Design and Implementation of a Smart Wireless Fire-Fighting System Based on NB-IoT Technology

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Abstract. The traditional smoke sensing systems have some disadvantages, including high implementation costs, difficulties in perceiving working states, low data accuracy and troubles in uniform and effective management. To address these problems, a new type of smart wireless fire monitoring system based on NB-IoT technology is innovatively designed, which realizes real-time remote monitoring and management. Compared with traditional smoke alarm systems, this system has such advantages as ultra-low power dissipation, lithium-ion battery power, no wiring, remote monitoring, low battery alarm and so forth. With great application prospect, it is worth to develop and rolled out.

1. Introduction

At present, as one of the hot topics in smart city construction [1], smart fire-fighting systems have attracted the attention of governments and become a development trend for intelligent fire protection in the future [2]. They can upload the collected data to cloud platforms by deploying on-site intelligent fire-fighting equipment and feed data back to users or relevant departments after big-data analytics and processing. By discovering hidden dangers in time, this method can take emergent measures to effectively protect lives and properties of users.

As a major indoor safety monitoring equipment, smoke detectors are used in all kinds of occasions with a wide. Fire-related analysis data show that 94% of Chinese fires occurred in micro- and small-scale sites, such as rural or urban areas, shantytowns that lack of fire prevention and regular measures, or ancient buildings, nursing homes, cultural relics, and collective dormitories with the highest death rates [3]. Besides the owners' weak safety awareness, this type of incident is partly due to the uneven quality of most battery-powered acousto-optic alarm products, which have many disadvantages, such as no networking function, no low-battery-power warning, and no equipment fault alarm [4]. On the other side, the installation cost of wired systems at these small-scale sites is expensive and they are also hard to maintain after installation. Hence, it is necessary to design a wireless fire protection system with long standby time, inter-connection function and multi-party active alarm. Such systems can provide long-term and high reliable early warning for indoor safety.

At present, there are mainly two data communication methods for smoke sensors in the market. The first is a wired communication method based on RS-232/485 [5]. This method is complicated in wiring design and implementation, leading to long installation periods, high maintenance costs, weak support for telephone/SMS (Short Message Service) alerts and etc. Therefore, the total cost of the project is high, while the utility performance is low.

Another way is a wireless communication method using Zigbee/GSM technology [6]. The communication mode based on ZigBee also has some disadvantages, including: short communication...
distances, weak ability to penetrate walls, and need to install a large amount of gateways overhead [7]. As to GSM communication mode, there are such shortcomings as high power consumption, short battery life, serious network congestion when smoke sensors are densely arranged, and so on.

To address these shortcomings of traditional smoke sensing equipment, this paper proposes a new kind of smart smoke sensing system based on NB-IoT (Narrow Band Internet of Things), which is in alignment with the development trend of smart fire protection [8].

As an emerging technology in the IoT field, NB-IoT supports cellular data connection of low-power devices in the WAN, also known as Low Power Wide Area Network (LPWAN) [9].

NB-IoT has four major features:
1) Wide coverage. The NB-IoT gain is 20 dB, at the maximum of 23 dB. In the same frequency band, its coverage area is increased by 100 times [10];
2) Large connections. One sector of NB-IoT supports 100,000 connections, realizing more efficient use of spectrums [11];
3) Low power consumption. NB-IoT provides connectivity, paging and PSM modes, which simplify protocols and reduce power consumption, with the standby time of up to 10 years for its terminal modules [12];
4) Low cost. A single module in enterprise environments is expected to be less than 5 dollars [13].

Due to above advantages, NB-IoT is very suitable for smart fire-fighting scenarios which require many scattered terminal nodes and special restrictions on power consumption.

2. Overall architecture design

2.1. Demand analysis

2.1.1. Analysis of traditional wired smoke detectors

As stated above, this paper proposes a solution to use lithium batteries to supply power, so that the equipment can get rid of cable power supply. By “Plug and Play”, the proposed devices are easy to install and debug, thus saving labor and material costs and reducing deployment costs by more than 90%.

Aiming at overcoming the shortcomings of no remote alarms, this paper proposes to use NB-IoT communication modules to upload alarm information to a cloud platform through NB-IoT, and then the alarm information is pushed to a monitoring center or customers’ mobile terminals by the cloud platform, so as to achieve the function of remote phone and SMS alarms.

2.1.2. Analysis of traditional wireless smoke detectors

Traditional wireless smoke detectors based on ZigBee have certain shortcomings. In contrast, the communication distance of NB-IoT is relatively far, generally reaching 15km. Compared with LTE (Long Term Evolution) and GPRS network, NB-IoT has a strong wall-penetrating capability and improves the gain by 20dB [14], and can cover areas where signals are difficult to reach, such as underground garages, basements and underground pipelines, thus saving a lot of gateway overheads.

To deal with the problems of GSM modes, this paper proposes a MCU of ultra-low power consumption: STM32L431RCT6, with NB-IoT module for communication and ultra-low NB-IoT power consumption, based on AA (5000mAh) battery, with a service life of more than 10 years.

Against the problem of network congestion when the equipment is dense, NB-IoT has the ability to support massive connections, and one sector can support 50,000 connections.

2.2. The architecture of system

The smart wireless fire-fighting system mainly include the following components: NB-IoT sensing terminal layer, network transmission layer, IoT platform management layer, and application service layer [15]. Figure 1 shows the entire system architecture of the smart smoke sensing system.
The smoke sensing terminal layer with NB-IoT chip is equipped with a China Mobile’s SIM card inside, which sends the collected data to telecommunication platforms through the NB-IoT communication module.

The transmission layer includes the NB-IoT telecommunication base station and the IoT core network. The NB-IoT base station transports the received data to China Telecom’s cloud platform through the core network [16].

The platform management layer provides functions such as data storage and device management. In addition, it offers a follow-up possibility for smart city by unified management. Once the platform is networked with Fire Services Departments’ systems, the fire fighters can react speedily to fire events and reduce the loss of life and property.

The application service layer is connected to the cloud platform through APIs (Application Program Interface), so as to realize the function of online data query and remote monitoring.

![Overall architecture of the system](image1.png)

3. System hardware design

The hardware of the system mainly includes four modules, namely, Lithium battery power supply, main control chip, smoke sensor and NB-IoT.

The Lithium battery module provides 3.3V DC (Direct Current) power for NB-IoT module and main control chip module, as well as 5V DC power for smoke sensor module. The MCU collects the smoke values and sends a beeper control signal through the GPIO port. The NB-IoT module communicates with the MCU through AT commands and with the base station through CoAP protocol.

The hardware architecture is shown in Figure 2.

3.1. Main control module

For the application scenario of IoT, this system adopts a STM32L431 chip, which is newly introduced by STMicroelectronics, with high performance and low power consumption. Based on ARM Cortex-M4 kernel and 32-bit width, the chip is internally integrated with 128K FLASH and 64K SRAM and adopts LQFP64 encapsulation, providing four patterns: work, sleep, stop and standby. Its operating frequency is up to 80 MHz, and it has rich interface resources, including the I2C, SPI, ADC, Uart, TIM and watch dog, which is very suitable for IoT systems [17].

The chip has an ultra-low 8nA power-down mode and an ultra-low 28nA standby mode. When RTC (Real Time Clock) is activated, the power consumption is only 280nA, well meeting the ultra-low power consumption requirement of smoke sensing systems.

3.2. Power supply module

The power of this system is provided by 2 lithium batteries, and each battery has a capacity of 2,600mAh. The model is 18650, at a nominal voltage of 3.7V. Tests show that if the system is at the stop mode, the battery is estimated to be used for about 5 years.

Since the device operates at different voltages, the entire system is supplied separately. The 3.7V voltage of lithium battery is boosted to 5V DC by IC chip PS7516 to supply power to the smoke
sensor module, while being stabilized to 3.3V DC by IC chip RT9013-33GB to supply power to the NB-IoT module, LED and buzzer alarm module and main control chip module [18].

Used in this module as a constant 5V boosting DC-to-DC converter, PS7516 is internally integrated with a low RDS(ON) (Static Drain-to-Source On-Resistance) power MOSEFT; and Schottky diodes are not needed externally, enabling high conversion efficiency. PS7516 is suitable for high efficiency applications of lithium battery in boosting to 5V/1A. RT9013-33GB is a high-performance 500mA LDO (Low Dropout Regulator), with a quiescent current of as low as 25uA to extend the battery life.

The schematic circuit diagram of the power supply module is shown in Figure 3.

Figure 3. Schematic circuit diagram of the power supply module

Figure 4. Schematic circuit diagram of the NB-IoT module

3.3. NB-IoT module
At present, NB-IoT chip manufacturers mainly include Qualcomm, Intel, Huawei Hisilicon, SIMCom and etc. This system adopts SIM7020C module from Shanghai SIMCom Wireless Solutions Limited Company. Its working frequency band is B1/B3/B5/B8, which can support NB-IoT SIMcard of China Mobile, China Unicom, and China Telecom. Its power supply voltage is about 3.3V and the transmission power is 23±2.7dB. When in the power saving mode (PSM), its current is as low as 3.4uA.

The serial port of this module can use AT commands for communication and data transmission. At a default baud rate of 115,200 bps, it supports many communication protocols, including LWM2M/CoAP/MQTT/ TCP/UDP/HTTP/HTTPS.

Currently, CoAP and MQTT are the two most promising IoT communication protocols for small devices. MQTT protocol is based on TCP and can maintain long connection, more suitable for real-time control. CoAP protocol is based on UDP at low power consumption, more suitable for data acquisition field scenes [19].

According to the functional requirements of data collection, communications between the NB-IoT terminal in this system and the IoT cloud platform are based on COAP protocol.

The characteristic of NB-IoT module meets the requirements of this design. The schematic circuit diagram is shown in Figure 4.

4. System software design
The programs of this system are developed on MDK5 platform in C language. The system software design is mainly divided into two parts, namely, the smoke terminal software and the cloud platform hardware of the system mainly includes four modules, namely, Lithium battery power supply, main control chip, smoke sensor and NB-IoT.
4.1. Design of the software

The flow chart of terminal software in this system is shown in Figure 5. After the device is powered on, the main program first initializes STM32’s serial ports, interrupts and timers before booting the NB-IOT module. After initialization, MCU enters the stop mode, and NB-IOT module enters PSM (power saving mode). The system collects smoke data every 5 seconds periodically. After each collection, the value will be compared with the threshold (set at 1,000).

1) If the value collected is higher than the set threshold, it means that a fire has occurred and an alarm needs to be issued immediately. MCU controls the LEDs and buzzer to issue an acousto-optic alarm. At the same time, MCU sends alarm information to the NB-IoT communication module, which exits from the PSM mode and packages the alarm information as a CoAP protocol packet to send it to the IoT platform. After the data are transmitted, the system enters the sleep state again, waiting for the next wake-up. On the other hand, after receiving the alarm information, the platform will immediately report the accurate location and alarm information to the user and the fire department through such channels as telephone, SMS (short message service) and mobile App, so as to realize smoke detection, alarm and linkage of the initial fire in real time, protecting the safety of life and property.

2) If the value collected is lower than the set threshold, it means that no fire has occurred, so the system enters the energy-saving state. The system regularly collects smoke data every 5 seconds, and reports relevant information (such as smoke data, signal values and others) to IoT cloud platform every 30 minutes.

In order to ensure the accuracy of smoke data and alarm information, this system uses the mean filter algorithm to process the collected data.

The network access of NB-IoT module generally includes the following steps:
1) Power on the module to initialize the SIM card;
2) Start to search for signals of nearby base stations;
3) Start to enter the connection state when finding a NB network;
4) Activate PDN (Public Data Network) to obtain IP (Internet Protocol) address;
5) Start to establish user data links to send and receive data;
6) When there is no data interaction, it starts to enter the mode of IDLE and PSM;
7) Wait for the user data to be sent out, or enter the connection state again.

4.2. Design of IoT platform

The IoT cloud platform provides capabilities for device access, management, and data analysis and storage, as well as other services to various applications. This system uses a China Mobile SIM card.
and China Telecom's Tianyiioot cloud platform, which is an IoT ecosystem with China Telecom's IoT connection management platform as its core. Based on core technologies such as IoT, cloud computing and big data, a unified and open IoT connection management platform is built to achieve seamless connection with upstream and downstream products through open APIs (Application Program Interface) and IoT agents, so as to provide clients with end-to-end high-value industrial applications. Development on Tianyiioot cloud platform mainly includes Profile definition and codec plug-in development.

As a product model, Profile is used to describe the capabilities and features of a device. By defining a Profile, users can build an abstract model of a device on the IoT platform, so that the platform can understand the services, properties, commands and other information supported by the device. This system creates a “smoke sensing” service, under which four properties are created: "smoke_value", "CSQ", "battery_level", and "set_value".

Codec plug-in can create sessions of binary data and Json-formatted data, so as to realize two-way communications of data reporting and command issuing between the device terminal and the cloud platform, as shown in Figure 6.

5. Analysis of test result
Some tests were conducted at Room 317, South Building of College of Physics and Information Engineering, Fuzhou University, to verify the reliability of the proposed smart fire-fighting system. After inserting SIM card into the device, connecting the antenna and powering on the device, the device will collect smoke data every 5s and upload relevant information to Tianyiioot cloud platform every half an hour. A lighter is pointed at the smoke detector to simulate a fire environment. When there is no combustible gas, the smoke value displayed on the cloud platform is about 50; when there is combustible gas, the smoke value soars to around 2,000, and the device will issue LED and buzzer alarm. The test results of data reporting function are shown in Figure 7. The parameters such as "smoke_value", "CSQ", "battery_level" and "set_value" can be seen.

During a long time of testing, the system can perform stably and transmit data timely.

6. Conclusion
To address the shortcomings of the existing fire-fighting systems, such as high wiring cost, heavy power consumption, inconvenience in unified management, this study innovatively proposes a smart fire-fighting system based on the latest NB-IoT technology and designs the circuit diagram, PCB (printed circuit board) diagram and software. Powered by lithium batteries, this system needs not to use mains electricity for power supply, thus saving expensive wiring costs and facilitating installation. Due to ultra-low power consumption, this device can ensure a long working duration of estimated 5 years [3]. Before the batteries are exhausted, the system can send a low-power alarm to the
management back-office, so that they can be replaced in time. This design solves an industry pain point at a low cost, conducive to industrial productions with high commercial values. In addition, by monitoring around the clock, it can effectively reduce the occurrence of various kinds of fire, contributing to the construction of smart cities.

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