Evolutionary Computation for Lifetime Maximization of Wireless Sensor Networks in Complex 3D Environments

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ABSTRACT
Scheduling the operating mode of nodes is an effective way to maximize the lifetime of wireless sensor networks (WSN). For a WSN with randomly and densely deployed sensors, we could maximize the lifetime of WSN through finding the maximum number of disjoint complete cover sets. Most of the related work focuses on 2D ideal plane. However, deploying sensors on the 3D surface is more practical in real world scenarios. We propose a novel genetic algorithm with redundant sensor auto-adjustment, termed RSAGA. In order to adapt the original GA into this application, we employ some effective mechanisms along with the basic crossover, mutation, and selection operation. The proposed operator of redundant sensor auto-adjustment schedules the redundant sensors in complete cover sets into incomplete cover sets so as to improve the coverage of the latters. A rearrangement operation specially designed for the critical sensors is embedded in the mutation operator to fine-tune the node arrangement of critical fields. Moreover, we modify the traditional cost function by increasing the penalty of incomplete cover sets for improving the convergence rate of finding feasible solutions. Simulation has been conducted to evaluate the performance of RSAGA. The experimental results show that the proposed RSAGA possesses very promising performance in terms of solution quality and robustness.

Categories and Subject Descriptors
I.2.8 [**Artificial Intelligence**]: Problem Solving, Control Methods, and Search – *heuristic method*

General Terms
Algorithms

Keywords
Redundant sensor auto-adjustment; 3D surface; genetic algorithm

1. INTRODUCTION
Most of the related studies focus on 2D ideal plane. Cardei and Du [1] designed a heuristic to compute the number of covers. In [2], Slijepcevic and Potkonjak proposed a most-constrained least-constraining heuristic to maximize the number of disjoint cover sets. Hu [3] proposed a hybrid genetic algorithm with schedule transition operations to find the maximum number of disjoint cover sets. However, sensors deployed on the 3D surface is more practical in many real world applications. For example, the project of monitoring volcano [4] conducted by Harvard Sensor Networks Lab. Therefore, it would be appealing to solve the set k-cover problem on the surface of target 3D terrains. In this paper, a novel genetic algorithm termed RSAGA is proposed in order to deal with this challenging task. Aiming at presenting a universal strategy which could be applied to most of 3D surfaces, which has not been reported to the best of our knowledge. We design a novel genetic algorithm without utilizing the information of the surface. Instead, we make full use of the advantage of evolutionary computation. To be specific, in RSAGA, two well-designed operators are added to the original GA. One is rearrangement and the other is redundant sensor auto-adjustment. Rearrangement is part of mutation operator specially designed for some critical sensors in order to adapt conventional mutation operator into this application. The proposed operator of redundant sensor auto-adjustment schedules the redundant sensors in complete cover sets into incomplete cover sets for fulfilling a higher coverage rate. Additionally, a penalty function is adopted to improve the convergence because the contributions of incomplete cover sets are less than complete cover sets. Therefore, individuals with more incomplete cover sets are easier to be eliminated than those with more complete cover sets.

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2. GENETIC ALGORITHM WITH REDUNDANT SENSORS AUTO-ADJUSRTMENT

2.1 Representation of Chromosome
Suppose that after the process of sensors deployment, the upper limit of disjoint complete cover sets is U_{pl}. Then, each chromosome can be encoded as $X_i=\{x_1, x_2 \dots x_i \dots x_N\}$, where X_i represents chromosome i, x_i belongs to $[0,U_{pl}-1]$.

2.2 Rearrangement Operator
To keep the evolving process under distribution restriction, we design an operator with rearrangement of critical sensors to mutate ordinary sensors and critical sensors separately. The mutation process is divided into two stages. Firstly, conventional mutation is carried out in which critical sensors are protected from mutation. Next, we mutate critical sensors through rearrangement of their sequences.

TABLE 1. Results of experiment I

Benchmark instances					Original GA			RASGA		
Case	*N*	*R*	*η*	U_{pl}	G_a	*Optimal value*	P_f	G_a	*Optimal value*	P_f
1	100	15	[3.562,4.712]	6	155.83	6	100%	17.23	6	100%
2	100	20	[3.454,4.570]	11	229.00	11	3.33%	12.90	11	100%
3	300	15	[3.771,4.990]	17	310.13	1	0%	217.23	17	46.67%
4	300	20	[4.071,5.386]	28	279.67	11	0%	120.17	28	100%
5	400	10	[4.750,6.283]	8	274.37	0	0%	19.57	8	100%
6	400	15	[4.274,5.655]	20	250.97	4	0%	178.70	20	90%
7	500	8	[4.342,5,745]	7	282.90	0	0%	229.367	7	10%
8	500	10	[4.317,5.712]	11	287.87	0	0%	263.90	11	23.33%
9	700	6	[4.787,6.333]	5	270.23	0	0%	276.5	5	6.67%
10	700	8	[5.526,7.311]	9	265.97	0	0%	255.83	9	16.67%

2.3 Evaluation

In original GA, we evaluate the fitness of an individual by (9) Likewise, the evaluation function of RSAGA corresponds to evaluating coverage rate of every DCS_i. A penalty function is introduced to improve the convergence as (10). The value of this penalty function corresponds to the coverage rate as (11), where c_i represents the coverage rate of DCS_i. Consequently, the contributions of incomplete cover sets are less than complete cover sets. Therefore, individuals with more incomplete cover sets are easier to be eliminated than those with more complete cover sets.

$$f = \sum_{i=1}^{U_{pl}} c_i \tag{9}$$

$$f = \sum_{i=1}^{U_{pl}} c_i \cdot w(c_i) \tag{10}$$

$$w(c_i) = \begin{cases} 0.2 & if\ c_i < 1 \\ 1.0 & else \end{cases} \tag{11}$$

2.4 Redundant Sensor Auto-adjustment

In order to accelerate search speed and improve search efficiency, an additional operator termed redundant sensor auto-adjustment is proposed in this paper. Suppose a disjoint complete cover set is DCS_i={ S_{i1}, S_{i2}, S_{i3}, S_{i4}, S_{i5}, S_{i6} }, S_{ij} is a redundant sensor means that the coverage rate will not change when S_{ij} is excluded from DCS_i. In the operator of redundant sensor auto-adjustment, RSAGA picks up the redundant sensors and reassigns them into a new disjoint cover set to help each DCS_i reach a higher coverage rate. A new disjoint cover set is selected from other candidate disjoint cover sets by the tournament selection model.

3. EXPERIMENTS AND DISCUSSION

We conducted three experiments to evaluate the performance of the RSAGA on Microsoft Visual Studio platform. In experiment I, we evaluated the fundamental performance of the two algorithms when solving the set k-cover problem in different cases where the number and the sensing radius of sensors are various. The results are all listed in TABLE 1. Next, we tested the convergence rate through checking the number of *DCS* and the fitness of best individual during the evolutionary process in experiment II. Finally, we focused on the solution quality of RSAGA influenced by redundant rate in experiment III. In this experiment, RSAGA could find the upper limit of disjoint cover sets in a large range of redundant rate.

4. CONCLUSION

In this paper, an efficient genetic algorithm with redundant sensor auto-adjustment is proposed to maximize the lifetime of WSN in complex 3D environments. We first analyzed the changes between 2D ideal plane and 3D surface. Improvements in distribution restriction, evaluation and settlement of redundant sensors have been made to adapt the original genetic algorithm into this specific application. We conducted a simulation to evaluate the performance of RSAGA, results showed that the proposed algorithm outperforms the original genetic algorithm. More importantly, RSAGA could find the upper limit of disjoint complete cover sets in every case. A further experiment is conducted to test the solution quality of RSAGA under different redundant rate. According to the results, we found it easier to get a better solution on a higher redundant rate. RSAGA could find the upper limit of disjoint cover sets in a large range of redundant rate. As can be noted from these experiments that RSAGA possesses very promising performance in terms of solution quality and robustness.

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