Research on Wake-up Mechanism of Wireless Sensor Network Nodes

Xiaolu Hao¹, a, Hai Lin², b

¹School of Software, Shenyang Normal University
Shenyang Normal University
Puyang, China
²School of Software, Shenyang Normal University
Tielin, China

a1351319862@qq.com, b2949491@qq.com

Abstract. The traditional node wake-up mechanism usually takes the huge cost of network energy and fails to consider the expensive price of the sensor node. In order to improve this shortcoming, this paper studies the wireless sensor network monitoring area coverage rate of 100% in the existing an improved node wake-up mechanism problem is proposed in the node wake-up mode. Firstly, the problem is transformed into SAT (the satisfiability of Boolean equation), and then the MiniSAT solver is used to solve the answer. The wireless sensor network is reached with as few working nodes as possible. The complete coverage of the monitoring area and the reduction of network energy consumption show that the new node wake-up mechanism can reduce the number of active nodes in the wireless sensor network monitoring area, improve network energy utilization, and reduce the application of WSN (wireless sensor network). Cost, driving the application of wireless sensor networks.

1. Introduction

1.1. Wireless Sensor Network Overview

Wireless Sensor Network (WSN) is a network of sensor nodes that can monitor, sense, and collect various information of perceived objects of interest to observers in the node deployment area, such as light intensity, humidity, noise, and harmful gases. Physical phenomena such as concentration, and processing these information and sending them wirelessly through the wireless network to the observer [1]. Applications of wireless sensor networks involve military battlefields, intelligent transportation, environmental monitoring, biomedical, industrial monitoring, etc. The fields are shown in Table I.
Table 1. Application fields of wireless sensor networks

| field                | Application scenario                     |
|----------------------|------------------------------------------|
| Military             | Enemy and me identification             |
|                      | War status monitoring                    |
|                      | Intelligence acquisition                 |
| Environmental monitoring | Disaster judgment                      |
|                      | Pollution level monitoring               |
| Medical              | Ecological monitoring                    |
|                      | Patient location and alert               |
|                      | Monitor patient physical condition in real time |
| Traffic monitoring   | Traffic management                      |
| Industrial control   | Application scenario                    |
| Building monitoring  | Enemy and me identification             |

The wireless sensor network architecture is shown in Fig. 1. Wireless sensor networks usually include sensor nodes, aggregation nodes, and management nodes. With the development of wireless sensor networks (WSN), wireless sensor nodes have become one of the research hotspots of wireless sensor networks. The data collected by the sensor node is transmitted hop by hop through the other sensor nodes in the network. The transmitted data may be processed by multiple sensor nodes, reach the aggregation node through multi-hop routing, and finally reach the data processing center by the Internet or satellite. In the opposite direction, the wireless sensor network is managed by the management node, the monitoring task is released, and the mobile phone senses the data. However, the wireless sensor network is different from the general wireless network, and has limited network resources, a large number of sensor nodes, and high density. The shortcomings of node communication distance and low communication reliability. The deployment of wireless sensor network nodes is the first problem that WSN needs to solve in specific applications. It is directly related to the accuracy,

![Figure 1. Wireless sensor network architecture](image-url)
Integrity and timeliness of network monitoring information, but sensors. Nodes typically use a limited capacity and non-replaceable power supply Therefore, how to effectively use limited energy is one of the core issues we need to study, so reducing the energy consumption and cost of nodes is one of the primary considerations in designing wireless sensor networks [2], which can wake up and sleep accordingly. The node completely covers the wireless sensor network monitoring area with the least working node.

1.2. Overview of Node Wakeup Mechanism

In wireless sensor networks, the wake-up methods of nodes are as follows: (1) Full wake-up mode: In this mode, all nodes in the wireless sensor network wake up at the same time, detecting and tracking the targets appearing in the network, although in this mode Higher tracking accuracy can be obtained, but at the cost of the huge consumption of network energy. (2) Random wake-up mode: In this mode, the nodes in the wireless sensor network are randomly awakened by the given wake-up probability p. (3) The wake-up mode is selected by the prediction mechanism: in this mode, the nodes in the wireless sensor network selectively wake up the nodes with higher tracking accuracy gains according to the needs of the tracking task, and predict the state of the target at the next moment through the information itself. And wake up the node. (4) Task cycle wake-up mode: In this mode, the nodes in the wireless sensor network are periodically awake, the nodes of this working mode can coexist with the nodes of other working modes, and assist other work. The mode of the node works.

At present, the wake-up mode selected by the prediction mechanism can obtain lower energy consumption loss and higher information benefit. [3] But it is far from meeting the minimum energy consumption requirement, and the coverage area of the working node cannot reach 100% accuracy to the target area. Full coverage [4], too many nodes and a large number of lines can make wireless sensor networks very complex and not working properly, and the price of a single sensor node is not cheap, the battery life is best It can only be kept for a few months, so it is necessary to develop an accurate node wake-up mechanism to optimize the distribution of nodes, awaken the least working nodes, achieve complete coverage of the target area, and make efficient use of node energy and reduce costs.

2. Sat Problem Description

There are hundreds of known NP-complete problems, but as the "ancestor" of these problems, the first proven NP-complete problem in history is from the SATISFIABILITY problem. For SAT [5], We know that a Boolean expression is an expression consisting of a Boolean variable and an operator (NOT, AND, OR). If a true, false assignment is made to a variable, the value of a Boolean expression is made. [6] True, the Boolean expression is satisfiable. For example, the Boolean formula \( A = ((\text{NOT } x \text{ AND } y) \text{ OR } (x \text{ AND } \text{NOT } z)) \), when \( x = \text{false}, y = \text{true}, z = \text{false} \), The Boolean expression value is true, then the expression A is satisfiable. Given a Boolean equation, judging whether there is a set of Boolean variables whose truth assignment makes the whole equation true, is called the satisfiability of the Boolean equation. Problem (SAT). Satisfiability (SAT) is a fundamental issue in logic and a core issue in today's computer science and artificial intelligence research. Many important aspects of engineering technology, military, business administration, transportation, and natural science research. [7] Problem, such as Automatic exchange of telephones, maintenance of large databases, automatic routing of large-scale integrated circuits, automatic software development, robot motion planning, etc. can all be converted into SAT problems. [8] The SAT problem proved to be an NP-hard problem. At present, there are two main methods for solving this problem: a complete method and an incomplete method. The advantage of the complete method is to ensure that the SAT problem can be correctly judged, but its computational efficiency is very low, the average calculation time is polynomial order, [10] and the worst case calculation time is exponential order, which is not suitable for solving large-scale SAT. Problem. The advantage of the incomplete method is that the solution time is much faster than the complete method, [11] but in a few cases it is not possible to correctly judge the satisfiability of the SAT problem. The traditional methods are: enumeration method, local search method and greedy algorithm, but because of the large search space, the problem is generally difficult to solve. For NP-hard problems
like SAT, [12] some modern heuristics such as evolutionary algorithms are often more effective. The SAT problem is NP-complete, but for SAT problems that meet certain constraints, still able to solve effectively. [13]

3. Minisat Solver Description
The SAT solver is the program that can complete the SAT solution. There are many well-known SAT solvers such as GRASP, Chaff, Zchaff, BerkMin and MiniSat. MiniSAT is a simple solver. The open source Boolean can satisfy the problem solver. Developed by researchers and developers. It is licensed and released by the Massachusetts Institute of Technology. [14] Give the SAT solver a logical proposition containing OR and Logic symbols and several Boolean variables. Based on this expression, the SAT solver determines whether the logic proposition is satisfied. Decide whether the proposition is true. If it is satisfied, the MiniSAT solver gets the result to determine that the proposition formula set is true. The MiniSAT solver takes the conjunction formula (CNF) as the input file of the conjunction clause. Each proposition formula (set) can be converted into a CNF file (the CNF file is generally suffixed with. dimacs.). The conjunction paradigm is a formula consisting of the basic sum product, consisting of or consisting of expressions.[15] The composition of the formula .CNF includes: the item, each item is a Boolean variable; the clause, each clause consists of one or more items, and the items are connected by a logical symbol OR (operator |), [16] not in a clause There will be repeated Boolean variables; expressions, each expression consists of one or more clauses, and clauses are connected by AND (operator &). Translating wireless sensor network node problems into SAT problems can be shipped MiniSAT solver to solve. [17]

4. Solution

4.1. Theoretical Analysis
The nodes in the wireless sensor network have three working states: Sleeping, Probing, and Working. All nodes are in the Sleeping state at the beginning. For each node, it can wake up at every moment, and the wake-up time satisfies the Poisson distribution. After it wakes up, it enters the Probing state. It uses the hello information to broadcast a certain range around it. If there is a working node around it, it will reply the message and then go to sleep after receiving the message.

For (any time slice)
{
Shuffle nodes;
For (any sensor node)
{
Check surrounding nodes;
If (surrounding nodes)
Node. Status=sleeping;
Else
Node. Status=working;
}

4.2. Analysis of Algorithms
Translate the wireless sensor network node wake-up mechanism problem into the SAT problem, and then convert the logical expression into a conjunction formula (CNF) such as "(x1 ∨ x5 ∨ x4) ∧ (x1 ∨ x3 ∨ x4)". Write the algorithm in programming language The DIMACS-CNF format file corresponding to the output propositional logic formula, the SAT problem is usually described in the
DIMACS-CNF format: an input file, where each line represents a separate separation. For example, a file with two lines

```
1 -5 4 0
-1 5 3 4 0
```

Then use MiniSAT solver to solve. MiniSAT runs in Linux environment, since most of the systems are Windows systems, Cygwin64 is used here (cygwin is the Linux simulation environment running on windows platform, cygwin is relatively installed virtual machine, vps is lightweight) software to simulate the Linux environment.

Definition:
Suppose there are m sensors S = {Sen1, Sen2, ... em}, n regions R = {R1, R2, ..., Rn}, a minimum coverage of R is a subset of S S*, S* satisfies the following Two conditions:

1) S* can cover R.
2) Any true subset of S* cannot cover R.

Problem Description:
Given m sensors S = {Sen1, Sen2... Senm}, n regions R = {R1, R2, ..., Rn}, the coverage area of the sensor can be represented by a two-dimensional array A (A[i][j] =1 if and only if the ith sensor covers the jth region). Calculate a minimum coverage of R for S*.

We need to generate a propositional logic formula Φ such that Φ satisfies if and only if R has a very small coverage, and makes Φ a true assignment exactly corresponding to the minimal coverage of R.

Problem realization:
If there are three sensors S = {Sen1, Sen2, Sen3}, the four coverage areas R = {R1, R2, R3, R4}. Sensor coverage area: Sen1: R1, R2 Sen2: R1, R2, R3 Sen3: R3, R4. It can be seen that when the sensor Sen1 is turned on, Sen3 can cover all areas, and the minimum coverage of R covers S* = {Sen1, Sen3}.

The corresponding two-dimensional array A is as follows: row i represents the sensor, column j represents the region (three sensors, i=3 two-dimensional array of four regions, j=4) A[i][j] =1 indicates the ith sensor covers the jth area, and the area is not covered by the sensor with 0, as shown in Table II:

|   | R1 | R2 | R3 | R4 |
|---|----|----|----|----|
| Sen1 | 1  | 1  | 0  | 0  |
| Sen2 | 1  | 1  | 1  | 0  |
| Sen3 | 0  | 0  | 1  | 1  |

Analysis from three parts:
1) The first part Φ1: The ith Seni (sensor) is open: S(i)=T, defines a function S(i)={i|A[i][j]=1}, A[i][j]={j,i|j(1,2,3,...,n),i(1,2,3,...,m)}

The pseudo code is as follows:

```java
For j = 1 to n
    Traversing n regions
For i = 1 to m
    Traversing m sensors
If (A[i][j]=1)
    If the ith sensor covers the area j
    Output S(i);
    Output this sensor is open
    Print S(i);
    Output 0 indicates the end of a clause
s(i){
    Return i;
}
```

According to the above pseudo code, the CNF file is output in C language (it should be n lines), and the CNF file output according to Table II is written.

```
Pcnf 3 4
1 2 0
1 0
2 3 0
3 0
```

2) The second part Φ2: defines the function X(i, j), indicating that the j-th region region is only covered by the ith sensor Seni, meaning that the other sensors in the region are closed when the i-th sensor covering this region is turned on.

The pseudo code is as follows:
For $i \leftarrow 1$ to $m$
Print $-S (i)$;
For $j \leftarrow 1$ to $n$
  If $(A[i][j]=1)$
    Print $X(i,j)$;
Print 0;
X (i) (j) {
  Return $j*m+i$;
}

Cannot be written as $j + i$ is different from the $S$ function return value $i$, avoiding duplicates causing logical errors

Table 2. Coverage area of wireless sensor nodes

|   |   |   |   |   |
|---|---|---|---|---|
| 1 | 1 | 0 | 0 | 0 |
| 0 | 0 | 1 | 1 | 1 |

The above code shows that when $S_i$ is necessary to open, theoretically other sensor nodes are not turned on. (Belong to the concept defined by yourself, the CNF file is also $n$ lines),

The CNF file output by the program according to Table II is

```
pcnf 3 4
1 -2 0
1 0
2 -3 0
3 0
```

(3) The third part $\Phi_3$: Define the $K$th sensor $S(k)=\{k | k \{1,..,m\}, ki\}$. The pseudo code is as follows:

For $i \leftarrow 1$ to $m$
For $j \leftarrow 1$ to $n$
For $k \leftarrow 1$ to $m$
  If $(A[k][j]=1 \text{ and } k!=i)$
    Print $-X (i, j)$;
Print $-S (k)$;
Print 0;
S (i) {
  Return i;
}

When the $k$th sensor covers the area $j$, and $K$ is not equal to $i$, it indicates that the area $j$ can be covered by the sensors $i$ and $k$ at the same time, and the output $X (i, j)$ is negated, that is, when the $j$ is covered, only the sensor $i$ is turned on, and the sensor $k$ is turned off.

When the $S_i$ sensor is turned on, the other sensors remain off. The output CNF file (the sensor in the off state has $n$ lines).

```
pcnf 3 4
1 -2 0
1 0
2 -3 0
3 0
```
In summary, $\Phi = \Phi_1 \land \Phi_2 \land \Phi_3$, the logical expression is converted to CNF format, expressed as, the MiniSAT solver uses the obtained CNF file to solve, it can be known that a minimal coverage of $R$ is $S^* = \{\text{Sen1, Sen2, Sen3}\}$. Just wake up the 1,3 sensor to cover the entire area. As an example, the wireless sensor network node wake-up mechanism can be studied.

5. Conclusion
This paper proposes an accurate node wake-up mechanism, which wakes up as few working nodes as possible to achieve complete coverage of the monitoring area. Experimental results show that the proposed precise node wake-up mechanism optimizes the distribution of nodes, enables efficient use of node energy, and improves the network. Energy utilization, reduce the application cost of WSN, and make wireless sensor networks widely used.

References
[1] Fan Gaojuan. Research on Wireless Sensor Network Coverage Control Technology [D]. Nanjing University of Posts and Telecommunications, 2010.
[2] Yu Kai, Xie Zhijun, Jin Guang, Qian Jiangbo. Design and Implementation of Low Power Wireless Sensor Network Node [J]. Microelectronics & Computer, 2012, 29 (09): 157 - 159+163.
[3] Shi Qinqin. Wireless sensor network node self-positioning system and its algorithm [D]. Shanghai Jiaotong University, 2009.
[4] Xuemei Sun, Yiming Zhang, Xu Ren, Ke Chen. Optimization deployment of wireless sensor networks based on culture-ant colony algorithm [J]. Applied Mathematics and Computation, 2015, 250.
[5] Bao Wei, Xu Yun, Huang Liusheng, Xu Hongli, Feng Wei. Speed Adaptive Tracking Algorithm in Wireless Sensor Networks [J]. Computer Engineering, 2010, 36 (02): 113-115+118.
[6] Ikeda Kohei, Suzuki Tsuyoshi, Sawai Kei, Yamashiro Hideyuki, Motohashi Mitsuya, Takemura Fumiaki, Kawabata Kuniaki. Study of Wireless Sensor Node Functions with Attached Algae Removal Ability for Under-water Monitoring Sensor Network [J]. The Abstracts of the international conference on advanced mechatronics: toward evolutionary fusion of IT and mechatronics: ICAM, 2015, 2015. 6(0).
[7] Bharat J. R. Sahu, Navrati Saxena, Abhishek Roy. Efficient M2M Gateway Planning for Next-Generation Cellular Networks [J]. IETE Technical Review, 2018, 35 (4).
[8] Cruz Hernández, C., López Mancilla, D. A note on chaos-based communication schemes [J]. Revista Mexicana de Física, 2005, 51(Regular).
[9] Florian Hagenauer, Christoph Sommer, Takamasa Higuchi et al.. Vehicular micro cloud in action: On gateway selection and gateway handovers [J]. Ad Hoc Networks, 2018, 78.
[10] Wallace Carolyn, Legro Marcia. Using formative evaluation in an implementation project to increase vaccination rates in high-risk veterans: QUERI Series [J]. Implementation Science, 2008, 3 (1).
[11] Laurent Segers, David Van Bavegem, Sam De Winne et al.. An Ultrasonic Multiple-Access Ranging Core Based on Frequency Shift Keying Towards Indoor Localization [J]. Sensors, 2015, 15 (8).
[12] Kanokorn Photinon, Shih-Han Wang, Chung-Chiun Liu. Thick-Film Carbon Dioxide Sensor via Anodic Adsorbate Stripping Technique and Its Structural Dependence [J]. Sensors, 2009, 9 (9).
[13] Vytautas Markevicius, Dangirutis Navikas, Darius Andriukaitis, Mindaugas Cepenas, Algimantas Valinevicius, Mindaugas Zilys, Reza Malekian, Arturas Janeliauskas, Wojciech Walendziuk, Adam Idzkowski. Two thermocouples low power wireless sensors network [J]. AEUE - International Journal of Electronics and Communications, 2018, 84.
[14] Marcin Golański, Radosław O. Schoeneich, Dawid Zgid, Marek Franciszkiewicz, Michał Kucharski. RBCP-WSN: The Reliable Bidirectional Control Protocol for Wireless Sensor Networks [J]. International Journal of Electronics and Telecommunications, 2017, 63 (2).
[15] Aleksejs Jurenoks, Dejan Jokić. Coordinator Role Mobility Method for Increasing the Life Expectancy of Wireless Sensor Networks [J]. Applied Computer Systems, 2017, 21 (1).

[16] Bogdan Dziadak, Łukasz Makowski, Andrzej Michalski. Survey of Energy Harvesting Systems for Wireless Sensor Networks in Environmental Monitoring [J]. Metrology and Measurement Systems, 2016, 23 (4).

[17] S. Ananda Kumar, P. Ilango, Grover Harsh Dinesh. A Modified LEACH Protocol for Increasing Lifetime of the Wireless Sensor Network [J]. Cybernetics and Information Technologies, 2016, 16 (3).