Fault Detection Platform for Wireless Sensor Networks

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Abstract. To point at the errors in development of wireless sensors network engineering as well as deal with the difficult issues of fast positioning and debugging, the Non-Intrusive fault detection platform is designed and consists of three parts, which includes the tested sensor networks, testing networks and testing tools. Besides, the mentioned parts can play a role in the development of network protocol, realizing the function of time synchronization testing, messages analysis, power consumption testing, reliability testing and delay test, etc. Through the detection platform can the long chain network be tested in the development process. The experimental results verify the fact that the validity of the detection platform performs in functions of time synchronization testing, reliability testing, power consumption testing and message analysis, even handling the problems of rapid locating and debugging.

1. Introduction

Wireless Sensor Network(WSN)[1,2] has become a newly developed technology, functioning as information acquisition as well as information processing. With its expanding application scope, WSN gradually ranging from military and environmental monitoring applications to agriculture, industry, medical treatment, education and their like. With the wide application and larger deployment scale of WSN, the application demand will follows its mainstream, which poses the challenge to the development of wireless sensor networks. In addition to the potential code issues while debugging in the PC, many interactive problems also exist in the process of interaction [3]. Therefore, the approaches to locate network faults quickly through fault detection platform in wireless network development is of great significance to improve the speed and quality of network development.

Presently there are several researches on systematic fault detection of wireless sensor networks at home and abroad [4-7], mainly focusing on fault detection algorithms. Yu Wang [4] mainly studies the detection methods of transient, noise and constant faults. Coming up with a new self-diagnosis model based on Petri Net Model, which is proposed to determine the health status of sensors by analyzing their behavior. Huatao Fan[5] proposed a real immune genetic fault detection algorithm based on KS Test and Voting, as well as a fault detection algorithm based on Integrated Deep Belief Network, which is able to detect various fault types and gains its platform verification. Motelab [8] is a series of wireless sensor network testing platform based on wired network, which involves fixed layout of wireless nodes and a central server. The central server is mainly responsible for data collection and recording. Server and wireless nodes can also be linked by wired connections, which enables the tasks in the test platform are generated and dispatched. The research of fault detection algorithm is of great importance for maintaining the quality of network and is suitable for improving the service quality of WSN as well as prolonging the network lifespan. However, most of these test platforms are designed for specific applications with strong pertinence and single function, resulting the failure of quickly finding the root cause of the problem in the process of protocol development.
In terms of the problem encountered and difficulties of fast location and debugging in the development of WSN, this paper designs and builds a fault detection platform for wireless sensor networks, which is able to analyzing on line through non-intrusive method, and eventually the faults of wireless sensor networks can be quickly located in the development process. Taking the development and testing of long-chain networks for experiments, the effectiveness of the debugging method proposed in this paper is verified.

2. Overview of Fault Detection Platform

In order to improve the development efficiency and locate network protocol faults quickly in the process of wireless sensor network protocol development, the detection platform is required with corresponding testing in the MAC layer, network layer and application layer of network protocol.

2.1. MAC Layer Testing

2.1.1. Time synchronization testing. As an important supporting technology in sensor networks, network time synchronization plays an important role in data fusion, node scheduling, node location, target tracking, time division multiple access communication and other functions.

2.2. Network Layer Testing

2.2.1. Routing Protocol Analysis. Routing protocol is responsible for the generation and selection of route, which plays core element technology role in process of forming networks by self-organizing sensor nodes. During the design of wireless sensor networks, the quality of the network is directly related to the design of routing protocols. Therefore, it is an important function of the detection platform to verify the designed routing protocols.

2.3. Application Layer Testing

2.3.1. Power Consumption Testing. In application scenarios with special requirements for power consumption of wireless sensor, power consumption can be a major consideration. In the development of wireless sensor network protocol with low power consumption, it is necessary to analyze the power consumption of wireless nodes at all times, so as to optimize the network protocol.

2.3.2. Reliability Testing. The reliability of data transmission in wireless sensor networks is directly related to the quality and speed of data transmission, and even affects the function of the whole sensor network. Meanwhile, many network changes such as dynamic variation in route, changes in network topology and dynamic allocation in message channel will also directly affect the reliability of the network.

2.3.3. Delay Testing. For the development of network protocols with high real-time requirement, especially in the circumstance of large-scale wireless sensor networks, the action of delay testing is indispensable for the study of delay optimization schemes.

In terms of the problem that it is difficult to locate and debug errors quickly in the development process of WSN protocol, this paper contributes to design and build a on-line fault detection platform, which combined with the property of non-intrusion for wireless sensor network. It tests the MAC layer, network layer and application layer of the network, and eventually can realize time synchronization testing, message timing analysis, power consumption testing, reliability testing and delay testing and so on.

The design of testing platform is mainly composed of three parts: the tested sensor network, the testing network and the testing tools. Among them, the tested sensor network includes the tested wireless node and tested wireless gateway equipment; the test network mainly consists of Ethernet switch, local Ethernet network and RS232 serial port network; the test tools include computer of data
collection, oscilloscope, DC Power Analyzer and wireless message monitoring tools. The overall system structure can be shown in Figure 1.

![Overall system architecture of wireless sensor network fault detection platform](image)

**Figure 1.** Overall system architecture of wireless sensor network fault detection platform

The main functions of the testing tools in the testing system are shown as follows:

(1) **Data Collection Computer** - running function of data collection and processing software to aggregate data, merging and sequencing analysis.

(2) **Oscilloscope** - In the oscilloscope based on the high precision clock, the time synchronization pulse signal of WSN node is detected.

(3) **DC Power Analyzer** - with special power analysis software, DC power analyzer realizes the full-cycle power measurement of wireless sensor network nodes.

(4) **Message Monitoring Tool** - A single monitoring tool can continuously monitor messages on a channel within its communication range at the same time. By decentralizing the monitoring tools in multiple areas, the message monitoring coverage can be achieved in whole network.

### 3. Realization of Specific Function Modules

This paper aims to design and build a fault detection platform for wireless sensor networks (WSN). As shown in Figure 1, the functions of time synchronization testing, message timing analysis, power consumption testing and reliability testing can be realized. The specific function modules are shown as follow.

#### 3.1. Time Synchronization Test Module

The time synchronization test module mainly measures the condition of time synchronization in different wireless nodes. Due to the inconsistency of several elements such as clock frequency, crystal frequency drift and program delay among different nodes, especially among different hardware nodes, the accuracy of clock synchronization in the whole network will be affected. Hence, time synchronization test is needed. Time synchronization sequence diagram is shown in the following figure 2.
The design of this detection platform system employs the oscilloscope testing method. The measurement channel of the oscilloscope is connected with the synchronous pulse output port of the tested wireless node by this platform, which observes and records the synchronous pulse output time of each channel on the oscilloscope. Assuming that an oscilloscope with m channels simultaneously measures n wireless nodes (n < m), if the testing output synchronization pulse time is t_1, t_2, t_3...t_i (1≤ i≤ n), the time synchronization accuracy $\tau$ is shown in the following equation:

$$T_{ave} = (\sum_{i=1}^{n} t_i)/n$$

$$\tau = (\sum_{i=1}^{n} |t_i - T_{ave}|)/n$$

### 3.2. Message Information Analysis Module

The format used for message information analysis in this paper conforms to the standard of IEEE 802.15.4. The specific format is shown in Figure 3.

**Figure 3.** The format of packets

Bytes 0 and 1 begin with message length bytes. The second byte begins with the frame control domain, which takes up 2 bytes. The format is shown in Figure 4. The first byte determines whether the message needs to respond. The last byte defines the address form of the link layer, which represents the long address, the short address or a mixture of the two.

**Figure 4.** The format of frame control field

Sequence Number represents the serial number of a message, which takes up one byte. The messages sent by each node are sorted by serial number.
ASN represents the absolute time slot number in the network, which occupies 5 bytes, indicating how many time slots have been experienced since the beginning of the network. It can be used as a unified timing in the network.

PANID is used to distinguish different IEEE802.15.4 networks, and each network has a unique PANID. In the process of experiment, the monitored message may come from many different networks. The message from the same network can be screened out according to the PANID value.

DLPDU Specifier is message description for a link layer with occupation of one byte, which indicates the content and the type of message. As shown in Figure 5:

![Figure 5. DLPDU Specifier](image)

When testing, in wireless sensor networks, firstly, message monitoring tools are distributed in multiple areas to achieve the coverage of message monitoring in the whole network; secondly, a LAN connection is established between message monitoring tools and PC machine to ensure the high bandwidth and low latency of message data acquisition channels; finally, message data collection and processing software are run on data collection computers, which realizes the unified collection, aggregation, merging and analysis of message data.

The message data analysis software used in this paper is developed and implemented by C++ language on the QT platform. The software can support TCP, serial port and other communication interface protocols, and can collect multiple channel data at the same time. In order to complete the collection and analysis of messages, this paper designs the system flow chart as shown in Figure 6 below.

![Figure 6. Process of packet analysis system](image)

The whole system process can be divided into the following parts:
a) Collecting message
Messages are distributed in the whole wireless sensor network, and can be obtained directly by using multiple message monitoring tools. The acquired message is sent to the computer through Ethernet for subsequent processing.

b) Preprocessing message
After obtaining the messages monitored by multiple message monitoring tools, it is necessary to pre-process the messages in order to obtain the messages for analysis. The preprocessing process mainly deletes duplicate messages and non-analytical messages, and ranks the messages according to time.

c) Message analysis
The work of this stage is the core part of the whole process, which includes data segmentation, deletion of interference messages and analysis of abnormal messages. Abnormal messages are not entirely problematic messages, so it is necessary to find out the problematic parts by manual analysis.

3.3. Power Consumption Test Module
Functional test module mainly tests the power consumption of a single node in the whole cycle, including dormancy power consumption, receiving state power consumption, sending state power consumption and so on.

Keysight N6705B DC power analyzer and corresponding power analysis software are used in the power test module in this paper, which can measure the power consumption of the node in the process of operation.

3.4. Reliability Test Module
Reliability test module mainly tests the packet loss rate of wireless sensor network communication data to reflect the reliability of network communication. In the process of network development, a little modification of routing protocol, network structure, hardware driver and other programs may affect the reliability of the network. The reliability of the network can be reflected directly and quickly by the loss rate test.

In this paper, the reliability test module adopts the two-way communication test method, which means node-to-node. Only once the communication is successful, a transceiver communication is completed, otherwise it belongs to packet loss. Supposing that the total number of transmissions is \( N_{Tx} \) and the total number of receipts and responses is \( N_{Rx} \), the data communication loss rate \( P_{loss} \) is:

\[
P_{loss} = \frac{(N_{Tx} - N_{Rx})}{N_{Tx}} \times 100\% \tag{3}
\]

4. Examples of Applying Fault Diagnosis Platform
This text take the development process test of long-chain wireless sensor network protocol with adaptive routing radius[9] as an example, to analyze its time synchronization, reliability, power consumption and message information analysis.

4.1. Test of Time Synchronization
When operating the network, taking four nodes of the same level routing, and observe the synchronization pulses output by them with the Agilent DSO7054B oscilloscope. As shown in Figure 7.

Figure 7. Picture of time synchronization test
On the oscilloscope, the test result of the pulse time from the nodes of the same level route is 6us, 18us, 29us and 45us respectively and is calculated by the formula (1) and formula (2), and the time synchronization precision is 15.5us.

4.2. Test of reliability

In order to detect the reliability of connection between the wireless nodes and the gateway device, the box with high and low temperature was used to test the success rate of connection between the test node and the gateway device. The total test time is 48 hours. The PC machine sends data to each wireless node through the gateway device every 10 seconds. If the module works normally, it will respond and data is collected by the PC. The ratio of the total number of data collected to the total number of data sent is the data receiving rate, as shown in Figure 8.

![Figure 8. reliability test](image)

### Table 1. Tests results

| No | Time: 9th Aug 18:30-10th Aug 18:30 | Time: 10th Aug 18:30-11th Aug 04:30 | Time: 11th Aug 5:30-11th Aug 15:30 |
|----|-----------------------------------|-----------------------------------|-----------------------------------|
|    | Temperature: 85℃                  | Temperature: -25℃                 | Temperature: -40℃                 |
| ID | Total number of data sent          | Total number of data received      | Success rate of receiving (%)     |
|    | 11122                            | 11120                            | 99.9                              |
|    | 11115                            | 11109                            | 99.9                              |
|    | 11109                            | 11104                            | 99.9                              |
|    | 11100                            | 11094                            | 99.9                              |
|    | 11093                            | 11090                            | 99.9                              |
|    | 11087                            | 11077                            | 99.9                              |
|    | 11079                            | 11073                            | 99.9                              |
|    | 11077                            | 11071                            | 99.9                              |
|    | 11073                            | 11068                            | 99.9                              |
|    | 11069                            | 11064                            | 99.9                              |
|    | 11074                            | 11070                            | 99.9                              |
|    | 11068                            | 11061                            | 99.9                              |
|    | 11075                            | 11072                            | 99.9                              |
|    | 11076                            | 11071                            | 99.9                              |
|    | 11084                            | 11079                            | 99.9                              |
|    | 11087                            | 11081                            | 99.9                              |
|    | 11108                            | 11101                            | 99.9                              |
|    | 11104                            | 11100                            | 99.9                              |
|    | 11112                            | 11108                            | 99.9                              |
|    | 11117                            | 11112                            | 99.9                              |
|    | 4634                             | 4630                             | 99.9                              |
|    | 4631                             | 4627                             | 99.9                              |
|    | 4629                             | 4620                             | 99.9                              |
|    | 4625                             | 4617                             | 99.9                              |
|    | 4622                             | 4616                             | 99.9                              |
|    | 4619                             | 4615                             | 99.9                              |
|    | 4616                             | 4614                             | 99.9                              |
|    | 4615                             | 4609                             | 99.9                              |
|    | 4613                             | 4608                             | 99.9                              |
|    | 4612                             | 4607                             | 99.9                              |
|    | 4608                             | 4601                             | 99.9                              |
|    | 4614                             | 4610                             | 99.9                              |
|    | 4626                             | 4621                             | 99.9                              |
|    | 4617                             | 4611                             | 99.9                              |
|    | 4615                             | 4609                             | 99.9                              |
|    | 4618                             | 4611                             | 99.9                              |
|    | 4619                             | 4612                             | 99.9                              |
|    | 4618                             | 4612                             | 99.9                              |
|    | 4630                             | 4624                             | 99.9                              |
|    | 4628                             | 4621                             | 99.9                              |
|    | 4171                             | 4166                             | 99.9                              |
|    | 4168                             | 4160                             | 99.9                              |
|    | 4166                             | 4161                             | 99.9                              |
|    | 4162                             | 4158                             | 99.9                              |
|    | 4160                             | 4154                             | 99.9                              |
|    | 4157                             | 4150                             | 99.9                              |
|    | 4155                             | 4149                             | 99.9                              |
|    | 4154                             | 4149                             | 99.9                              |
|    | 4152                             | 4147                             | 99.9                              |
|    | 4151                             | 4146                             | 99.9                              |
|    | 4149                             | 4144                             | 99.9                              |
|    | 4160                             | 4156                             | 99.9                              |
|    | 4165                             | 4160                             | 99.9                              |
|    | 4159                             | 4155                             | 99.9                              |
|    | 4166                             | 4164                             | 99.9                              |
|    | 4168                             | 4164                             | 99.9                              |
|    | 4168                             | 4164                             | 99.9                              |
|    | 4167                             | 4164                             | 99.9                              |
|    | 4165                             | 4164                             | 99.9                              |
|    | 4164                             | 4159                             | 99.9                              |
The test results show that 20 wireless nodes and gateway devices are able to work normally in the environment with a temperature from -40 °C to 85 °C, and the receiving success rate is greater than 99.9%.

4.3. Test of Power Consumption
Select a wireless node that is powered by the Agilent DC Power Analyzer. The supply voltage is set to 3.3V and the wireless node's transmit power is set to 20dBm. The wireless node synchronizes with the gateway every 1 second and communicates every 5 seconds. The test is shown in Figure 9 below.

![Figure 9. power consumption test](image)

Test results shows that, when the power supply is 3.3V, the average current of the wireless node is 7.05mA, the minimum current is 404.4μA, and the maximum current is 129.4mA.

4.4. Analysis of Message Information
This part of the text is to analysis the routing protocol conflict problem of the network. In a long-chain wireless sensor network with 310 nodes, some nodes are found to have communication conflicts, within a week of operation, and the sequence number of the conflicting nodes is not fixed. Unit testing for a single node is integrated. No problems were found in the test. After analyzing the information of a large amount of intercepted messages, it is found that the timing of the packets of some nodes in the adjacent routing levels is incorrect. The final conclusion from the analysis is that, there were problems with the network design time slot algorithm. The slot calculation leads to the conflict between the first and last nodes in the adjacent routing levels, as shown in Figure 10.

![Figure 10. Analysis of message information](image)

5. Conclusion and Future Planning
In this paper, a non-intrusive online fault detection platform is designed and built, as the problem of wireless sensor network development process is difficult to locate and debug immediately. The developing long-chain network is tested by this platform. The experiments results verify the effectiveness of the test platform in the aspects of time synchronization test, reliability test, power test and message analysis.
As of now, the message analysis software involved in this paper only supports the network system that the author is developing, and does not support the automatic parsing function of the message protocol, and its versatility needs to improve. In future, it will expand on its existing work, and add multiple protocol automatic resolution functions to improve the speed and accuracy of subsequent wireless sensor network development.

6. Acknowledgment
The authors would like to thank the editor and reviewers for their valuable suggestions and comments. This work has been supported in part by Pearl River S&T Nova Program of Guangzhou (201710010023).

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