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Research on Fire Alarm Network for High-rise Buildings Based on Wireless Sensor Networks

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Abstract:

This paper presents the design of a fire safety and security network for high-rise buildings based on wireless sensor networks. Utilizing the Zigbee system's topology and Zigbee technology for wireless sensor network communication, the design enables intercommunication among sensor nodes, forming a multi-network system. This system facilitates the preemptive warning and dissemination of fire-related information, facilitating efficient information transmission. Simulation results affirm the practical effectiveness of this design scheme, underscoring its substantial applicability.

Keyword: Wireless sensor, Coordinator, Fire safety and security, Wireless sensor network

1. Introduction

Fire is one of the most common disasters that poses a threat to human life and property. Effectively monitoring and preventing fires has become an essential safety concern in daily life. With the rapid development of society, a majority of people now reside or work in high-rise buildings. However, due to the high population density and complex environments in high-rise buildings, they are prone to fire hazards that are difficult to manage. In the event of a sudden fire, delayed notification often results in missed opportunities for timely evacuation, leading to the spread of fire and causing severe casualties and property losses.

Traditional indoor fire detectors often target singular characteristics. While they utilize wireless sensor networks to process fire data, they are limited to transmitting data to terminals for dispatching rescue personnel. However, they suffer from the drawback of time-consuming procedures and lack the capability to promptly notify nearby individuals through the sensors. Consequently, they fail to provide timely warnings to nearby individuals in the event of emergencies, resulting in a high probability of casualties. Furthermore, there is a significant delay in message delivery to individuals in disaster areas.

In real-life scenarios, wireless sensor networks are widely employed in disaster monitoring systems, such as landslide and forest fire detection systems. [1] These networks exhibit characteristics including high communication efficiency, low complexity, low power consumption, low data rates, low cost, high security, and full digitization. Sensor nodes within wireless sensor networks can be randomly distributed throughout the monitoring area, autonomously forming wireless network systems. They continuously measure and process data within the monitoring area, enabling rapid message transmission.

2. Research Background

There have been proposals both domestically and internationally for utilizing wireless sensor networks in early warning systems. For instance, a dormitory fire monitoring and alarm system, designed by Tian Yi, Hu Jiaxing, and others, is based on ESP8266 and Zigbee technologies [2]. This system employs ESP8266 as the core control device and utilizes sensors such as flame, gas, and temperature sensors to construct a monitoring system. It incorporates Zigbee technology for wireless transmission, enabling the monitoring and early warning of fire incidents. Additionally, Li Zhengzhou, Fang Chaoyang, and their team proposed a fire detection system based on wireless multi-sensor information fusion [3]. This system aims to address issues such as inconvenient wiring, poor environmental adaptability, and weak anti-interference capabilities of traditional fire monitoring systems. It achieves more accurate fire detection, reduces false alarm rates, and enhances system reliability. However, despite their effectiveness in fire warning, these systems only notify messages to system terminals and do not disseminate messages to affected users in fire-affected areas more quickly.

A prototype of an early fire detection system for home monitoring based on wireless sensor networks, proposed by A. Saputra and colleagues [4], employs temperature, air humidity, carbon monoxide, and smoke sensors for fire early detection and home monitoring. If the probability of fire is assessed as high, the system will unlock the home door lock, activate the alarm, and notify the user. However, there may still be errors in the fire probability calculation, with an error rate as high as 0.3%.Tao Jianfeng proposed a wireless fire automatic alarm system based on wireless sensor networks[5], which comprehensively analyzes the technical characteristics of fire automatic alarm systems and wireless fire automatic alarm systems, as well as the development and application status of wireless fire alarm systems domestically and internationally. It suggests vigorously promoting wireless fire automatic alarm systems to enhance the level of fire protection technology application.

In other scenarios, wireless sensor networks are widely utilized. Yang Lele, Dang Guogang, and others addressed the frequent occurrence of forest fires by proposing a forest fire monitoring and early warning system based on wireless sensor networks [6]. This system utilizes wireless sensor networks (WSN) to collect a large amount of data such as temperature, humidity, light intensity, and atmospheric pressure. The nodes integrate and store the data, which is then analyzed and organized by servers to monitor forest fire risks. Chen Weixing conducted research on forest fire prevention and control and designed a forest fire early warning and prevention system based on wireless sensor networks [7]. This system deploys sensors to detect carbon monoxide, temperature, humidity, smoke particle concentration, and flame signals. It establishes a wireless sensor network using Zigbee to transmit data and utilizes backend computers to process data, enabling real-time monitoring of forest conditions.

3. Communication structure of wireless sensor network

In a Zigbee network, there are three logical device types: Coordinator, Router, and End-Device. The Zigbee network consists of one Coordinator, multiple Routers, and multiple End-Devices. Zigbee networks support three types of network topologies: star, tree, and mesh. To achieve multipoint transmission and communication functions for smart home applications, this system adopts a mesh topology.

In a Zigbee network within a wireless sensor network, there are three types of logical devices: Coordinator, Router, and End Device. In Zigbee networks, Zigbee consists of one Coordinator, along with multiple Routers and End Devices. Zigbee networks can support three network topologies: star, tree, and mesh, among which the mesh topology model enables smart homes to achieve multi-point transmission and mutual communication functionalities.

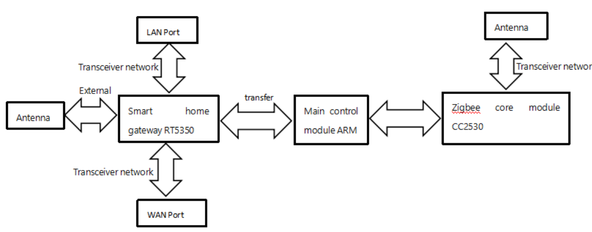
Mesh network topology features a more flexible information routing pattern, where routing nodes in general can achieve direct communication. This topology can form highly complex networks with robust functionality, enabling multi-hop communication. With multiple paths connecting nodes, even if certain paths fail, data can still be transmitted through alternate routes, enhancing network reliability and fault tolerance. Additionally, mesh networks possess outstanding self-organizing and self-healing capabilities.

In a mesh network, terminal data is forwarded to the coordinator via routers, while the coordinator only needs to connect to the gateway to transmit data to the external network. The coordinator, as the network's initial device, is responsible for initiating the entire network by selecting a channel and network ID. Moreover, the coordinator can assist in establishing security and application layer bindings across the entire network. Routers allow other devices to join the network and facilitate communication on behalf of battery-powered end devices using multi-hop routing. Typically, routers remain active and require mains power for operation. However, in tree network topologies, router operations may be intermittent, allowing mains power to be utilized for supply. End devices are used for data transmission and reception, relying on routers within the network to ensure data reaches the target node correctly. They do not have specific responsibilities for maintaining the network structure and can sleep or be awakened, making them battery-powered devices.

Implementation of wireless sensor network

According to the topology of wireless sensor networks, a redesign has been carried out for the coordinator, routers, and terminal devices in the context of high-rise fire scenarios.

Coordinator: The coordinator consists of modules including the CC2530 RF MCU, ARM, and RT5350. ARM serves as the main control module for receiving and managing data, while CC2530 acts as the network module responsible for sending and receiving data. RT5350 functions as the data forwarding module [8]. The network structure of the coordinator processes and analyzes real-time collected data, issues alerts for abnormal data, and transmits signals to each terminal device through routers, achieving the effect of early warning for high-rise fires.



Utilizing ZigBee CC2530-based design as the transmission and reception module for the internal ZigBee network. The CC2530 RF sensor integrates a 8051 core microcontroller, featuring a 16-bit CPU with 21 general-purpose I/O pins, and operates at a clock frequency of up to 24 MHz, enabling sufficient sensor integration on the microcontroller. CC2530 incorporates a built-in low-power 2.4 GHz RF transceiver supporting IEEE 802.15.4 standard RF communication. Its ADC supports up to 12-bit resolution, accurately converting analog signals to digital. With 256 KB of Flash for program storage and 8 KB of RAM for data storage, CC2530 offers five different power modes and a wireless transceiver design, ensuring transmission distance [9]. With excellent low-power characteristics, CC2530 is suitable for battery-powered wireless sensor nodes.

Using the RT5350 chip as the gateway module: To achieve data forwarding to the wireless internet, this system employs an integrated gateway. It integrates a MIPS24KEc processor core, typically operating at a frequency of 360MHz.

Based on the Ralink RT5350, only a few external components are required to achieve low-cost 2.4GHz 802.11n wireless products. It integrates a 2.4GHz 802.11n Wi-Fi wireless LAN (WLAN) controller, supporting 1T1R (one transmit, one receive) single antenna configuration, which can provide greater coverage and higher wireless throughput. RT5350 offers rich peripheral interfaces, including Ethernet interface, USB Host/Device interface, SD/MMC interface, UART interface, etc., supporting connection and data exchange with external devices. Internally, RT5350 integrates a baseband processor, radio frequency, RF power amplifier, a high-performance MIPS 24kc CPU core (with a maximum clock frequency of 360MHz), and a five-port Gigabit Ethernet switch.

ZigBee Router: Utilizing the ZigBee RF chip CC2530 as the hardware module, by modifying the network protocol stack, this module serves as a data routing function. Consequently, it sends information wirelessly to the coordinator by covering high-rise areas with the wireless network.

ZigBee End Device: Utilizing the ZigBee RF chip CC2530 as the hardware module, this module serves as a sensor information collection terminal by modifying the network protocol stack. It achieves the collection and integration of data, facilitating subsequent analysis and processing.

4. Peroration

This paper presents a design of high-rise fire alarm network based on wireless sensor networks, utilizing ARM as the main control module for receiving and managing data. The CC2530 is employed to collect environmental data in high-rise areas and issue alerts for abnormal data, thereby proposing the hardware design scheme for the system. This approach aims to achieve real-time monitoring and secure management in high-rise fire alarm network design.

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