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Target Coverage Research Based on Improved Binary Differential Algorithm

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Abstract. *The TH-HESN (three-dimensional heterogeneous sensor networks) target coverage measures have been studied in the recent years. Most of these measures often fall into local optimum and prematurity, and it has different target coverage quality when the combinations of the same number working nodes are different, such as the genetic algorithm (GA) and the binary differential evolution (BDE). In this paper, we introduce the chaotic location binary differential algorithm (CLBDE), in which chaotic mapping is used to improve the BDE ergodicity and the similar scheduling in the terminal iteration is raised to optimize the working nodes. The intention of the target coverage module based on the CLBDE is to minimize the equivalent number of working sensor nodes by considering different parameters. Simulation results show that the job nodes number of the proposed algorithm is less than BDE and GA.*

Keywords: Heterogeneous sensor networks; Target coverage; Binary differential evolution; Chaotic mapping; Similar scheduling; Working nodes number

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1. **Introduction.** Wireless sensor network has a lot of remarkable merits such as high sensing fidelity, on-board process, fault tolerance, rapid deployment and low cost. These features enable a wide range of practical applications for sensor networks. The Coverage control of wireless sensor network (WSN) is to dominate the monitoring area by managing sensor nodes[1]. Target coverage problems are to cover a set of specific targets within monitoring area to collect and monitor data. In recent years, many scholars study coverage control of WSN, but most of them are based on omni-directional sensing model[2-4], and this sensing model has full range perception ability but not applicable for the actual WSN monitoring tasks. Therefore the directed sensing model and the probabilistic sensing model are raised. Wang solves target coverage by genetic algorithm according to different detecting target priority[5]. Fusco presents the greedy algorithm to gain the given target K-coverage by collecting minimum directed nodes[6]. Xing presents coverage and connectivity probability model to calculate the sensor nodes number of different coverage probability [7]. Moreover, these documents only consider homogeneous sensing models, for which sensors need to have an identical sensing capability. In document [8]-[11], the three-dimensional homogeneous sensor networks target coverage and two-dimensional heterogeneous sensor networks target coverage are researched. In document [12], the GA is

proposed to realize the TH-HESN target coverage based on the probabilistic sensing, but it is easy to fall into local optimum. In [13], the binary differential evolution (BDE) is raised to realize discrete optimization.

In this paper, based on that all the target nodes satisfies the coverage requirements, free distribution of nodes are managed to collect the minimum target covering set so as to prolong the networks lifetime. We consider the different sensing capability and different spatial location, the TH-HESN target coverage based on the CLBDE is proposed. Experimental results are demonstrated on three target coverage modules acquired by the GA, the BDE and the CLBDE. The performance measures used are the equivalent number of working sensor nodes under different parameters, such as the maximum no effect radius, the attenuation factor and so on.

The remaining of this paper is organized as follows. Section 2 presents the basic concept. In Section 3, we explain the target coverage modules and algorithm. We give the process of target coverage based on the CLBDE. In Section 4, by means of simulation examples, we evaluate the performance of proposed algorithm. Finally, concluding remarks are given in Section 5.

2. **The related concept introduce.**

2.1. **Heterogeneous networks revisit.** Duarte gives the concept of heterogeneous sensor network[14], and heterogeneous sensor networks (HSN) allows the coexistence of sensors of different genres and ranges on a common platform. Sensor node isomerization is inevitable because of the different device parameters and the different working environment and the workload imbalance[15]. Sensor nodes are divided into four categories: sensing capability, data processing capability, communication capability and remaining energy[16]. This paper focuses on the sensing capability.

Typical HSN architecture is shown in Fig. 1, in which the triangle represents sink nodes and the hexagon represents super nodes and the circle represents ordinary nodes. Ordinary nodes are primarily responsible for collecting data and transferring to the super nodes. Super nodes remove redundancy of the collected data and transmit processed data to the control center, then to the user by the sink nodes.

The random distribution of nodes and targets in the TH-HESN is shown in Fig. 2. The black big circle represents the super nodes and the black small circle represents ordinary nodes and the white circle represents target nodes.

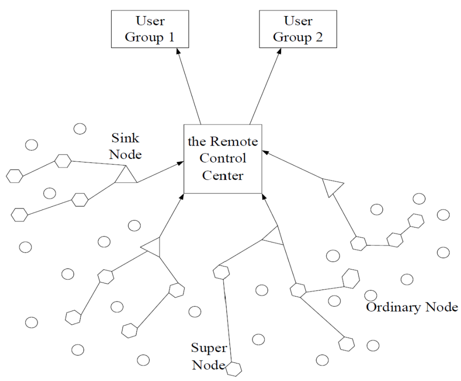

Figure 1. HSN architecture diagram

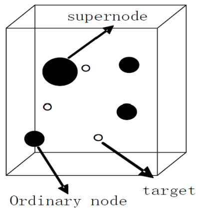

FIGURE 2. The three-dimensional HSN

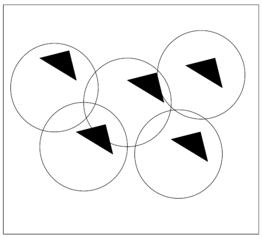

FIGURE 3. Target coverage model

2.2. **Target coverage.** The coverage problems are classified into two categories: area coverage and target coverage. Area coverage is to monitor each point in the area by sensor nodes. Target coverage is the special circumstances of area coverage, and its purpose is to cover one or more discrete points in the monitoring area. As shown in Fig. 3, the triangle represents discrete target and circular area represents the coverage area.

3. **Target coverage modules and CLBDE.** Suppose n sensing nodes and m target nodes are given in the three-dimensional area. The ordinary nodes number is 3 times the super nodes number. The ordinary nodes coverage radius is R_1, the absolute coverage radius is r_1 and the attenuation factor is α_1. The super nodes coverage radius is R_2, the absolute coverage radius is r_2 and the attenuation factor is α_2.

3.1. **The HSN probabilistic sensing module.** The probabilistic sensing model is used to simulate the real network coverage. The improved probabilistic sensing module is raised in [17], which is defined as:

$$P_{ag} = \begin{cases} 1 & d(a,g) \leq r \\ e^{-\alpha[d(a,g)-r]} & r \leq d(a,g) \leq R \\ 0 & d(a,g) > R \end{cases} \tag{1}$$

where a represents sensor nodes, g represents target nodes, P_{ag} is the coverage probability of a to g, α is the attenuation, $d(a,g)$ is the distance between a and g, r is the influence radius and R is the no influence radius. The HSN coverage probability matrix P is defined as:

$$\mathbf{P} = \begin{array}{c} \\ g_1 \\ g_2 \\ \vdots \\ g_i \\ \vdots \\ g_m \end{array} \begin{array}{c} \begin{array}{cccccc} a_1 & a_2 & \cdots & a_j & \cdots & a_n \end{array} \\ \begin{bmatrix} P_{11} & P_{12} & \cdots & P_{1j} & \cdots & P_{1n} \\ P_{21} & P_{22} & \cdots & P_{2j} & \cdots & P_{2n} \\ \vdots & \ddots & \ddots & \ddots & \ddots & \vdots \\ P_{i1} & P_{i2} & \cdots & P_{ij} & \cdots & P_{in} \\ \vdots & \ddots & \ddots & \ddots & \ddots & \vdots \\ P_{m1} & P_{m2} & \cdots & P_{mj} & \cdots & P_{mn} \end{bmatrix} \end{array} \tag{2}$$

3.2. **The HSN target coverage probability.** The coordinated multi-point target coverage can increase the coverage probability[18]. In the cooperative sensing probability module (CSP), the target is monitored by one or more nodes. The coverage probability based on the CSP is given below.

$$\begin{aligned} p_g &= 1 - \prod_{i=1}^{n} (1 - P_{ag}) \\ &= 1 - (1 - P_{1g})(1 - P_{2g}) \cdots (1 - P_{ng}) \end{aligned} \tag{3}$$

The target coverage purpose is to make all targets meet certain coverage probability. The formula (4) is to decide whether each target is covered and satisfies the coverage requirements.

$$p_g \geq \gamma \quad (g = 1, 2...m) \tag{4}$$

where γ is the threshold.

3.3. **The HSN Target coverage implement based on CLBDE.** In this paper, we introduce the CLBDE, which is derived from the BDE. The CLBDE uses the chaotic mapping to generate the discrete possible solutions to improve the ergodicity of BDE. In the terminal iteration, some outstanding individuals are extracted to conduct the similar scheduling. Each iteration the new individuals are generated by transformation, mutation, crossover and selection operation[18]. The procedure of the discrete possible solutions generated by the chaotic mapping is as follows:
1 The random sequence of U(0,1)[19] is generated by the formula (5).

$$x_{i+1} = \begin{cases} \frac{3}{2}x_i + \frac{1}{4} & 0 \leq x_i < \frac{1}{2} \\ \frac{1}{2}x_i - \frac{1}{4} & \frac{1}{2} \leq x_i < 1 \end{cases} \quad (i = 1, 2...) \tag{5}$$

2 After removing redundancy then the chaotic code is mapped to the actual solution space by the formula (6).

$$X_i = a + x_i(b - a) \tag{6}$$

where a is the lower and b is the upper.
3 The actual solutions are dispersed, where the number of 1 is the solution value. The flowchart of CLBDE is shown as Fig. 4. The implementation of the target coverage based on CLBDE principles is as follows:
Step 1 Initialization-Setting the initial parameters.
Step 2 Calculate the coverage probability using (1).
Step 3 Generate the possible solutions using (5) and (6).
Step 4 Generate the initial population using (3) and (4).
Step 5 Generate new individuals using the operators.
Step 6 Select the next generation compared to parent fitness.
Step 7 Determine whether the terminal condition is satisfied, and if not, return to step 5.
Step 8 Select 20% outstanding individuals and generate random combinations.
Step 9 Select the optimal individual compared to parent fitness.

4. **Results and discussions.** The area size is 100m × 100m × 100m. The ordinary nodes and super nodes ratio is 3:1. The parameters are $r_1 = R_1/6$, $R_2 = 2R_1$, $r_2 = R_2/6$ and $\alpha_2 = \alpha_1/2$. The population number is 30. The scaling factor is 0.1 and the crossover probability is 0.3. The random combinatorial number is 10. The simulation results (in 20 experiments the average) are compared with the GA and BDE.

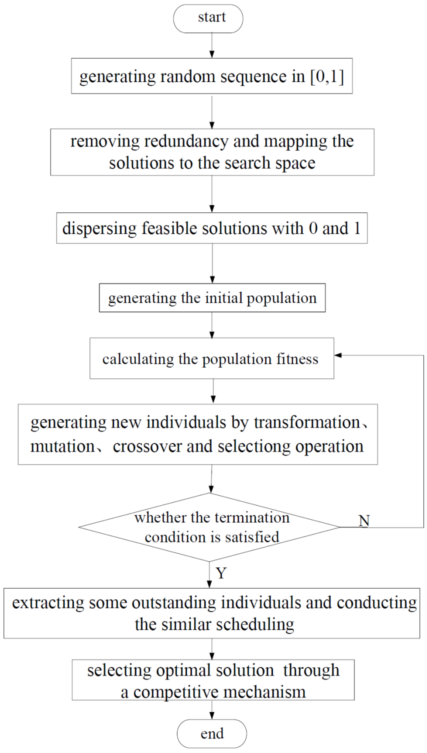

FIGURE 4. The procedure of target coverage based on CLBDE

4.1. **The R_1 and α_1 influence to the job sensor number.** The change curves are shown in the Fig. 5 and Fig. 6 based on all target nodes satisfying coverage threshold to discuss R_1 and α_1 influence. From Fig. 5 (m=60, n=280, γ =0.9, α_1 =0.06), we can observe that the working nodes number decreases with R_1

increasing and the job sensor number of the CLBDE is least under the same R_1.

From Fig. 6 (m=60, n=280, γ =0.9, R_1 = 30m),

we can observe that the sensor ability decreases and the job sensor number increases with α_1 increasing, and the equivalent working nodes number of CLBDE is least.

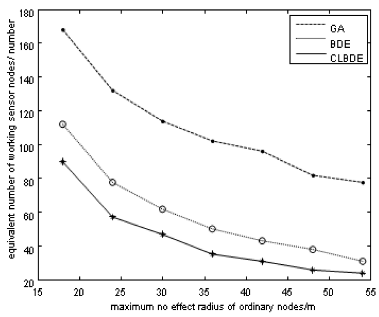

FIGURE 5. The job sensor equivalent number under different R_1

4.2. **The target number influence.** In order to discuss the target number influence, the change curves under different target number are given in Fig. 7 (n=280, R_1 = 30m, γ = 0.9, α_1 = 0.02).

From figure, we can observe that the GA increases slowly in the initial phase with the target number increasing, and when the target number is more than 60, the working

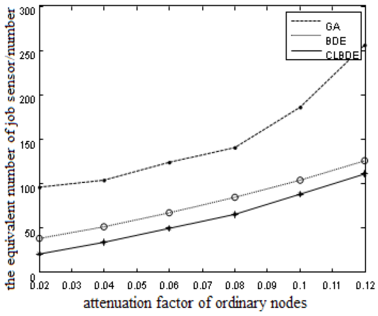

FIGURE 6. The job sensor equivalent number under different attenuation factor

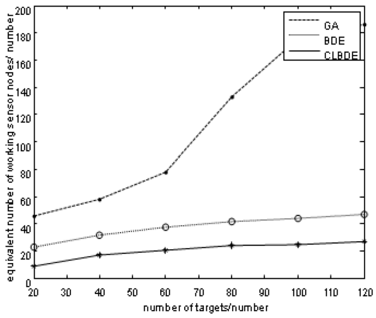

FIGURE 7. The job sensor equivalent number under different target number

nodes number increases sharply. The BDE and the CLBDE always increase gently. The CLBDE using the working nodes number is least.

4.3. **The coverage threshold influence.** In this part, the sensor nodes and target nodes number are certain (m=60, n=280). In order to discuss the job sensor number change with coverage threshold varying, the details are given in table 1($R_1 = 30m$, $\alpha_1 = 0.02$).

From table 1, we can conclude that the working sensor number increases with the coverage threshold rising and the working nodes number of CLBDE is least.

γ	GA	BDE	CLBDE
0.7	83	30	13
0.75	94	31	13
0.8	96	33	14
0.85	107	37	15
0.9	119	41	21
0.95	123	43	26

TABLE 1. The working nodes number under different coverage threshold

4.4. **Effects of the region size.** The target nodes are spread in the designated area. The area size should be considered before calculating the target coverage probability. The working nodes number under different area size is listed in the table 2 (m=300, n=560, R_1 = 60m, α_1 = 0.02).

From table 2, we can conclude that with the area size magnifying, the distance between sensor nodes increases and few target can be in multiple sensor common sensing range. Therefore in order to achieve the same coverage threshold, the working nodes number will increase. Under the same area size, the CLBDE algorithm can greatly reduce the average working sensor number.

Area length /m	GA	BDE	CLBDE
100	85	71	10
150	142	84	26
200	285	108	58
250	381	146	103
300	411	176	151
350	438	239	219
400	451	279	266

TABLE 2. The working nodes number under different area size

5. **Conclusions.** The target coverage module and the chaotic local binary differential evolution is proposed and implemented in this paper, in which chaotic mapping and similar scheduling are used to reduce the job sensor nodes number. The three-dimensional heterogeneous sensor networks and sensing probability model are considered. The proposed method could successfully perform the target coverage using the least working sensor nodes number. The experimental results show that the proposed method is better than other algorithms namely GA and BDE, and to save the network energy and prolong the networks lifetime.

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