A Zigbee and Bluetooth Protocol Converter Based on Multi-sinks Wireless Sensor Network

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Abstract—A Zigbee and Bluetooth converter is designed in this paper. A multi-sinks wireless sensor network is used to solve the notable problems appeared in the single node wireless sensor network. These problems are solved in converter system such as data transmission reliability and energy consumption imbalance and so on. The converter system can be better adapted to the large-scale, high-density development trend of network layout. Zigbee technology has low power consumption, low cost. And Bluetooth technology shows outstanding advantages in terms of terminal access. This paper attempts to combine the advantages of two wireless technology, and design a point-to-many method of Zigbee and Bluetooth protocol converter. Then apply the Zigbee and Bluetooth protocol of converter to the multi-sinks wireless sensor networks. At the sensor nodes, it forms a network based on the Zigbee protocol. At the converter nodes, it communicates with Bluetooth devices through point-to-many method. The experiment results show that the point-to-many method of Zigbee and Bluetooth system can convert data effectively, and improve the data transmission reliability of the wireless sensor network. It has important values in the application of wireless sensor networks.

Index Terms—Zigbee; Bluetooth; Protocol Conversion; Multi-Sinks

I. INTRODUCTION

With the development of the Internet of Things and wireless sensor network technology, large-scale, high-density network layout becomes the development trend of wireless sensor networks. In the single node wireless sensor network, data collected from all sensor nodes are uploaded through a single sink node. This data transfer mode has many drawbacks, such as poor data transmission reliability, energy consumption imbalance and so on. The network layout of multi-sinks is able to cope well with the above issues: (1) Sink node failure doesn’t interrupt data transmission. The single node network is poor in data transmission reliability, since all sensor nodes upload data through a single sink node. If the sink node fails, the entire network will be paralyzed. If there is another sink node exists in the network, the paralysis caused by the failure of sink node will be efficiently prevented. (2) Balance the node energy consumption. In the single sink node network, since the transmission of data information collected by the sensor node points to unique sink node, the sensor node near to the sink node is always on a high energy consumption caused by more data transmission tasks. Therefore, the network is unable to continue working as nodes near the sink node died, even a large number of nodes are still alive in the network. But if a plurality of sink nodes exists in the network, the density of data transmission from the node near to the sink nodes has been reduced. So energy consumption becomes more balanced among the sensor nodes, the network life has been extended. In addition to that, the design of multi-sinks is beneficial for simplifying data fusion and controlling different data streams [1, 2, 3].

Zigbee technology is developed base on IEEE802.15.4 standard, which involves networking, security, application and other aspects. It has a short range, low power, low data rate and low cost, and supports star network topology, tree network topology and mesh network topology. Due to its outstanding advantages of low power consumption and low cost, it is very conducive to large-scale spread and long lasting communication. Therefore, Zigbee technology has been widely used in industrial automation, smart home, environmental protection, digital medical and so on [4, 5]. Bluetooth is also a short range wireless communication technology, which is designed to replace the cable entity to establish a short range wireless connection between mobile devices. Bluetooth technology proposed in 1998, with the rapid development of these years, the technology supporters has grown to more than two thousand members. Since its release, the Bluetooth technology has been widely used in more and more fields. Now the mobile communications equipment market has been flooded with many kinds of Bluetooth-enabled devices [6].

This paper is intended to combine Zigbee’s advantage of low power, low cost and Bluetooth’s advantage on the terminal access, design a point-to-many Zigbee and Bluetooth protocol converter. And apply this point-to-many Zigbee and Bluetooth protocol converter to the multi-sinks wireless sensor networks: (1) set up the network by Zigbee technology. (2) Use a Bluetooth device as a data terminal. (3) Transform packets by Zigbee and Bluetooth protocol converter. The present study shows that, Zigbee device and Bluetooth device can work in a common environment at the same time, which provides feasibility to the design of Zigbee and Bluetooth protocol converter [10, 11].
The converter is a dual stack device based on Zigbee protocol and Bluetooth protocol [12, 13]. It includes a Zigbee RF module, a Bluetooth RF module and a single chip microcomputer in terms of hardware architecture. In the program design, it includes data forwarding process, address table management process and order handling process. The data forwarding process also includes a design scheme of data buffer. This paper focuses on the design of multi-sinks wireless sensor network based on Zigbee protocol. Its characteristic is that multiple sink nodes are arranged in the wireless sensor network. Each sink node is responsible for data uploading of its neighboring sensor nodes. When a sink node fails, sensor nodes in its adjacent areas can upload data through other sink nodes. The key to this design of multi-sinks is a sink node switching mechanism, which is achieved by collaborative design between sink node and sensor node. All design of the sensor nodes are cater to the sink node switching mechanism, which include design of data buffer, design of feedback mechanism and design of order receiving. Design of sink node includes producing feedback and delivering orders from terminal.

The innovation of this paper is to achieve the communication of two different devices through Zigbee and Bluetooth protocol converter, which combining Zigbee’s advantage of large scale spread, long-lasting communication and Bluetooth’s advantage on the terminal access. The design complements their weaknesses, thus Bluetooth device’s communication distance has been improved, and Zigbee device can upload data to Bluetooth device. So the application of Zigbee technology and Bluetooth technology has been expanded. The converter in this paper is under the mode of point-to-many, which is different from current research. Design of multi-sinks can solve the problem of poor data transmission reliability and energy consumption imbalance effectively. Due to the design, network will no longer be paralyzed because of sink node failure, and data forwarding tasks of sink nodes’ neighboring sensor node will also be diluted. Therefore, data transmission system’s performance has been improved.

Finally, the experiment proved that the point-to-many Zigbee and Bluetooth protocol converter can effectively convert data, and the converter is able to integrate into the multi-sinks wireless sensor networks.

II. DESIGN OF MULTI-SINKS WIRELESS SENSOR NETWORKS BASED ON ZIGBEE PROTOCOL

The set of sensor node is defined as \( SE \), and the set of sink node is \( SI \). Then the set of all nodes in the network is \( V = SE \cup SI \). The set of all communication links is \( E \).

\[
E = \{(i, j) | i, j \in SE \} \cup \{(i, j) | i \in SE, j \in SI\}
\]  

(1)

Neighbor nodes of node \( i \) is defined as \( N_i \).

\[
N_i = \{ j | (i, j) \in E \} \subseteq V
\]  

(2)

Therefore, the number of neighbor nodes of sink node set \( SI \) with \( M \) elements is \( N_{SI} \).

\[
N_{SI} = \text{card} \left( \sum_{i \in SI} \{ j | (i, j) \in E \} \cap j \in V \right)
\]  

(3)

Function \( \text{card} ( \cdot ) \) indicates the element number of set. Since all data transfer tasks of the network are completed through sink nodes’ neighbor nodes, if the sum of transfer tasks is defined as \( T \), then the average task of each sink nodes’ neighbor undertaking is \( \text{ave}(T) \).

\[
\text{ave}(T) = \frac{T}{\text{card} \left( \sum_{i \in SI} \{ j | (i, j) \in E \} \cap j \in V \right)}
\]  

(4)

Therefore, comparing to the network layout of single node, the design of multi-sinks averagely reduce the power consumption of sink nodes’ neighbor nodes as the margin of \( D \).

\[
D = \left( 1 - \frac{\text{card} \left( \sum_{i \in SI} \{ j | (i, j) \in E \} \cap j \in V \right)}{\text{card} \left( \sum_{i \in SI} \{ j | (i, j) \in E \} \cap j \in V \right)} \right) \times 100\%
\]  

(5)

If the average probability of each sink node failure is \( P \), then, for each sensor node, the probability of failure data upload caused by sink node failure is \( p \).

\[
p = P^{\text{card}(SI)}
\]  

(6)

Obviously, the more the number of sink nodes, the stronger data transmission reliability is. Studies have shown that, the design of multi-sinks has a significant effect on improving packet delivery rate and extending the network lifetime [7, 8].

A. Zigbee Network Model

IEEE802.15.4 standard defines two types of devices: the full function device (FFD) and the reduced function device (RFD). The FFD can perform all functions of the IEEE802.15.4 standard in the network. It can be designed into any roles. The RFD can only be designed into simple transceiver node. The RFD can only search and join the network, but can’t establish a network, and it also can’t allow other devices to join the network through itself. Zigbee network which is based on IEEE802.15.4 standard defines three types of devices: the Zigbee Coordinator, the Zigbee Router and the Zigbee End Device [9]. The coordinator and router must be a FFD, but the end device can be a FFD or a RFD.

Zigbee network is set up by a coordinator. The coordinator is responsible for selecting channel, PAN ID, security and protocol specifications in the process of networking. After the above parameters have been determined, the coordinator node can allow other devices to join the network. The router and end device discover the nearby network through PAN scan and channel scan, and evaluate the network by response information of the network devices. If the network is available, the router and end device will send join request, and join the
network with the permission of device in the network. Fig. 1 shows three network topologies of Zigbee: Star network topology, Tree network topology and Mesh network topology. Star network has a central node, through which all data are uploaded. Tree network has a top node and many leaf nodes, data first upstream and then downstream. Mesh network is similar to Tree network, but its leaf nodes can be connected, so it has a stronger network robustness and system reliability.

**B. Model of Multi-Sinks Sensor Networks Based on Zigbee Protocol**

Establishing a network with sensor nodes and sink nodes based on Zigbee protocol means that, all sensor nodes and sink nodes are connected physically by Zigbee RF modules. This sensor network needs to have these characteristics: (1) a number of sink nodes within the sensor network coverage area are responsible for the data uploading of sensor nodes in neighboring area. (2) Sensor nodes need a sink node switching mechanism, in response to the data transmission when the sink node in its area fails.

First, establish a network with sensor nodes and sink nodes base on Fig. 2. In this network, each sink node within the sensor network coverage area is responsible for the data uploading of sensor nodes in neighboring area. The sink node of sensor nodes in “cross area” can be designed to one of the sink nodes in areas which are crossing. The above characteristic can be implemented by set parameters of Zigbee RF module. Setting to the Zigbee RF module mainly includes the following aspects: the type of device, PAN ID and address information.

The location is mainly considered when set the type of a device. Sensor nodes in edge region only need to upload data without routing data, it should be designed to end device. Sensor nodes in intermediate region need both uploading and routing. It should be designed to router. A coordinator must exist in a network, and every router can act as a coordinator theoretically. According to the process of establishing a Zigbee network, since all nodes are in the same network, channel and PAN ID of each node must be set to consistency. Setting of address information means that, the destination address of sensor node should be set as the source address of the sink node in its neighboring area.

Second, design the sink node switching mechanism base on the network model finished in first step. This mechanism is intended to solve the data upload problem of sensor nodes in the area which the sink node inside, which is caused by the sink node failure. This mechanism is realized by the design of sensor node and sink node. In this mechanism, when the sink node receives the data uploading by sensor nodes, it will answer a feedback immediately. During the process of data uploading, if the sensor node doesn’t get the feedback from the sink node, it will switch its sink node by modifying its destination address and continue uploading. Considering the complexity of the application environment, the sensor node should have protection time.

Considering the sensor node R in area b of figure 2, its default sink node is c2 in area b. If R gets a feedback from c2 after R transmitting data to c2, it means that data uploading succeeds. If R doesn’t get a feedback from c2, it means data uploading fails. Then R will switch its sink node by modifying the destination address of its Zigbee RF module, and upload data through c1 and c3.

**C. Design of Sensor Node**

The key to the design of sensor node is to achieve sink node switching mechanism. When the current sink node fails, sensor node should switch its sink node to complete data uploading. To achieve the sink node switching mechanisms includes the following three aspects: (1) Sensor node needs to continue to test the state of current sink node. (2) Sensor node needs to backup data information, to avoid the loss of data information caused by the failure of current sink node. (3) Sensor node switches its sink node when the current sink node fails.

The state test of current sink node can carry out with data uploading each time. As data uploading occurs randomly in network, comparing to regular periodic test this test mode’s advantage is that, the test of each time is meaningful, and the latter is likely to cause waste of resources. When sink node receives data from sensor node, it will answer a feedback immediately. The feedback is only used to the sink node state testing by sensor node, it is not responsible to the error control of data transmission. Therefore, in a continued process of data uploading, the feedback can be produce by the sink node at any time.

Considering the protection of data information, a storage area should be set up in the sensor node. The data
read by sensor firstly go into the storage area, and will not upload until the upload condition touched off. If the sensor node receives a feedback from the sink node during data uploading, the storage area will be empty after the upload completes. If the sensor node doesn’t receive a feedback from the sink node, it will switch its sink node and complete the upload. This design of storage area is also meets the design requirements of the response mechanism between sensor nodes and sink nodes.

A. Zigbee and Bluetooth Protocol Convert

1) The Analysis on Coexistence of Zigbee and Bluetooth

Zigbee and Bluetooth are both working on the 2.4GHz band, so two types of equipment may conflict on the physical layer. Bluetooth use the frequency-hopping spread spectrum (FHSS), it divide the 2.4GHz band into 79 channels with width of 1MHz. And jump in these 79 channels at the rate of 1600 times per minute, by the way of a pseudo-random code. After the channel coding, data to be transmitted need to do the module-2-sum operation with pseudo-noise sequence, to generate composite codes which will modulate the carrier. Zigbee use the direct sequence spread spectrum (DSSS), to modulate the carrier with pseudo-noise sequence. Therefore, the frequency coincidence will occur once in 79 communications between Bluetooth and Zigbee.

Since Zigbee device has a lower transmission rate and lower power consumption compared to Bluetooth device, and its work are often burst of. So the interference from Zigbee device to Bluetooth device is slight. But the interference from Bluetooth device to Zigbee device can’t be ignored, especially in data acquisition system, which needs high reliability of data transmission. In order to solve the interference from Bluetooth to Zigbee, when a Zigbee device sends out data, the receiving device should answer a feedback to the sending device. If the sending device doesn’t receive the feedback from the receiving device, data should be sent again until be received correctly.

2) The Principle of Zigbee and Bluetooth Protocol Converter

Since Zigbee and Bluetooth use different communication protocol and different data format, the architecture of them is also completely different. To realize the communication between these two types of devices, a converter should be designed between them. This converter needs to have the function of: (1) The ability to communicate with Zigbee device and Bluetooth device individually, (2) the ability to convert the Zigbee protocol and the Bluetooth protocol, specifically, the convert can package data according to the specified format, so that the data packets under the current system format can be read by another system. So, the converter is a dual stack device, which can identify both Zigbee device and Bluetooth device. In addition to that, the converter should include a function module to resolve and restructure data packets. Fig. 4 shows the protocol structure of Zigbee and Bluetooth protocol converter.

Fig. 5 shows the structure of Zigbee data packet and Bluetooth data packet. The outer of Zigbee data packet is...
physical layer, which consists of SHR, PHR and PSDU. SHR is synchronization header, including preamble sequence of frames and frame start delimiter. PHR is physical layer header, including the length information of PSDU. PSDU is physical layer service data unit, which is MPDU. The inner of Zigbee data packet is MAC layer, consisting of MHR, MSDU and MFR. MHR is MAC layer header, including the control field of MAC frame, the beacon sequence code and addressing information. MSDU is MAC layer service data unit, which is NPDU. Here is intended to narrative the conversion of data packet, so the NWK layer is not in the consideration. MFR is MAC layer foot, including frame check sequence.

Bluetooth data packet consists of ACCESS CODE, HEADER and PAYLOAD. ACCESS CODE is used to synchronous data, DC offset compensation and data packet identification. HEADER includes the information of link control. PAYLOAD can be data field or voice field, this paper only considers the former. Data field consists of load’s header, load’s body and CRC code.

When Zigbee and Bluetooth protocol converter receive a Zigbee data packet, firstly, the physical layer header (includes SHR and MHR) will be removed, and get the PSDU. Then remove the MAC layer header and check information to get the data. Secondly, the single chip microcomputer will add the ACCESS CODE, HEADER and CRC of standard Bluetooth packet for the data from step one. Finally, the Zigbee and Bluetooth protocol converter will send this Bluetooth packet to the Bluetooth data terminal. Therefore, the Bluetooth data terminal receives the data packet from a Zigbee device. Its inverse process can also realize the Zigbee device receiving the Bluetooth data packet [14, 15].

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B. The Design of Zigbee and Bluetooth Protocol Converter as a Sink Node

The design of Zigbee and Bluetooth protocol converter as a sink node should include the following two respects: (1) when the converter receives the data packet from sensor node, a feedback show sent out immediately, (2) the converter is responsible for sending orders from data terminal to specified sensor node. In this paper, the sink node use broadcast to send out feedback and order from data terminal, to avoid switching the destination address of sink node’s Zigbee RF module frequently. Since broadcast may cause a significant increase in network load, the design of sensor node should expand the size of the storage area as much as possible, to reduce the number of broadcast. In addition to that, the converter needs to focus on solving the problem of address information loss and data buffer caused by point-to-many protocol conversion.

1) The Design of Data Domain

In the data transmission system, the Bluetooth terminal hopes to get the source address of Zigbee data packets, to analyze data further. Similarly, only under the permission of informing the source address of sensor node, the Bluetooth data terminal can visit the sensor node and operate it. According to the narrative of the principle of Zigbee and Bluetooth protocol conversion, data load has been transferred in the process of protocol conversion, but the address information of the data packet is lost.

This paper takes the method of carrying the address information in the data load, to mark the Zigbee sensor node. Specific ideas is, design the data load to be commonwealth of data entity and address information, which is source address in data uploading and destination address in visiting from data terminal. Fig. 6 shows that. Though the transferred one is still data load in the process of protocol conversion, since address information is contained in the data load, sensor nodes can be distinguished.

![Figure 6. The design of data domain](image)

The length of Zigbee RF module’s MAC address is 64. Considering the size of the data acquisition system, address of that length is not necessary. Therefore, the address information in the data load can use custom address. The length of custom address can be determined by the scale of the actual system.

In the above design of data domain, the Zigbee and Bluetooth protocol converter’s work includes two aspects: transmitting Zigbee data packets to the Bluetooth terminal and transmitting Bluetooth data packets to Zigbee sensor node, both of them are according to the address table shows in Fig. 9. In the process of transmitting Zigbee data packets to Bluetooth terminal, when the serial port receives data packets, system should judge whether the address information of the data packets is included in the address table. If the address information is not included, it will be entered into the address table with the number of corresponding serial port. It means that the sensor node of this address communicate with the system through that serial port. In the process of sending Bluetooth data packets to Zigbee sensor node, when the serial port receives data packets, system will make a judgment of the serial port according to the address table. Then transfer the data packet to the destination node through the serial port.

2) The Design of Data Buffer

Considering the Zigbee and Bluetooth protocol converter shows in Fig. 7 [16], if three Zigbee RF modules are all in the state of receiving data, there is a possibility that the speed of receiving Zigbee data flow is
higher than the speed of transmitting Bluetooth data flow. Therefore, there is a problem of data loss when the converter can’t handle data as soon as possible. In order to solve the problem of data rate mismatch, a data buffer needs to be established between the Zigbee data flow and Bluetooth data flow.

Specific method is, set some data units of the single chip microcomputer’s storage area as data buffer. Zigbee data flow enter the data buffer when they arrive the Zigbee and Bluetooth protocol converter. The single chip microcomputer testing the state of data buffer periodically, trigger the Bluetooth flow when the data buffer is not empty. This buffer mechanism also left storage space for overflow data, can properly deal with the data packet which can’t be processed as soon as possible. Fig. 8 shows the principle of data buffer. Fig. 9 shows the whole program design of Zigbee and Bluetooth protocol converter as a sink node.

IV. EXPERIMENTAL TESTS AND RESULTS

A. Experimental Equipment

Zigbee RF module use the DIGI XBee-pro module, deploy with X-CTU. Bluetooth RF module uses the BC417 module with core of CSR BlueCore 4 Externa, based on the Bluetooth V2.0 protocol specification. The single chip microcomputer of Zigbee and Bluetooth protocol converter use the Arduino module with core of Atmega328p-pu. Both Zigbee RF module and Bluetooth RF module connect with single chip microcomputer through serial port. Bluetooth data terminal use the personal computer (PC) with Bluetooth adapter.

B. Experimental Platform Establishing and Testing

Establish the experimental platform shows in Fig. 10, set the sensor node S2 in the state of continuous uploading. Complete the function test and performance test through controlling the sensor node S1. After several tests, the results are as follows:

(1) Function test. The test is completed by transmitting data packets from sensor node S1 to PC. First, power-on C1 and power-off C2, PC can receive data packets from sensor node S1. Then power on C2 and power-off C1, PC can also receive data packets from sensor node S1. The test results show that, the sink node switching mechanism proposed above is feasible.

(2) Performance test. The test’s main content is the packet loss rate of transmission system under different sampling frequency and different communication distance.

Fig. 11 shows the results. The experimental results show that, within a sampling frequency of 80Hz, packet loss rate is very low. With the increase of communication distance, packet loss rate increases. The trend is consistent with the theoretical analysis.
distance, the transmission quality has significantly felt. Complex communication environment is the main reason.

V. Conclusion

This paper designs a point-to-many Zigbee and Bluetooth protocol converter based on Zigbee protocol and Bluetooth protocol, and introduces the converter into multi-sinks wireless sensor network. In the network, sensor nodes are organized based on Zigbee protocol, and the data terminal is a Bluetooth device. Sensor nodes communicate with Bluetooth data terminal through Zigbee and Bluetooth protocol converter. This design has taken advantage of Zigbee features about low power consumption, low cost and convincing to large-spread, and combine the outstanding advantage on Bluetooth’s terminal access. This design has expanded the application range of Zigbee and Bluetooth effectively.

Since data transmission reliability in single node sensor network is poor, and node’s energy consumption is imbalance, this paper uses the design of multi-sinks. The key to the design of multi-sinks wireless sensor network based on Zigbee protocol is to achieve a sink node switching mechanism through the collaborative design of sensor node and sink node. The design of multi-sinks has a significant effect on improving the data transmission reliability. In the process of protocol conversion, the problem of address information loss and mismatch of input and output is inevitable. For the former, this paper uses a new design of data domain. The core idea is to place the address information in the data load to avoid the loss. For the latter, this paper introduces a design of data buffer, to solve the problem of data overflow caused by the mismatch of input and output through setting up storage space in the single chip microcomputer.

Finally, the test results show that, the design of Zigbee and Bluetooth protocol converter is practicable. Design of multi-sinks has a significant improve on data transmission reliability. The performance testing shows that, the system is in line with practical application. Since the processing capacity of single chip microcomputer is limited, the switching mechanism in this paper use a simplified way, if the sensor node can draw the optimal sink node by evaluating the network environment, the system will adapt to more complex application environment better.

ACKNOWLEDGMENT

This work has been financially supported by National Natural Sciences Funds of China (No. 61071198), Nature Science Funds of Zhejiang Province (No. LY13F010015) and Nature Science Funds of Ningbo (No. 2012A610019), and sponsored by K. C. Wong Magna Fund in Ningbo University.

REFERENCES


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