Deployment Optimization of Perception Layer Nodes in the Internet of Things Based on NB-IoT Technology

Rui Liu[1], Jie-ran Shen[1], Feng Jiao[1], and Ming-hao Ding[2(✉)]

[1] State Grid Liaoning Electric Power, Slwply Co. Ltd., Shenyang 110006, China
huangdongping8962@163.com

[2] Department of Computer and Software Technology, Tianjin Electronic Information College, Tianjin 300350, China

Abstract. The traditional deployment optimization method of perception layer nodes in the Internet of Things has the drawbacks of poor optimization performance. Therefore, this paper proposes a research on deployment optimization of perception layer nodes in the Internet of Things based on NB-loT technology. The genetic algorithm is used to code the nodes in the perception layer of the Internet of Things, and the initial population is determined. Based on the coding of the nodes in the perception layer and the initial population, the fitness function is designed, and the NB-loT technology is used to optimize the deployment of the nodes in the perception layer of the Internet of Things. Experiments show that the average coverage of the proposed method is 24% higher than that of the traditional method, which shows that the proposed method has better optimization performance.

Keywords: Internet of things · Perception layer · Node · Deployment · Optimization

1 Introduction

The Internet of Things (IOT) is a kind of network that uses modern communication technology to connect sensors, people and objects in a new way to form information and intelligence. It can be divided into four layers: perception layer, network layer, middle layer and application layer [1]. The perception layer is a bridge connecting the physical world and the information world, and is also the bottom layer of the entire Internet of Things. It connects sensors on various devices through wired or wireless ways to form a network of information collection and control, and transmits the collected information to the upper layer of the Internet of Things. In the application process of the Internet of Things, it is necessary to monitor and reconnaissance the ecological environment and battlefield environment. It is required that all the targets moving along any path in the monitoring area can be found by the perception layer nodes. In order to fulfill the above requirements, multiple nodes must work together. This requires that the perception layer nodes deploy with high coverage and good node communication. At the same time, during the work process, the layout of network

S. Liu and L. Xia (Eds.): ADHIP 2020, LNICST 348, pp. 202–210, 2021.
https://doi.org/10.1007/978-3-030-67874-6_19

nodes should be automatically adjusted according to the location and importance of the goods to optimize the role of the Internet of Things. Therefore, it is the most important problem for the Internet of Things to design an effective optimization method for deployment of sensor layer nodes, to achieve reasonable and dynamic deployment of sensor layer nodes according to the monitoring area, to improve coverage and target detection probability of wireless sensor networks, and to reduce network energy consumption and maximize network lifetime.

NB-loT technology, known as narrowband Internet of Things, is an important branch of the Internet of Things. NB-IoT is built in cellular network and consumes only about 180 kHz bandwidth. It can be directly deployed in GSM network, UMTS network or LTE network to reduce deployment cost and achieve smooth upgrade. NB-IoT is a new technology in the field of IoT. It supports low power devices'cellular data connection in WAN. It is also called low power wide area network (LPWAN). NB-IoT supports efficient connection of devices with long standby time and high network connection requirements. It is said that the battery life of NB-IoT devices can be increased by at least 10 years, while providing a very comprehensive coverage of indoor cellular data connections [2]. The traditional method of node deployment optimization at the perception layer in the Internet of Things has the disadvantage of poor optimization performance and cannot meet today's increasing demand. Therefore, this paper proposes a research on deployment optimization of perception layer nodes in the Internet of Things based on NB-loT technology.

2 Design of Optimal Deployment Method for Perception Layer Nodes in the Internet of Things

The Internet of Things (IOT) has the characteristics of large scale, complex environment, limited network resources, random deployment and self-organization. These characteristics determine the importance of node deployment and conflict prevention technology in the implementation of the Internet of Things. Node deployment is a key low-energy technology, which can not only ensure the quality of Internet of Things, but also improve the reliability of the entire Internet of Things and ensure the safety of goods in the transport process [3]. In the Internet of Things, first of all, we should solve the deployment problem of nodes, that is, how to deploy the perception layer nodes of the Internet of Things, achieve the maximum coverage of the perception layer nodes, and optimize the performance of the Internet of Things.

In practical applications, the deployment of sensor nodes needs to consider many factors such as application environment, label distribution density, interference and so on. The distribution of nodes not only ensures the maximum coverage of the target area, but also satisfies the requirement of reading rate. It also reduces the cost of equipment and additional economic costs. A reasonable node topology will greatly reduce the cost of network construction. Therefore, the design of node deployment optimization in the Internet of Things is a multi-objective combinatorial optimization problem. According to the characteristics of the Internet of Things, genetic algorithms are used to optimize the deployment of sensing layer nodes. The specific process is as follows.

2.1 Perception Layer Node Coding

The genetic algorithm is used to code the nodes in the perception layer of the Internet of Things to prepare for the optimization of node deployment.

The genetic algorithm is proposed by Professor Yu of the University of Michigan. With the in-depth study of other scholars, genetic algorithm has become more perfect. At present, genetic algorithm is widely used in machine learning, industrial optimization control, biology, pattern recognition, image processing, software technology, neural network, genetics and so on. Generally speaking, genetic algorithm constructs a fitness function according to the objective function to solve the problem, evaluates and operates on a population composed of multiple individual solutions. After many iterations, the individuals with the best fitness function value are taken as the output of the optimal solution [4].

Genetic algorithm is an important branch of artificial intelligence. It combines "genetic" and "algorithm" well. It is an adaptive, global optimization and probabilistic search algorithm, which simulates the natural selection and genetic mechanism of organisms by using Darwin's evolutionism for reference. It is based on the natural evolutionary rules of "survival of the fittest, survival of the fittest", searching in the solution space and solving the problem.

The genetic algorithm introduces the principle of biological evolution in nature into the solving process of practical complex problems. Firstly, the candidate solutions of the problem to be optimized are coded to form a population containing several individuals. According to the fitness function corresponding to the optimization objective, the individuals with higher fitness function values are screened. Then the new individuals are crossed and mutated by genetic operation. The fitness function of the individual in the population will be improved continuously until the termination condition of the algorithm is satisfied by the continuous iteration operation. The individual with the highest value of the final output fitness function is regarded as the optimal solution of the problem to be optimized [5]. The specific coding process of the perception layer nodes is shown below.

Coding is the expression of solution space. According to the workflow of genetic algorithm to solve the problem, the candidate set of the problem should be coded first. Encoding is a mechanism that converts the parameters of practical problems into direct operation with genetic operators. The appropriateness of coding directly affects the speed and quality of problem solving. Binary encoding, Gray encoding and real number encoding are currently the three main encoding methods.

The problem of deployment optimization of perception layer nodes in the Internet of Things studied in this paper is how to deploy perception layer nodes reasonably. For the problem of deployment of perception layer nodes, this paper uses real coding method [6, 11]. Therefore, the possible solution $X_n(n = 1, 2, \cdots, n)$ of the problem can be set to a random array in the working area, that is:

$$X_n = \{X_1, X_2, \cdots, X_N\}, X_N \in (0, 30) \quad (1)$$

In the formula, individual X_n is randomly generated, and N represents the number of populations. $X_{n1} = \left\{X_1, X_2, \cdots, X_{\frac{m}{2}}\right\}$ represents the abscissa of the n th node, $X_{n2} =$

$\left\{X_{\frac{m}{2}}, X_{\frac{m+1}{2}}, \cdots, X_m\right\}$ represents the ordinate of the n th node, and $\frac{m}{2}$ represents the number of nodes in the perception layer of the Internet of Things.

Since genetic algorithm operates mainly on a group of individuals, it is necessary to prepare an initial population consisting of multiple candidate solutions. Initial population is the starting point of genetic algorithm optimization, and its construction is related to the execution efficiency of genetic algorithm. Initial population generation is generally divided into random method and priori-based method. This paper optimizes the deployment of the perception layer nodes in the Internet of Things. The initial deployment of the nodes is based on the random spraying method, so the initial population is randomly generated [7, 12].

Through the coding of the above perceptual layer nodes and the determination of the initial population, data support is provided for the following fitness function design.

2.2 Design of Fitness Function

The fitness function is designed based on the coding of the perception layer nodes and the initial population. The specific process is shown below.

Fitness function is mainly used to simulate the evolutionary selection process in nature. In order to implement the principle of "natural selection, survival of the fittest", genetic algorithm uses fitness function value to evaluate each individual in the population. Fitness function is a measure of the quality of each individual in the population. The selection of fitness function will directly affect the efficiency of the algorithm. Generally, individuals with higher fitness function have better survival ability, and the probability of inheritance to the next generation is higher; on the contrary, poor individuals have lower fitness function value, and their survival ability is weaker [8–10]. As fitness function is the only deterministic index to measure whether an individual in a population can inherit to the next generation, it directly determines the evolution of the population, so the selection of fitness function is very important in genetic algorithm.

The deployment optimization of perception layer nodes in the Internet of Things is a multi-objective optimization problem. It not only achieves the maximum coverage of goods, but also minimizes the level of interference between nodes. Therefore, the optimal objective function of node deployment is designed as follows:

$$f(\tau) = w_1 \cdot f_1(\tau) + w_2 \cdot f_2(\tau) \tag{2}$$

The objective function of node deployment optimization is the weighted sum of two sub-objective functions. Among them: $f_1(\tau) = Ind(\tau)$. $f_2(\tau) = Cov(\tau)$, w_1, w_2 is the weight of the two sub-objective functions in the whole optimization objective function. It mainly determines the size of these two weights according to the comprehensive requirements of the deployment of the perception layer nodes in the Internet of Things, and they satisfy $w_1 + w_2 = 1$. Larger w_1 guarantees the maximum coverage of goods, while larger w_2 can minimize the interference between intelligent nodes. In order to ensure the maximum coverage of cargo and minimize the interference between nodes, according to the empirical value, this paper sets $w_1 = 0.9, w_2 = 0.1$.

Through the above process, the fitness function is designed, and the goal of node optimization is determined, which provides the goal for the realization of the following node deployment optimization.

2.3 Implementation of Node Deployment Optimization

Based on the above fitness function, i.e. the optimization objective function of node deployment, NB-loT technology is used to optimize node deployment. The specific optimization process is shown below.

In the genetic algorithm, if the fitness function value of the individual X_i in the group is $f(X_i)$, the probability that the individual X_i is selected is:

$$P(X_i) = \frac{f(X_i)}{\sum_{i=1}^{q} f(X_i)} \tag{3}$$

Where q is the number of candidate solutions in each generation group. In order to ensure that the genetic algorithm can effectively converge to the optimal solution in the search space, certain protection measures can be taken when selecting all individuals in the population, that is, the individuals whose current fitness function value is the largest are not involved in the genetic operation. Instead, let it directly replace the individuals with low fitness function values in the next generation of populations, thus preserving the optimal individuals in the population.

The crossover probability P_c is defined as the ratio of the number of subalgebras produced by the crossover operation to the total number of individuals in the population in each generation of population. Obviously, a higher crossover probability can achieve a larger solution space, thereby reducing the probability of selecting a non-optimal solution individual; but if the crossover probability is too high, it will waste a lot of time because too many other solution spaces are searched. Reduce the search speed of the algorithm.

Let a pair of parent individuals be X_A and X_B respectively, then the pair of offspring individuals after the intersection are:

$$\begin{cases} X'_A = \alpha X_B + (1 - \alpha) X_A \\ X'_B = \alpha X_A + (1 - \alpha) X_B \end{cases} \tag{4}$$

Where α is a random number on [0, 1].

The mutation operation mainly simulates the mutation of a certain gene in an individual, thereby changing the characteristics and attributes of the individual. The probability of variation P_v is defined as the percentage of the number of individuals in the population as a percentage of the total number of individuals in the population. The probability of mutation controls the proportion of new individuals entering the population.

The optimization process of the IoT awareness layer node deployment is as follows:

Step 1: First, encode every possible point in the search space of the Internet of Things perception layer node deployment problem;

Step 2: Determine the size N of the initial population, the number of iterations DT, the fitness function $f(f > 0)$, the crossover probability P_c, and the mutation probability P_v;

Step 3: randomly generate N individuals in the search space to form the initial group $P(k)$, and let $k = 0$;
Step 4: Calculate the fitness function value of each individual in $P(k)$;
Step 5: Calculate whether the current population performance meets certain indicators. If yes, go to step 8; if not, go to step 6.
Step 6: According to the genetic strategy, the selection, crossover and mutation operations are applied to the current population to generate the next generation populations $P(k)$, $k = k + 1$;
Step 7: Determine whether k reaches the predetermined number of iterations, if yes, go to step 9; if not, go to step 4;
Step 8: Select the individual with the highest fitness function value in the population as the optimal solution output found by the algorithm;
Step 9: The algorithm ends and no optimal solution is found.

According to the above basic idea, a flowchart for optimizing the deployment of the Internet of Things sensing layer node as shown in Fig. 1 is obtained.

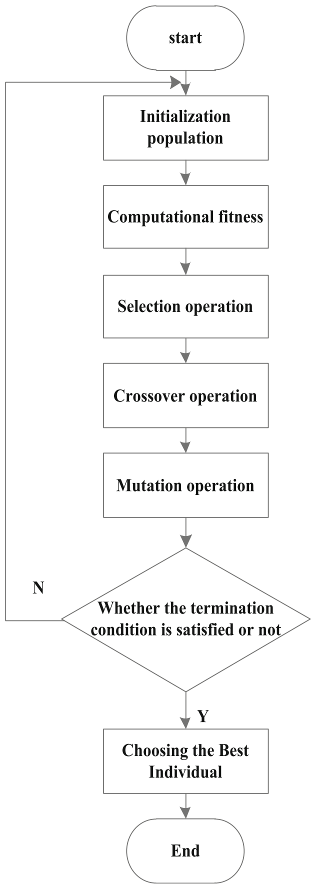


Fig. 1. Flow chart of optimization of IoT awareness layer node deployment

3 Performance Optimization Analysis of IoT Sensing Layer Node Deployment Optimization Method

In order to ensure the optimization performance of the IoT sensing layer node deployment optimization method proposed in this paper, the design experiment verifies it. In the experiment process, the Internet of Things sensing layer is taken as the experimental object, mainly to optimize its node deployment. In order to ensure the accuracy of the experimental process and the results, the proposed IoT perception layer node deployment optimization method is compared with the traditional IoT perception layer node deployment optimization method, and the experimental comparison results are observed. In the experiment process, the traditional IoT perception layer node deployment optimization method is called the control group, and the proposed IoT perception layer node deployment optimization method is called the experimental group.

3.1 Experimental Parameter Number Preparation

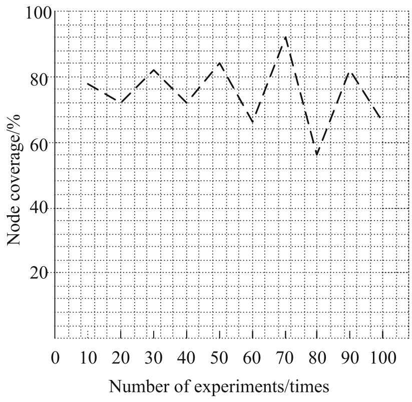
In order to ensure the accuracy of the experimental results as much as possible, the simulation analysis is carried out under the environment of Microsoft Windows XP operating system, Intel (R) Celeron (R) 2.6 GHz processor, matlab simulation tool and 24.0 gb memory. And in the experimental environment, the parameters in the experimental process are set up. This paper uses different optimization methods to optimize the deployment of the IoT perception layer nodes. Because the methods used are different, therefore, during the experiment. The external environmental parameters must be consistent. The experimental parameter setting results in this paper are shown in Table 1.

Table 1. Experimental parameter setting results

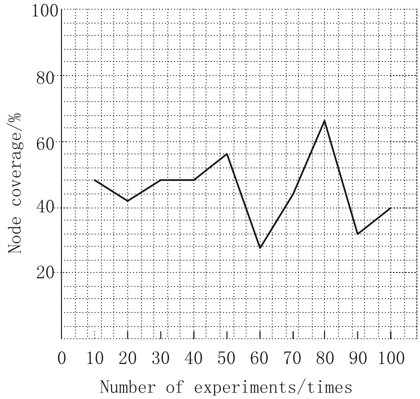
Parameter name	Parameter setting
Operation Status of Internet of Things	Normal operation
Number of Sensory Layer Nodes	6T
Population group number	10–50
α	0.523
Number of experiments	100 s

3.2 Node Coverage Analysis

During the experiment, because the statistical data and experimental data are recorded in different methods, statistical methods are used. Taking node coverage as an experimental indicator, a comparative analysis was made between the node coverage of the IoT perception layer of the experimental group and the control group. The comparison result is shown in Fig. 2.



(a) Node coverage of experimental group



(b) Node coverage of control group

Fig. 2. Comparison of the results of the node coverage experiment

According to the data in Fig. 2, the experimental group's IoT perception layer node coverage is between 59% and 92%, and the maximum coverage rate is as high as 92%, while the control group's IoT perception layer node coverage rate is 66%. The node coverage of the IoT perception layer of the experimental group is higher than that of the control group, indicating that the proposed IoT sensor node deployment optimization method has better optimization performance.

4 Conclusions

The proposed optimization method of IoT perception layer node deployment greatly improves the coverage of nodes, increases the probability of cargo detection of the Internet of Things, and improves the degree of deployment optimization of the IoT perception layer nodes. However, due to the parameter setting during the experiment. Ignoring the interference of most influencing factors will affect the results of the experiment to a certain extent, and further research on the deployment optimization method of the IoT sensing layer nodes is needed [13].

References

1. Zhang, Q.: Technical performance and application of the honeycomb-based Narrow Band Internet of Things (NB-loT). Sci. Technol. Commun. **9**(20), 12–15 (2017)
2. Zhu, W., Yao, Y.: Analysis on coverage enhancement technology of NB-loT Internet of Things. Wirel. Interconnect. Technol. **16**(8), 28–29 (2017)
3. Wu, J., Cheng, W., Liang, Y.: Discussion on the deployment strategy of NB-IoT and eMTC for operator cellular Internet of Things. China New Commun. **18**(23), 64–65 (2016)
4. Ye, Y., Jiang, S., Xing, L., et al.: End-to-end deployment strategy of NB-loT [J]. Guangdong Commun. Technol. **26**(2), 51–53 (2018)
5. Wang, J.: Discussion on coverage enhancement technology of NB-LoT Internet of Things. Commun. World **31**(23), 3–4 (2017)
6. Xing, Y., Hu, Y.: Narrow-band Internet of things deployment strategy. Inf. Commun. Technol. **62**(1), 33–39 (2017)
7. Fu, W., Liu, S., Srivastava, G.: Optimization of big data scheduling in social networks. Entropy **21**(9), 902 (2019)
8. Mingjun, L., Shiping, J.: Business Application of Narrow Band Internet of Things (NB-loT). Inf. Commun. **50**(10), 254–255 (2017)
9. Negash, B., Rahmani, A.M., Westerlund, T., et al.: LISA 20: lightweight internet of things service bus architecture using node centric networking. J. Ambient Intell. Humaniz. Comput. **7**(3), 305–319 (2016)
10. Liu, S., Bai, W., Srivastava, G., Machado, J.A.T.: Property of self-similarity between baseband and modulated signals. Mob. Networks Appl. **25**(4), 1537–1547 (2019). https://doi.org/10.1007/s11036-019-01358-9
11. Lu, M., Liu, S.: Nucleosome positioning based on generalized relative entropy. Soft. Comput. **23**(19), 9175–9188 (2018). https://doi.org/10.1007/s00500-018-3602-2
12. Yongbin, W., Zhongping, Z.: Low power, Dalian Wide Area Internet of Things access technology and deployment strategy. Inf. Commun. Technol. **52**(1), 27–32 (2017)
13. Shuai, L., Weiling, B., Nianyin, Z., et al.: A fast fractal based compression for MRI images. IEEE Access **7**, 62412–62420 (2019)