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Research Article

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Design for underground gas monitoring system based on ZigBee

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ABSTRACT

To meet the need of gas monitoring in mine laneway environment, designed a gas monitoring system based on ZigBee technology, the chip of CC2430 is the core, and this system conquers the defect of wired sensor networks and avoids the high-energy cost of other wireless technology.The hardware design and software design method had been presented, and the result had been given. This system has the advantages of low power consumption, low cost, wireless technology and flexibility, with good prospects.

Key words: ZigBee; Gas Monitoring;CC2430;wireles

INTRODUCTION

In recent years, with continuous development of coal industry, coal accident rate is constantly rising; the majority of coal accidents are gas accidents. Happening of accidents seriously endangers the safety of mine workers, causing enormous economic and property damage, greatly influencing the development of coal industry. Therefore, it's very important to monitor gas generation, leakage and thickness timely for safe operation of the mine, personal safety of miners and environmental protection. At the same time, higher requirement of deepen the gas monitoring system is proposed [1].

Currently, most coal mine monitoring systems employ networks combined with wired and fixed sensors. There are many defects in these monitoring systems, for examples, poor monitoring system mobility, large limitations of installation, many blind spots in the mine such as goaf, fully mechanized coal face, etc.[2]. For the above defects, a gas monitoring system underground based on ZigBee is designed according to coal mine monitoring requirements. Test results show that this system can meet design requirements.

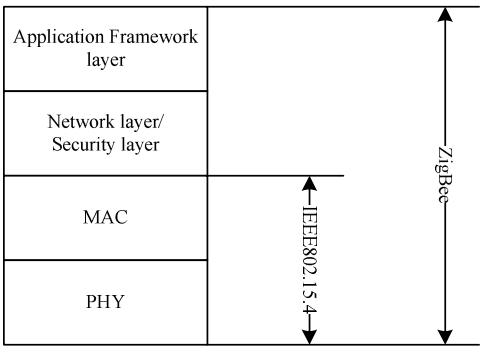

Fig.1 Construct of ZigBee protocol

ZIGBEE

ZigBee technology is a kind of short-range wireless communication technology with uniform technical standards. Its MAC layer and PHY layer protocols are IEEE802.15.4 protocol stack standards, and application layer and network layer are draw up by ZigBee technology alliance, the protocol stack structure being shown in Fig.1.

The specific features of MAC layer are: beacon management, channel access, slot management, confirmation frame sending, request sending, disconnect request, and providing some methods for application appropriate security mechanisms [3]. Characteristics of PHY layer are start-up and shut down the wireless transceiver, energy detection, link quality, channel selection, channel clearing assessment (CCA), as well as sending and receiving data packets through physical media [3]. Application Framework layer is mainly to provide some application framework models for the practical applications of ZigBee technology [3].

Network layer/security layer is mainly used for network connection of LR-WPAN (Low Rate Wireless Personal Area Network) network, data management and network security of ZigBee [3].

In a ZigBee wireless network, ZigBee Alliance provides typically three devices: coordinator, router and terminal equipment. According to different functions of the devices, devices in the network are divided into full-function devices (FFD) and reduced function devices (RFD) by IEEE802.15.4. Coordinator and router must be FFD, and terminal equipment is RFD[4].

According to the different environment, ZigBee networks can apply star network topology, cluster network topology, and mesh topology, with the ultimate goal being mesh network. Mesh network allows all the nodes with routing functions in the network to directly connect to each other, by router's routing table to realize the with the network road of news. This structure is helpful for reducing communication delay, and improves network reliability. But its drawback is that mesh structure needs to store many nodes information, with higher requirements for sensor hardware [4]. From Fig. 2, from left to right are star network, cluster network and mesh network topology.

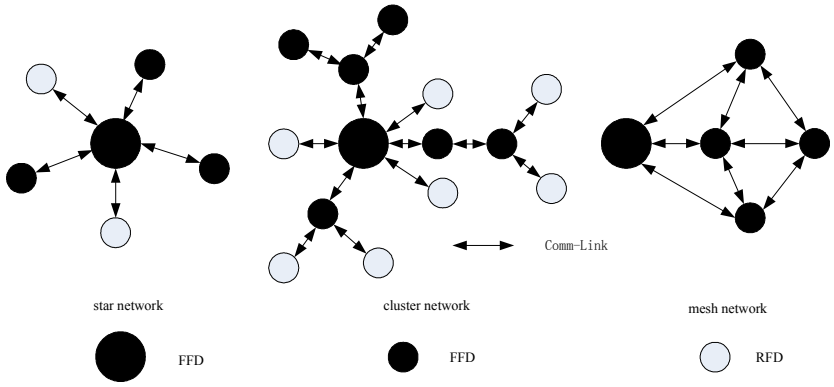

Fig.2 topology of star network, cluster network and mesh network

3. UNDERGROUND GAS MONITORING SYSTEM BASED ON ZIGBEE

3.1 System Overview

Wireless sensor network (WSN) applied to coal mine as a new technology is a trend in the future. For laneway, branch laneway is most suitable for WSN. Information usually access to backbone network underground tunnel only from branch laneway, thus forming a pattern of vary information flowing to one side, resulting in uneven traffic statistics information and presenting one small and one large wooden club structure. Therefore, WSN node with lower performance can be used for branch laneway, general WSN node only needing to complete data collection and transmission; multiple aggregation node (Sink) with higher performance can work in turns or at the same time in the bifurcation of laneway, reinforcing system data processing capability, coordinating and collecting the work state and monitoring data of the rest nodes in branch laneway, and is accessed into backbone network through wired network [5]. Shown as in Fig.3, common node of branch laneway is responsible for collecting gas concentration, and then it's converged to sink node (Sink) through wireless sensor network, sink node (Sink) being connected with backbone by wired way. Parameters target information collected by wireless sensor network is sent to local ground control center through backbone network, the mine is real-time monitored by ground control center according to collected parameters information, variation of regional parameters information and each section of the mine are noted at any time, make rapid emergency response is made for emergency situations, early warning signals are sent to danger zone by accurate positioning technology, thus real-time monitoring and scheduling for coal mine safe production is achieved by control center [5].

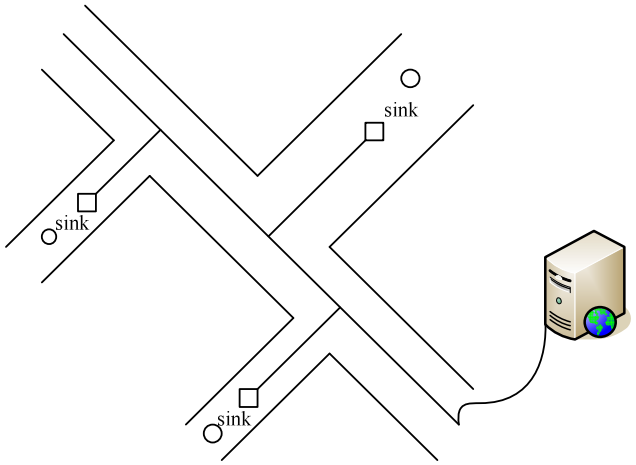

Fig.3 Monitoring system of laneway

3.2 Design for hardware system

A common wireless sensor network node is acted as streamlined front-end equipment for network function, and data collected by sensor mainly is read and transmitted through external interface, and the transition is implemented between different states such as nodes in sleep, detection, and wireless transmission [5].

Ordinary sensor node is consisting of CC2430, gas sensors, power supply, battery management circuit and external circuit. Its internal structure diagram is shown in Fig.4.

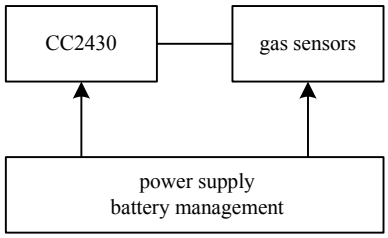

Fig.4 Hardware diagram of ordinary sensor node

CC2430 chip is applied for processor and communication module. CC2430 RF chip is the world's first 2.4GHz RF chip that meets ZigBee Alliance standards[3].The ship continually use the architecture of previous CC2420 chip, a single chip integrated with ZigBee RF front-end, memory and microcontroller. It uses an 8-bit MCU (8051), with 128 KB programmable flash memory and 8 KB RAM, also including ADC, timer, etc. [3]. Thus it meets wireless sensor network's requirements for low-cost and low-power while simplifying circuit design.

Gas sensor module is responsible for collection of methane gas concentration data. Its working principle is that: infrared gas sensor device measures gas concentration in the mine, concentration data is stated by voltage signal, and then differential operation with a standard voltage is done by al amplifier, at last, voltage difference will be sent to control section, as shown in Fig.5 [6]. U1, R1, R2 and U2, R3, R4 respectively constitute measured signal and standard signal amplifier circuit, U3, R5 ~ R8 constitute differential operation circuit.

Alarming whether the gas concentration is over proof and transmitting data to micro-controller can be achieved by CH217. The chip has two alarm channels inside, which is able to send forecasts and dangerous alarm signals, alarm signals being divided as visual and auditory signals [6].

Power and battery management circuit module is the key part of the system, responsible for supplying power for each modules of sensor nodes, using ordinary potassium button 3.6 V rechargeable battery-powered mode and staff can periodically replace the battery. Parameters around collected by sensor are sent into processor through pre-circuit, after handling by processor the data is sent to Sink node through the RF transceiver, setting the indicator light flashes when send or receive data. Debug Interface is used for local debugging.

Sink node is mainly responsible for processing data, sending control information, establishing network, distributing addresses, and allowing the child nodes into network, in addition, sink node do not collect external data, nor implementing sleep[5].

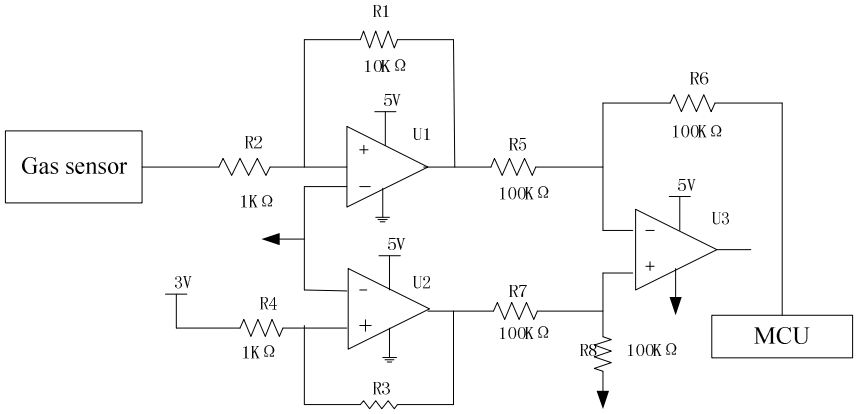

Fig.5 Amplifier and differential operation circuit of gas signals

Sink node is consist of PIC18F4620, power and battery management circuits, memory, alarm circuit, local displace, CC2420 and interface circuit. Its internal structure diagram is shown in Fig.6[5].

SCM PIC18F4620 is chose as Microprocessor unit, which is a kind of low-power consumption SoC. Its rich instruction set and high-capacity internal storage system can guarantee software stack to run completely; it has sleep mode that can greatly reduce power, and sleep mode could be waken-up via an external interrupt[5].

Communication module applies CC2420 RF chip, which works in 2.4GHz frequency band, supporting IEEE802.15.4 protocol, with the properties of low voltage (2.1 ~ 3.6V), low power, high sensitivity, small size, received signal strength indicator (RSSI) and so on, its data transfer rate up to 250kbps. The chip provides functions of physical layer and part of data link layer. In addition, CC2420 also supports hardware for packet control, data buffering, data encapsulation, data validation, and link quality and data packet timeliness, these greatly reducing the burden of control part. And its radio transmitter power is programmable controlled, that is, wireless transmission power can be controlled through register configuration so that nodes can use different transmission power for different applications, providing the possibility of energy-saving[6].

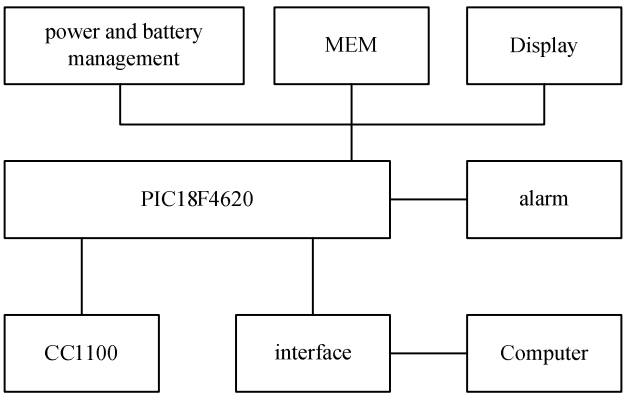

Fig.6 Hardware diagram of sink node

For power and battery management circuit module, considering energy consumption of sink nodes is relatively too large, the design of sink node module can apply three ordinary 5 AA batteries, thus can maintain longer working time.

For interface circuit module, which only sink node of serial port circuit has, sink node is responsible for the communication between sensor network and embedded computer, sending query command to lower node, receiving data returned by lower node and sending to embedded computer by interface. For experimental convenience, here only the RS-485 is used as wired transmission interface between sink node and host.

3.3 Design for software

Software of the entire system is designed with C language in IAR development and debug environment supported by TI company, and modular programming method is used, which is divided into main control module, information dissemination module, data acquisition module, wireless communication module and serial communication module [7]. The main control module is the dialogue interface between user and information terminal, mainly responsible for handling collected information, controlling other function modules, early warning of emergency situations and providing users with good man-machine interface. The main function of information distribution module is to publish information user required through terminal node. The main function of data acquisition module is to capture gas concentration information on spot and send it to sink node upwards. The main function of wireless communication module is to complete interactive communication between nodes in network, realizing data transmission. Serial communication module is the interface between Zigbee network and host computer, mainly to complete the communication of network coordinator node and host computer [8].

Program flow chart of terminal node and sink node are shown in Fig. 7 and Fig. 8.

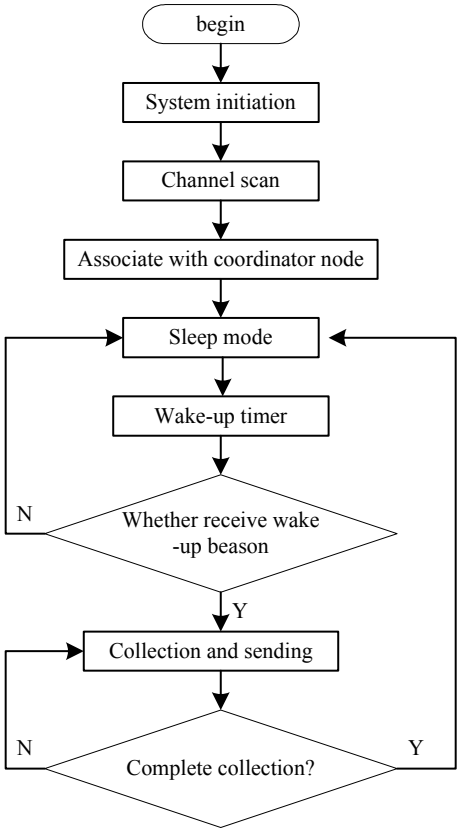

Fig.7 Program flow chart of terminal node

4. TEST RESULTS

The gas monitoring system is tested in coal mine underground, the test results shown in Table 1. As can be seen from Table 1, the system measurement error is relatively small and can satisfy usage demand. The error between measurement and actual value is mainly due to the error existing in sensor itself and restrictions of the underground environment, but there almost does not any error in network transmission, and the system is stable and reliable.

Table 1 Test results

Actual value/CH_4	Measured value/CH_4	Test times
0.54%	0.52%	1900
0.18%	0.13%	2500
0.42%	0.45%	3000
0.11%	0.14%	5000
0.46%	0.43%	2800

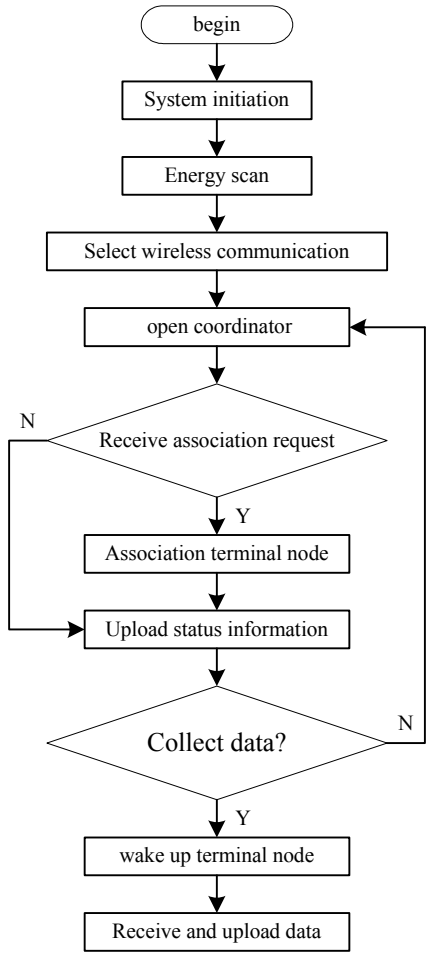

Fig.8 Program flow chart of sink aggregation node

CONCLUSION

WSN is an important mean of coal mine monitoring. For the flaws of monitoring system in coal security production, a gas monitoring system is presented with PIC18F4620 SCM as central processor, setting the function of WSN-based monitoring, display, alarm, communication in one based on WSN. It takes full advantage of PIC18F4620 characteristics of small size, high integration, low power consumption, powerful, reliable performance, while taking advantage of WSN for monitoring data transmission, effectively realizing real-time monitoring of coal mine gas. In addition, the system can monitor other signals of the coal mine such as temperature, humidity, water, etc.

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