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Design and Implementation of Automatic Fire Alarm System based on Wireless Sensor Networks

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***Abstract*—Fire disaster is a great threat to lives and property. Automatic fire alarm system provides real-time surveillance, monitoring and automatic alarm. It sends early alarm when the fire occurs and helps to reduce the fire damage. Wireless sensor network has become the most important technology in environmental monitoring and home or factory automation in recent years. In this paper, an automatic fire alarm system based on wireless sensor networks is developed, which is designed for high-rise buildings. In order to provide early extinguishing of a fire disaster, large numbers of detectors which periodically measure smoke concentration or temperature are deployed in buildings. Those scattered detectors report their monitoring information to the surveillance center via the self-organizing hierarchical wireless sensor networks. Test results from the prototype system show that the automatic fire alarm system achieves the design requirements.**

***Index Terms*—fire alarm system, wireless sensor networks, smoke concentration**

I. INTRODUCTION

Nowadays, securing one's property and business against fire is becoming more and more important. Monitoring commercial and residential areas all-round is an effective method to reduce personal and property losses due to fire disasters. Automatic fire alarm system is widely deployed in those sites recent years. Large numbers of small fire detectors should report their information to the control center of a building or a block. But the cost of wiring is very high in traditional wired fire alarm systems.

Networking without pre-exist infrastructure reduces the wiring cost greatly. In recent years, wireless sensor networks (WSNs) are widely deployed in environmental monitoring, structural health monitoring and industrial monitoring. It provides low cost solutions for such applications. It consists of small size, low-power, and low-cost devices that integrated with limited computation, sensing, and radio communication capabilities [1]. So WSN is very suitable for communication between detectors in fire alarm system.

A simple automatic fire alarm system for buildings based on wireless sensor networks is designed and implemented in this paper. We focus on the design of network architecture and communication protocol here.

II. RELATED WORKS

Fire surveillance has been an important research topic for a long time. In order to implement large-scale remote monitoring, networking techniques are introduced. Traditional wired networking technique has been widely used in fire alarm system. But deployment cost bring by wired network is expensive, and cabling is difficult in some environment. Wireless sensor networks are dense wireless networks of small, low-cost sensors, which collect and disseminate environmental data [1]. Therefore wireless sensor networks can be an alternative in these cases since WSNs are deployed without the need for any pre-existing infrastructure and with little maintenance [2]. As we known, the reliability of wireless communication is lower than wired communication. Faouzi Derbel researched the reliability of wireless communication for fire detection systems in commercial and residential areas, and analyzed parameters that can influence the radio transmission within buildings [3].

The requirements and challenges of WSN-based fire rescue applications are analyzed in Ref. [4]. In order to real-time monitor and control fire-fighting operations, this work focuses on self-organization, fault tolerant, mobile localization. A fire detection and rescue support framework with wireless sensor networks is proposed in Ref. [5]. The development of a forest-fires surveillance system for South Korea Mountains is introduced in Ref. [6]. These two systems are both based on the common WSN develop platform: Crossbow motes and TinyOS, the communication standard is IEEE 802.15.4. But the architecture is too complex for our application. Our system is designed for fire surveillance in buildings. We design and develop the hardware and software independently.

III. WSN FOR FIRE ALARM SYSTEM

A. Network Architecture

As we know, large numbers of monitoring points are required in high-rise buildings. Due to transmission distance limitations of low-power radio, repeaters are required to relay monitoring information from detectors to surveillance center. If all the monitoring information is

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transmitted to the surveillance center directly, the network load becomes very heavy. In order to reduce the communication overload and improve the stability of network, a hierarchical structure is designed for our system. The network architecture is shown in Fig. 1.

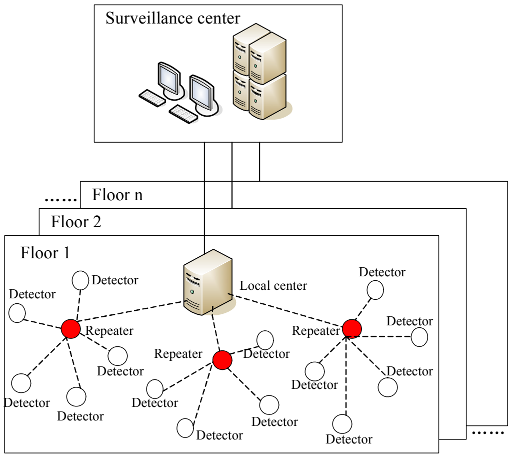

Figure 1 Network architecture

Large numbers of detectors, some repeaters and a local center constitute the wireless sensor network, which responsible for fire detection of one floor. The detector is the simplest monitor, which must connect to repeater to report its monitoring information. The repeater not only monitoring its area, but also provide network access for detectors. The surveillance information of one floor is aggregated by local center, and local centers of every floor report the monitoring information of the floor to the surveillance center through cable connection.

B. *Networking Protocol*

Self-organizing and self-healing are the remarkable characteristic of wireless sensor network. When wireless nodes startup, they can find and join the nearest network automatically. And when some node failure, they can reorganize the network as soon as possible.

As shown in Fig. 1, the topological structure of our fire alarm system is a tree. The system is networked in accordance with the deployed locations. In order to identify sensors based on their locations, addressing is required. In fact, a fire alarm system involves no more than 10,000 detectors. So 2 bytes communication address is used in our fire alarm system to indicate the source end and the destination end of a message. The high 8 bits represents network address, and the low 8 bits are assigned to represents node address. Therefore, a network can accommodate up to 255 repeaters, each repeater can hold up to 255 detectors. Each repeater is allocated one network address by the surveillance center. And the repeater allocates node addresses for its detectors independently.

In our fire alarm system, the messages are transported through wireless links up to two hops. So the networking operation is relatively simple. New node broadcasts a networking request message, declaring its serial number. Repeaters received the networking request will check whether the serial number it announced is permitted, and send back a response with the communication address allocated for the new node. To avoid confusion bring by more than one repeater responding, the detector transmits a networking confirm message to the repeater it chosen. And the repeater received the confirm message updates its neighbor table and report the topology change to the surveillance center. Other repeaters wait until waiting times up, and then cancel the address allocation operation. When a new repeater wants to join the network, the networking operation is similar to a common detector. The only different is that it sends requests to local center instead.

IV. SYSTEM DESIGN AND IMPLEMENTATION

A. *RF Chipset CC1100*

Long period continuous monitoring is required in fire alarm system, so low-power communication must be considered in our design. We choose CC1100 of Texas Instrument as the RF chipset of the detector and the repeater. CC1100 is a low-cost transceiver designed for very low-power wireless applications, which is used in industrial control, wireless security, smart home widely. It operates in the 315/433/868/915 MHz ISM band. It is a programmable chipset. We can modify some parameter easily, such as data rate, carrier sense indicator and output power. Packet transceiver, carrier sense and wakeup mechanism are the main task of CC1100.

Data from MCU must be framing before sending. Frame format of CC1100 is shown in Fig. 2. The preamble pattern is an alternating sequence of ones and zeros (10101010…). The number of preamble bytes is programmed. The synchronization word provides byte synchronization of the incoming packet. CC1100 supports both constant packet length protocols and variable length protocols. The optional length field defines the length of payload data. Therefore, data field of a packet is no longer than 255 bytes. The optional address field defines the address of destination node. But 8 bits does not meet the requirement of address space in our system. So address field does not be used here. CRC-16 is automatic inserted CRC checking code.

Preamble bits (1010…1010)	Sync word	Length field	Addr field	Data field	CRC-16
8×n bits	16/32 bits	8 bits	8 bits	8×n bits	16bits

Figure 2 CC1100 packet format

Packet collisions not only reduce transmission efficiency but also waste node power. Carrier sense before sending is a good method to avoid collision in wireless sensor network. CC1100 provide two carrier sense methods, absolute threshold carrier sense and relative threshold carrier sense.

RF consumes most power of node, and for fire monitoring application, node only need report its monitor result period. So sleep and wake up mechanism can save power consumption efficiently. CC1100 provides wake on radio functionality enables CC1100 to periodically wake up from sleep state and listen for incoming packets without MCU interaction.

B. Communication Protocol

In order to implement communications between equipments, messages format are defined carefully. All messages we defined are filled in the data field of CC1100 packet. The first bytes of all those messages are packet type field, which indicates the function of the message. Five packet type values we defined are shown in Table I.

TABLE I. PACKET TYPE VALUES

Packet type	Message
0x01	Networking request
0x02	Networking response
0x03	Networking confirm
0x11	Fire alarm report
0x12	Parameter modify

The communication addresses are allocated in the networking communication process, and the sensor network is organized or updated. The format of networking messages is shown in Fig. 3. The networking message involves 3 type messages: networking request, networking response and networking confirm.

Packet type	Source Address	Destination Address	Serial Number
|←8bits→|	← 16bits →|	← 16bits →|	← 5×8bits →|

Figure 3 Networking message

Networking request is a broadcast frame, whose source address and destination address are both set to 0xFFFF. The identification of node is 5 bytes serial number which is storied in EEPROM of each node. The serial number of each node is record before installing in the building, and the installation location of each node is pre-arranged. So the surveillance center is able to accurately locate the alarm source.

Our system works at 433MHz (433.30-434.79MHz). In order to minimize wireless interferences, the band is divided into 8 channels, and the channel spacing is 200KHz. RF of nodes can work at any channel. Repeaters choose one channel to work at. New detector sends request message at each channel to join network. After sending the request, it will listen on this channel for a period to receive possible responses. If there is repeaters work on the channel, they will check whether the serial number it announced is permitted and response this request.

The information of allowed node serial numbers are updated periodically and recorded in repeaters' memories. If it is a permitted node, the repeater will allocate address for it and send a response with the allocated address in destination address field and the repeater's address in the source address. The node will record the source address of the strongest signal response and send back a networking confirm message to the chosen repeater. The repeater receives the networking confirm message will record the new node's information in its neighbor table, including serial number, allocated address, node status etc. Center controller checks repeaters' neighbor table periodically to acquire the topology of the whole alarm system real time. The repeaters did not receive the networking confirm message will cancel the address allocation after a period.

The detectors report their detection information to the repeater once they detected fire alarm. Else the detection information is send to repeater periodically. The format of fire alarm report message is shown in Fig. 4.

Packet type	Src. Addr.	Dest. Addr.	Comm. counter	Alarm status	Smoke concn.	Battery energy
|←8bits→|	←16 bits→|	←16 bits →|	←8bits →|	←8bits→|	←8bits→|	← 8bits →|

Figure 4 Fire alarm message

Communication counter field records the successful communication times between the detector and the repeater. So that repeater can identify whether the message is a retransmitted one. Alarm type is shown in alarm status, including NORMAL, FIRE_ALARM, BATTERY_FAULT and DETECTOR_AGING. Smoke concentration field is the smoke concentration or temperature value measured by the detector. Battery energy field shows the voltage of the detector, so that the controller center knows the energy status of each detector.

When repeater receives a fire alarm message, it will forward the message to control center and send back a parameter modify message to confirm that it has received the fire alarm message. The parameter modify message is also sent by surveillance center to control detectors' status and modify their detect parameters. The format of parameter modify message is shown in Fig. 5.

Packet type	Src. Addr	Dest. Addr	Report period	Wakeup period	Alarm threshold	Reset
|←8bits →|	←16 bits→|	← 16 bits→|	←16bits→|	←16bits→|	←16bits →|	← 16 bits →|

Figure 5 Parameter modify message

The report period defines sending interval of fire alarm message, and wakeup period is the monitoring interval of smoke concentration or temperature. When smoke concentration measured is higher than alarm threshold, the detector will send fire alarm message to the repeater with the alarm status field marked FIRE_ALARM. Reset field is set to 0x80 to notify detector that the repeater has received the alarm message and let the detector cancel repetition alarm. It is set to 0x81 means that the detector should reset and re-join the network.

C. Design and Implementation of Wireless Nodes

The detection component of detector is photoelectric smoke sensor or differential-constant temperature detector. For the detector is battery-powered, energy consumption becomes the key problem of system design. The control chip we adopt is the ultra-low power 16-bit RISC mixed-signal processor TI MSP430F1232PW. And low-power CMOS Serial EEPROM ATMEL AT24C02 is used. The detector work flow is shown in Fig. 6.

The control chip of repeater is also TI MSP430F1232PW. The repeaters need more storage space to store neighbor table and allowed node table. So the EEPROM is AT24C512 which provide 512KB storage space. The repeater is complex function detector, which works as a detector and a repeater. There are two processes in a repeater. The work flow of detector process is similar to common detector, but the messages are sent to the repeater process directly instead by radio. And the work flow of repeater process is shown as in Fig. 7.

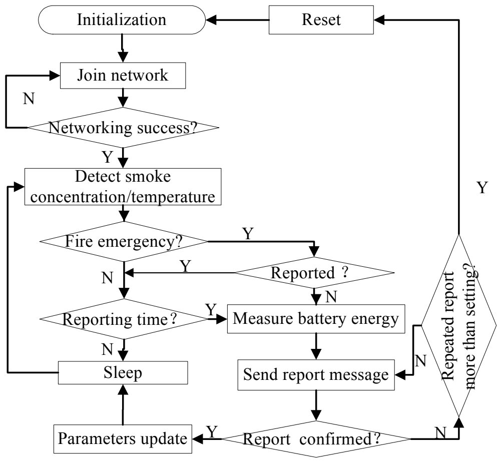

Figure 6 Detector work flow

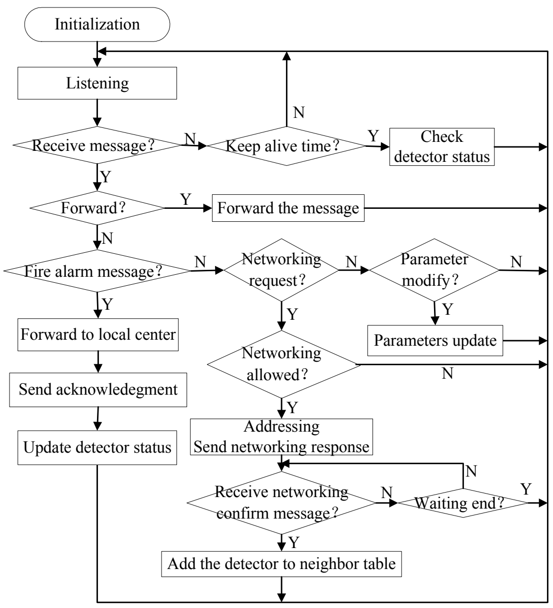

Figure 7 Repeater work flow

D. System Evaluation

The prototype system is implemented and tested. The prototype system contains 11 detectors, 3 repeaters and one surveillance center, which are distributed in one floor as shown in Fig. 8. For there are only one floor, the local center is removed in the prototype test. Tests include network operation, routine report and fire alarm. The test results show that the system can self-organize, real time monitor and report the smoke concentration and temperature in the surveillance region. Once the fire broke out, the surveillance center could quickly locate the location of fire.

For the detectors and repeaters are powered by battery, the energy consumption is one focus of the system tests. Test results show that quiescent current of wireless smoke detector is lower than 7µA, and the operating current of single-chip microprocessor is 1.4mA, the average current is lower than 40µA. The average current of wireless temperature detector is about 20µA, for it has no infrared light emitting diode and operational amplifier. So 1000mAh battery is able to continuous work for about 2 years.

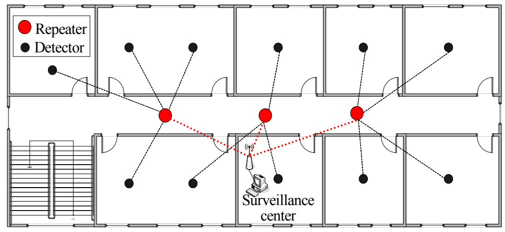

Figure 8 Test scenario

V. Conclusions and Future Works

In this paper, an automatic fire alarm system based on wireless sensor networks is designed and developed with emphasis on the network architecture and communication protocol. Prototype system tests show that the system provides early extinguishing of a fire disaster so that damages will be reduced effectively. We must pre-arrange the installing location of each detector in this system due to localization mechanism is not considered. In order to reduce the installation workload and make the system more convenient, automatic localization mechanism is the focus of our future work.

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