networks, nodes scatter randomly in the monitored area. Nodes form the network in the form of the self-organization, send the monitor data to sink node through the multiple hops relaying mode and finally transmit the data in entire area to the remote center for the centralized processing by means of long-distance or temporarily built slot link. In the new wireless sensor network applications, acting as the communication link between sink nodes, nodes not only collect the data but also work together, and therefore, there also exists data communication among nodes [7]. Fig. 2 describes the general form of the sensor network architecture [8, 9].

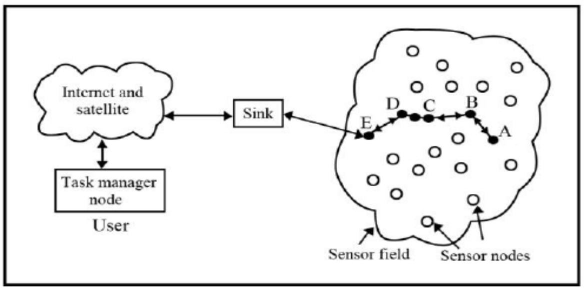


FIGURE 2 Architecture of wireless sensor network

In the large-scale deployed sensor network area coverage, by using high density and high redundancy of sensor nodes, the network lifetime can also be prolonged when the coverage quality is ensured. Divide all sensor nodes in the network into several mutually disjoint sets of sensor nodes with each set completely covering the target area[10]. At any time, there is only one set in working status, and others in the dormant state with low power consumption. The alternative work among different nodes can effectively prolong network lifetime. Obviously, in terms of the sensor network using such way of work, the more mutually disjoint collections are found, the longer the network lifetime will be [11].

3 Design of Hybrid Ant Colony Algorithm

The current evolutionary algorithm solving multi-objective optimization mainly considers how to deal with the optimization among multiple conflicted targets, rarely considering the solution of the constraint conditions [12].

3.1 NETWORK PARTITIONING

Partition the network R_W into sub-network R_{Wi} with roughly same scale according to specific constraint conditions. When problems of demand solution are different, the classified methods of network will also be changed. Such partitioning method not only meets the actual need, but also ensures the suspension point will be avoided when the global optimization is conducted in the upper genetic algorithm. The method adopting sub-network partitioning to deal with some constraints can reduce the search node, thus greatly improving the algorithm performance [13].

3.2 SOLVING STEPS OF HYBRID ANT COLONY ALGORITHM

For multi-objective constraint optimization problems, this article adopts the Pareto method based on the minimization problem. According to the characteristics of the path constraint problem, solving step of the algorithm are as follows:

(1) Genetic encoding: adopt the natural encoding scheme. Considering the presence of variable-length path, adopt variable-length chromosomes in the natural coding design.

(2) Initial population: based on optimization results of the lower level algorithm in each sub-network, adopt the optional path connection method to generate the initial population.

In general, as the lower scale, the sub-network is relatively small, so Max-Min ant colony algorithm is adopted.

(a)Structure of path: under the condition of satisfying the constraints, the ants choose the next code in equation (1) probability.

$$p_{ij}^k(t)=\begin{cases}\dfrac{[\tau_{ij}(t)]^\alpha[\eta_{ij}(t)]^\beta}{\sum\limits_{S\subset allowed_k}[\tau_{is}(t)]^\alpha[\eta_{is}(t)]^\beta}, & j\in allowed_k\\ 0, & Otherwise\end{cases} \quad (1)$$

In the above equation, $allowed_k$ represents the node that ant k is allowed to select in the next step at the time t, α the heuristic factor for information, β heuristic factor for expectation, and η_{ij} the heuristic function.

(b)Pheromone update: after one iteration is finished, all ants built a path, and the information on the path may be adjusted according to equation (2) rules.

$$\tau_{ij}\leftarrow(1-\rho)\tau_{ij}+\Delta\tau_{ij}^{best} \quad . \quad (2)$$

Herein $\Delta\tau_{ij}^{best}=1/L^{best}$, L^{best} is the length of optimized path.

At the beginning of the algorithm, set the initial value of pheromone at a measure value of the upper bounds of the pheromone. When the system reaches the address state, or when the better solution will not appear any longer in a certain number of iterations, all pheromone values solved will be initialized again. The pheromone size of each path will be limited to the interval $[\tau_{min},\tau_{max}]$, pheromone will only be released on the path built so far by the optimal ants when the optimal ants are iterated [14].

(3) Crossover operator: adopt the operating mode only allowing only one-point cross in repeated node location. Because each individual is a shortest path, so there's no need to mutate but just to cross. As sub-networks have same endpoints, so there is no need to judge the suspension point.

(4) Selection: in order to avoid offspring atavism, for offspring individuals under crossover and mutation, abandon if it has already existed in the parent. To ensure fast convergence of the algorithm, ($\mu+\lambda$) evolution strategy is used to implement the elite maintenance, so as to avoid the degradation of offspring. Combine parental and offspring individuals and select individuals with smaller Rank values to enter into the next generation [15].

(5) Termination rule: if the algorithm reaches the maximum evolution algebra G_{max} or there is no new individual appearing in successive generations, terminate it and solution set obtained serves as the optimal solution set of path network.

3.3 REALIZATION OF HYBRID ANT COLONY ALGORITHM

Hybrid algorithm designed in this article is as follows:

Step 0: First of all, process some constraints Combine with specific constraints, use the node that is necessary to pass to divide network R_w into sub-network R_{wi} with roughly same scale. When problems of demand solution are is not the same, the classified methods of network also can be changed. Such partitioning method not only meets the actual need, but also ensures the suspension point will be avoided when the global optimization is conducted in the upper genetic algorithm. The path network laying strategy decompose the optimal path problem in the original network into the searching issue in each sub-network, and due to the size of each sub-network is far less than the original network, thus computing efficiency can be greatly improved.

Step 1: Initialize parameter to determine the encoding scheme of the genetic algorithm. This article adopts the natural encoding scheme. Considering the presence of variable-length path, adopt variable-length chromosomes in the natural coding design.

Step 2: Based on ant colony algorithm, conduct the sub-network optimization to generate initial individual of the upper genetic algorithm. Adopt the optional path connection method to generate the initial population based on the optimization result of each sub-network.

Sub-Step 2.1 Put m ants at the starting point of each sub-network and initialize the pheromone matrix, and put the initial position in the tabu table.

Sub-Step 2.2 Select the next node that each ant will transfer according to the transfer probability of ant colony algorithm until one path loop is searched and completed by each ant.

Sub-Step 2.3 Record the current optimal solution of each ant.

Sub-Step 2.4 Update global pheromone matrix and empty tabu table.

Sub-Step 2.5 Meet ending conditions and output optimal solution.

Step 3: Calculate the objective function value and fitness function value. Because the solution to be solved belongs to the minimization problem, so the smaller the set fitness is, the better the results will be. For multi-objective constraint optimization, this article adopts the Pareto method based on the minimization problem.

Step 4: Genetic operations

Sub-Step 4.1 Selection: To ensure fast convergence of the algorithm, ($\mu+\lambda$) evolution strategy is used to implement the elite maintenance, so as to avoid the degradation of offspring. Combine parental and offspring individuals and select individuals with smaller Rank values to enter into the next generation.

Sub-Step 4.2 Crossover: crossover is the method to exchange some genes of two pairs of chromosomes by certain methods, thus two new individuals will be shaped, and it is the main way to produce new good genes. Here, according to the given crossover probability P_c, the operating mode only allowing only one-point cross in repeated node location is adopted.

Sub-Step 4.3 Mutation: as each individual is a shortest path, so there's no need to mutate.

Step 5: Convergence test: if the algorithm reaches the maximum evolution algebra G_{max} or there is no new individual appearing in successive generations, terminate it and solution set obtained serves as the optimal solution set of path network; otherwise, return to Step 3.

4 Efficient WSN coverage based on multi-objective hybrid ant colony algorithm

The wireless sensor network usually scatters a large number of sensor nodes in the monitoring target area intensively, if these sensor nodes work simultaneously, it will result in a collision conflict of the sensor nodes in the network, meanwhile, the plenty redundancy of coverage, data awareness and collection and data transmission will also cause a waste of network energy. Considering this, under the premise of ensuring the quality of network service, it is the key research content of the wireless sensor network by scheduling the activity of sensor nodes, making part of the sensor nodes enter active state and the redundant nodes enter the dormant state, so as to save energy consumption and prolong the maximum lifetime of network.

4.1 THE NODE SCHEDULING COVERAGE CONTROL STRATEGY BASED ON MULTI-OBJECTIVE HYBRID ANT COLONY ALGORITHM

Assuming that deploy N sensor nodes in the target monitoring area randomly with the responsibility of collecting and processing the information of all the targets in the monitoring area. The perception radius and the ability of calculating and processing information of all the sensor nodes are the same. The perception model in the sensor is a disk perception model, that is, when the sensing radius of the sensor is *R*, it can cover all target points within the circle which takes the sensor itself as the center and *R* as the radius. This paper deploys a lot of sensor nodes in the target area randomly through hybrid ant colony, divides the sensor nodes into several covering subsets, and each covering subset can completely cover this target area, schedules these covering subsets periodically, and prolongs the life cycle of the entire network by maximizing the total working time of each covering subset.

4.2 DESCRIPTION OF THE ANT COLONY

At the initial stage, divide the ant colony into *k* covering subsets randomly $(N_1, N_2, \cdots, N_K)$, give a random number (0~1) to each covering subset, when the random number is larger than the dormancy rate, the ant colony set is set 1, and the corresponding ants will enter the working state; otherwise, the ant colony set is set 0, and the corresponding ants will enter the dormant state. Wherein, the dormancy rate is calculated according to the formula (3) as follows:

$$pro = \alpha\left(1 - \frac{E_{ci}}{E_{mi}}\right) + b\frac{I_n - 1}{I_n} \quad , \tag{3}$$

wherein, *a* and *b* are constants, and *a*+*b*=1. E_{ci} is the current residual energy of node *i*, E_{mi} is the initial energy of the node. I_n the number of neighboring nodes of node *i* within its perception range.

4.3 COVERAGE TARGET

Deploy *N* sensors to cover the entire target area randomly, wherein, $N = \{n_1, \cdots, n_N\}$. Assuming that every sensor is equipped with the initial energy *E*, the sensing radius is *R*, the corresponding energy consumption is $\{e_1, \cdots, e_n\}$. Define subset $N' \in N$ to enable:

Objective 1: the maximum of the coverage rate of the network as a whole. Namely:

$$MAX.f_1(\bar{x}) = R_{area}(N') = A_{area}(N') / A_s \tag{4}$$

Constraint: Use standard deviation of the distance between nodes to indicate the distribution condition of the sensor nodes in the monitoring area, the smaller the standard deviation, the better the coverage uniformity. Namely:

$$s.t. \quad U = \frac{1}{N}\sum_{i=1}^{N} U_i = \sqrt{\frac{1}{k_i}\sum_{i=1}^{k_i}(d(n_i, n_j) - D_i)^2} \quad , \tag{5}$$

wherein: *U* represents uniformity, k_i represents the number of neighbor nodes of node n_i, $d(n_i, n_j)$ represents the Euclidean distance between n_i and n_j, D_i represents the average of distance between it and all the nodes that intersect its sensing radius.

Objective 2: Minimum of the Number of Sensors

$$MAX.f_2(\bar{x}) = 1 - |N'|/N \; . \tag{6}$$

In the two-dimensional monitoring area *A*, it has become an important issue of people's concern on find the way to solve the subset of *N'*, $N' \in N$ in order to maximize the life of the sensor network. The Objective function is to minimize the number of network node |*N'*| while realizing the maximum of the entire coverage rate $R_{area}(N')$.

5 Experimental simulation and analysis

5.1 PROBLEM DESCRIPTION OF COVERAGE OPTIMIZATION

5.1.1 Network model

The wireless sensor network is constituted by sensor nodes with perception capability and wireless communication capability. The location optimization strategy of nodes refers to allocate the location of node efficiently, expand the effective coverage area of network, and enhance network measurement and communication capability. Assuming that randomly deploy the nodes in the area to be monitored, S_i represents No.*i* node in the wireless sensor network, the set of sensor nodes is $S = \{S_1, S_2, S_3, \cdots S_n\}$, each node has the same perception radius R_s and communication radius $R_c(R_c = 2R_s)$ and can acquire the location information of itself and other nodes, and it supports and moves the node to complete the moving process of location.

5.1.2 Node measurement model

Assume the two-dimensional coordinate of node S_i is (x_i, y_i), *i* is the sequence number of node, point $P(x, y)$ is an arbitrary point in the monitoring area, then the detection probability of S_i to point *P* is calculated as:

$$C_p(S_i, p) = \begin{cases} 1, & d(S_i, p) \le R_s - R_e \\ \exp\left(\dfrac{-\lambda_1 \alpha_1^{\beta_1}}{\alpha_2^{\beta_2} + \lambda_2}\right) & R_s - R_e < d(S_i, p) < R_s + R_e \\ 0, & Otherwise \end{cases} \tag{7}$$

The joint detection probability of all the nodes to point *P* simultaneously is:

$$C_p(s_{all}, p) = 1 - \prod_{i=n}(1 - C_p(s_i, p)) \; . \tag{8}$$

$R_e(0 < R_e < R_s)$ is the reliability parameter for the measurement of sensor node, R_s is the sensing radius of node, $d(S_i, p)$ is the Euclidean distance between the target point P and the sensor node S_i, $\alpha_1 = R_e - R_s + d(S_i, p)$ $\alpha_2 = R_e - R_s - d(S_i, p)$ and $\lambda_1, \lambda_2, \beta_1, \beta_2$ are measurement parameters related to the nodes.

5.1.3 Network coverage model

Divide the area to be measured into $m*n$ grids, then simplify each grid into a single pixel, use the center point of the grid to represent the grid, and then calculate the detection probability of each pixel by using the formula (8), make statistics of the number of detected pixels, and finally calculate the ratio of number of detected pixels to the total number of grid points, and this ratio is the coverage rate of the wireless sensor network, it is shown as follows:

$$C_r = \frac{\sum_{x_{p=1}}^{m}\sum_{y_{p=1}}^{n} C_p(S_{all}, p)}{m \times n} \quad . \tag{9}$$

5.2 EXPERIMENTAL ANALYSIS

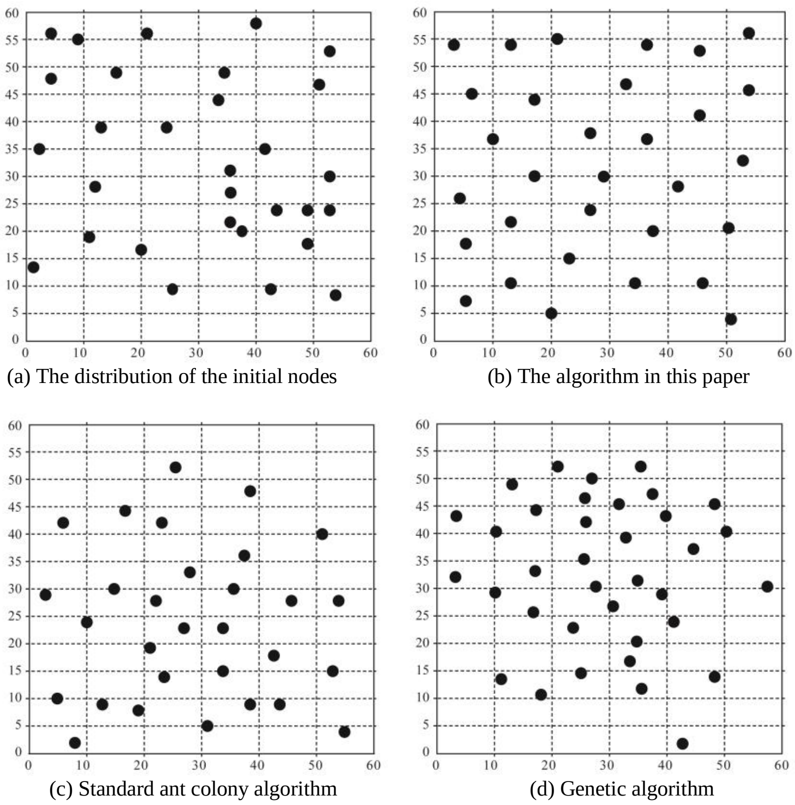
Assuming that within the measurement range of the square with the side length of 60m, it required to deploy 30 wireless sensor nodes, the sensing radius of the nodes is R_s=5, the communication radius is R_c=2R_s=10, the probability model parameters are α_1=1, α_2=0, β_1=1, β_2=1.5. The measurement reliability parameter R_e=0.5R_s=2.5.

To further illustrate the advantage of the new algorithm, the standard ant colony algorithm and the genetic algorithm are compared in this paper. The experimental result is shown in Table1. See from Table1, compared with other optimization algorithms, the algorithm adopted in this paper can increase the network coverage of the wireless sensor more effectively.

TABLE 1 Comparison of the coverage rate between the algorithm adopted in this paper and other algorithms

Algorithm	**Standard ant colony algorithm**	**Genetic algorithm**	**Algorithm in this paper**
Coverage rate	80.2%	83.6%	88.7%

In order to make the comparison of the effect of the algorithm on the coverage optimization more convenient, this paper adopts the same simulation condition, makes pictures of the signal of the location of the sensor nodes after the algorithm optimization. Wherein the initial distribution of the nodes location of the sensor is shown in Figure 3a. Figure 3b shows the distribution of the nodes after the optimization algorithm adopted in this paper. Figure 3c shows the distribution of the nodes after the optimization of standard ant colony algorithm. Figure 4d shows the distribution of the nodes after the optimization of standard genetic algorithm.



(a) The distribution of the initial nodes
(b) The algorithm in this paper
(c) Standard ant colony algorithm
(d) Genetic algorithm

FIGURE 3 The distribution figure of the nodes after optimization of different algorithms

From the Figure 3 it is clear to see that the distribution of the nodes after the optimization of intelligent algorithm is more uniform compared with the initial distribution. wherein, the optimization effect of the algorithm in this paper is more obvious.

6 Conclusion

The hybrid ant colony algorithm proposed in this paper has better global search ability and fast convergence speed, compared with the standard ant colony and genetic algorithms, it is equipped with the advantages of both the standard ant colony algorithm and the genetic algorithm, its performance has been improved to a certain degree. In the application of network coverage optimization of wireless sensor, the algorithm adopted in this paper can make the distribution of the wireless sensor more uniform and the coverage rate higher, so as to maintain the stable operation and prolong the lifetime of the network.

Acknowledgments

The work described in this paper was sponsored in part by the Suzhou University research platform open projects (Grant NO. 2012YKF37) ,and Anhui Provincial Projects of Science Research in Colleges and Universities (Grant No.KJ2014A247 and No.KJ2014ZD31).

References

[1] Chizari H, Poston T, Razak Sh A, Abdullah A H, Salleh Shaharuddin 2014 Local coverage measurement algorithm in GPS-free wireless sensor networks *Ad Hoc Networks* **23** 1-17

[2] Castaño Fabian, Rossi André, Sevaux Marc, Velasco Nubia 2014 A column generation approach to extend lifetime in wireless sensor networks with coverage and connectivity constraints *Computers & Operations Research* **52**(B) 220-230

[3] Dash D, Gupta A, Bishnu A, Nandy S C 2014 Line coverage measures in wireless sensor networks *Journal of Parallel and Distributed Computing* **74**(7) 2596-2614

[4] Tan Haisheng, Hao Xiaohong, Wang Yuexuan, Lau F C M, Lv Yuezhou 2013 An Approximate Approach for Area Coverage in Wireless Sensor Networks *Procedia Computer Science* **19** 240-247.

[5] Tomera Mirosław 2014 Ant Colony Optimization Algorithm Applied to Ship Steering Control *Procedia Computer Science* **35**, 83-92

[6] Nia Ali R, Far Mohammad H, Niaki S T A 2014 A fuzzy vendor managed inventory of multi-item economic order quantity model under shortage: An ant colony optimization algorithm. *International Journal of Production Economics* **155** 259-271

[7] Gorain Barun, Mandal Partha Sarathi 2014 Approximation algorithms for sweep coverage in wireless sensor networks *Journal of Parallel and Distributed Computing* **74**(8) 2699-2707

[8] Nudurupati D P, Singh R K 2014 Enhancing Coverage Ratio Using Mobility in Heterogeneous Wireless Sensor Network. *Procedia Technology* **10** 538-545

[9] Ndzi D L, Harun A, Ramli F M, et al 2014 Wireless sensor network coverage measurement and planning in mixed crop farming *Computers and Electronics in Agriculture* **105** 83-94

[10] Jedda A, Khair M, Mouftah H T 2012 Connected Coverage for RFID and Wireless Sensor Networks *Procedia Computer Science* **10** 1046-1051

[11] Taghikhaki Z, Meratnia N, Havinga P J M 2013 A Trust-based Probabilistic Coverage Algorithm for Wireless Sensor Networks. *Procedia Computer Science* **21** 455-464

[12] Rezaei Gh, Afshar M H, Rohani M 2014 Layout optimization of looped networks by constrained ant colony optimisation algorithm. *Advances in Engineering Software* **70** 123-133

[13] Rizk-Allah R M, Zaki El M, El-Sawy A A 2013 Hybridizing ant colony optimization with firefly algorithm for unconstrained optimization problems *Applied Mathematics and Computation* **224**(1) 473-483

[14] Tabakhi S, Moradi P, Akhlaghian F 2014 An unsupervised feature selection algorithm based on ant colony optimization *Engineering Applications of Artificial Intelligence* **32** 112-123

[15] Cao Huaihu 2012 A QoS Routing Algorithm Based on Ant Colony Optimization and Mobile Agent *Procedia Engineering* **29** 1208-1212

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