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Mine environment monitoring system based on wireless sensor network

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Abstract

There are a large number of sensors to detect information in mine environment system, which provides the original data for the prevention and treatment of mine accidents. According to data flow of data acquisition, data transmission, data storage and data processing, this paper used CC2530 to design the wireless sensor nodes, analyzed the Zigbee network topology and designed an optimized PEGASIS protocol. The multi-sensor data fusion method was applied to the multi-parameter and large-scale mine data, solved the nonlinear problems in the multi-feature selection and extraction and also improved the performance of mine monitoring system.

Keywords*: Wireless sensor network, Zigbee, Data fusion, Network topology, Early-warning system.*

1. Introduction

China is one of the most serious countries in disasters all over the word. In the numerous disasters, the number of deaths caused by the mining accident followed after road traffic and ranked the second [1]. In recent years, all kinds of mine disasters, especially mine gas explosion accidents frequently broadcasted in newspapers. The party and state leaders have made instructions repeatedly on mine accidents, but mine accidents of production safety have not been fundamentally solved at present. It is important to adopt new technologies and new methods to predict the accident before it happens, and it will be of great benefit to economy and society [2, 3].

There are some ways to ensure the smooth production underground and prevent the occurrence of accidents, such as improving work environment and reducing the unsafe factors. In order to ensure the safe and efficient mine production, automatic monitoring system is need for all the links in the production of mine. Early warning systems meet this demand and can be applied to mine safety production and management. Scientific and reasonable warning method helps the enterprises find out the conditions and characteristics of gas accident, grasps the cause, the regularity and the development trend of the accident. Early warning system may prevent accidents or reduce the losses caused by the accident [4]. Due to the many influence factors of mine gas concentration, it is difficult to describe all the changing factors using one model system. Essentially, mine system is a complex nonlinear system. Due to the special environment of the mine system, there was not a good way to solve the data transmission underground. Recently, the wireless sensor network technology appeared and it will provide a good method for data acquisition in mine security monitoring system [5, 6].

2. Structure of the Mine Monitoring System

The mine environment monitoring system consists of two main parts according to the function, one part is the information monitoring subsystem, another part is the mine information acquisition subsystem. The overall structure of the mine monitoring system is shown in Figure 1. The information monitoring subsystem equipped with database server and Web server, and the terminals internal can connect to each other via Ethernet. Through the firewall, the information monitoring subsystem provides remote access capabilities to the Internet. The main function of

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the information monitoring subsystem is to save the underground environment information to the database, to process and analysis the mine data collected for underground and to provide monitoring information to the users. The mine information acquisition subsystem composed of a Zigbee network gateway, router nodes and sensor nodes. The mine information acquisition subsystem has two main functions: (1) collect environment parameters and personnel information by different sensors, (2) transmit the environmental information to the gateway accurately. In the mine information acquisition subsystem, the gateway has a very important position. On the one hand, the gateway establishes a Zigbee network and collects the various sensor data in the network in real-time, on the other hand, the gateway handles the protocol conversion and sends the collected data to the database server via Ethernet.

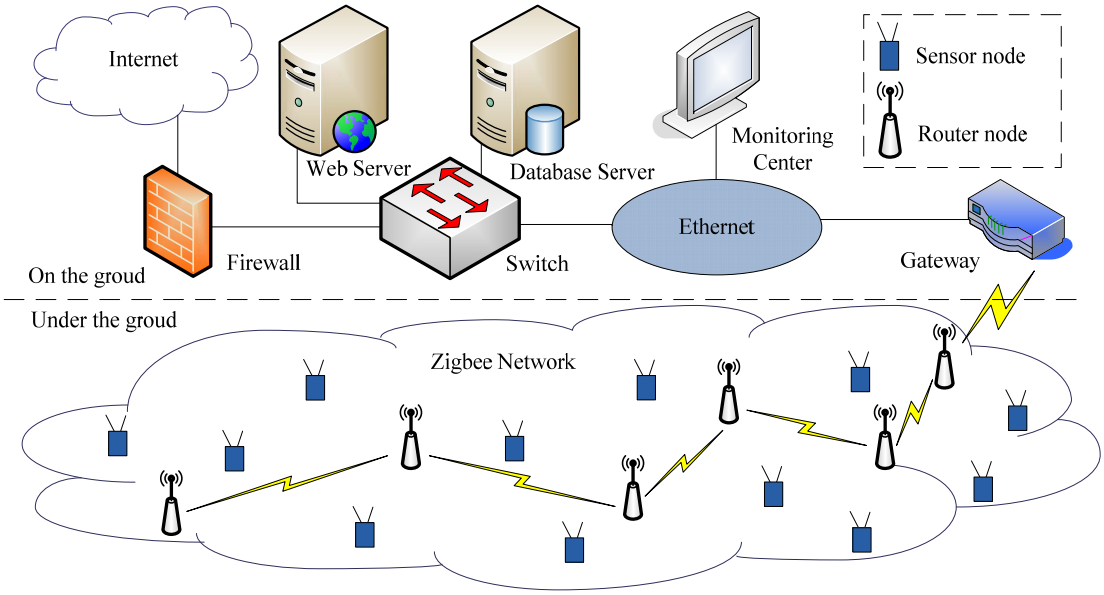

Figure 1. Overall structure of the mine monitoring system

3. Hardware Design of Nodes

There are two physical types of devices specified in 802.15.4: the Full Function Device (FFD) and the Reduced Function Device (RFD). ZigBee network defines three ZigBee devices: ZigBee Coordinator, ZigBee Router and ZigBee end devices [7,8] . The ZigBee coordinator is a FFD, responsible for initiating and maintaining the devices on the network. It may also perform the roles of trust center and network channel manager. ZigBee routers are required to act as routing agents on behalf of their end device children, they are usually used to extend the network. ZigBee end devices are joined to and managed by ZigBee routers or the ZigBee coordinator, usually powered by battery. In the mine monitoring system, we designed all the three Zigbee devices.

3.1. Design of Sensor Node

In general there are two types of sensor nodes. One type node is used to collect the underground environmental information, which matching various types of sensors, such as temperature, humidity, barometric pressure, wind speed, gas, CO sensor, etc. Another type node is mainly used for the position of personnel or equipments. For the first type of sensor nodes, they were designed by the CC2530 chips and the corresponding sensors, whose block diagram is shown in Figure 2. The sensors and conditioning circuits are selected according to the different sensor nodes in dotted line. For the second type of position nodes, they were designed by the CC2530 chip. The position node implements a distributed computation algorithm that uses received signal strength indicator (RSSI) values from known reference nodes, such as the routing nodes, and we can get the position of the node by measurement of the RSSI [9].

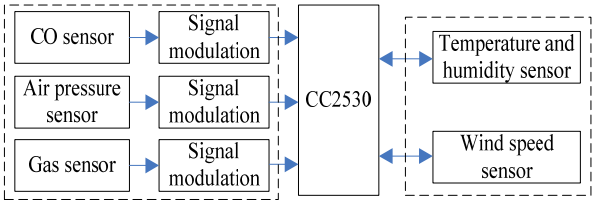

Figure 2. Structure diagram of sensor node

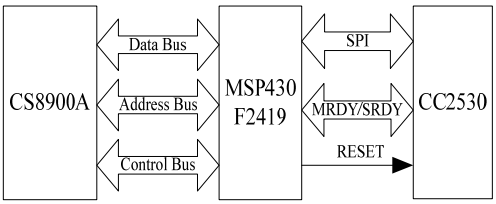

Figure 3. Architecture diagram of gateway

3.2. Design of Router Node

The router nodes collect data from the sensor nodes nearby and transmit it to the gateway node, mainly complete the routing function. The router nodes are designed by CC2530 chip. During the deployment of the routing nodes in mine environment, they should be deployed in order along the digging tunnel and be placed on both sides of the lane in accordance with triangular arrangement, so that each routing node can communicate with two routing nodes near the gateway to guarantee the robustness of the network. In addition, the deployment of the routing nodes allows the location node associate with at least three routing node communication and complete self-location.

3.3. Design of Gateway

The architecture of the gateway is shown in Figure 3. The master chip is MSP430F2419. On the one hand, MSP430F2419 connects with CS8900A to get Ethernet access point. On the other hand, MSP430F2419 connects with CC2530 through the SPI interface and get the CC2530-based application program interface. TI's ZigBee protocol provides CC2530-ZNP program interface, users can easily add Zigbee application to their products through CC2530-ZNP [10]. In this solution, the ZigBee stack runs on a CC2530 chip and the application runs on MSP430F2419 microcontroller. CC2530 handles all the ZigBee protocol tasks and MSP430F2419 handles the other application tasks, it will make good use of system resources.

4. Wireless Sensor Network Topology

When starting up a network, the actual situation is always considered to determine the network topology. The structure of the network topology will affect the network's the cost, the stability, the reliability and maintenance difficult. There are three basic network topologies, the star topology, the cluster-tree topology and the mesh topology. In the star topology, the communication is established between devices and a single central controller, called the PAN coordinator. The star topology network supports point-to-point and point-to-multipoint communication, one device communicates with another through the PAN coordinator. The cluster-tree network is a special case of a peer-to-peer network in which most devices are FFDs (full function device). Any of the FFDs may act as a coordinator and provide synchronization services to other devices or other coordinators. Only one of these coordinators can be the overall PAN coordinator. The PAN coordinator forms the first cluster by establishing itself as the cluster head (CLH) with a cluster identifier (CID) of zero, choosing an unused PAN identifier, and broadcasting beacon frames to neighboring devices. The cluster-tree network can be understood as a multi-level hierarchical network. The main features of cluster-tree network are that the function of each node is relatively clear, which will benefit for the use of resources. In the mesh network, each node must not only capture and disseminate its own data, but also serve as a relay for other nodes, that is, it must collaborate to propagate the data in the network. The self-healing capability enables the mesh network quite reliable [11, 12]. As the mine work area is long and narrow distribution and will grow up with the expansion of the underground excavation, the underground topology is almost fixed. Considering the reliability and convenience of the system, we adopted the tree-cluster topology.

5. Routing Protocol

The routing protocol is responsible for the transmission of data packet from the source node to the destination node. Wireless sensor network routing protocols generally have the following characteristics: 1) energy priority; 2) based on local topology information; 3) data-central. With the cluster-tree topology, we designed an optimized power-efficient gathering in sensor information system (OPEGASIS) protocol. In OPEGASIS protocol, the network is divided into clusters, each cluster consists of a cluster head and multiple cluster members, the cluster heads form high level network [13]. In mine information acquisition subsystem, the router node is a cluster head, the sensor node act as a cluster member, and the gateway is the cluster head of high level network. Sensor nodes need only to communicate with the nearest router node that collocated along the lane surface. The OPEGASIS protocol optimizes management of network communication and improves the reaction speed of the network.

6. Model of Data-Fusion

Mine environment monitoring system is a complex nonlinear system essentially, there are a large number of sensors to detect information underground in mine, such as gas sensor, temperature and humidity sensor, air pressure sensor, wind speed sensor, etc. In the multi-sensor system, the environment information (ie, evidence) provided uncertainty more or less to determine the actual mine state. The uncertainty mainly manifested in the imprecision of data expression, the unreliability of obtained data and the incompleteness of data itself. According to data flow of data acquisition, data transmission, data storage and data processing, the mine monitoring system involved in data-level fusion, feature-level fusion and decision-level fusion. To improve the information processing capabilities and the warning performance of the monitoring system, multi-sensor data fusion methods were applied to estimate the underground situation from the multi-parameter and large-scale mine data [14, 15]. The wireless sensor network data fusion model is shown as Figure 4.

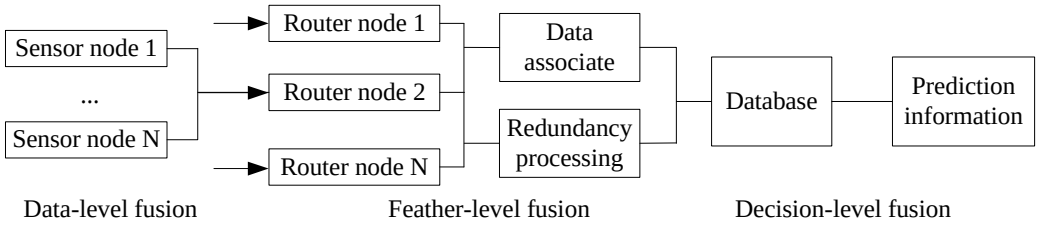

Figure 4. Wireless sensor network data fusion model

In data-level fusion, the operation is directly on the collected original data, all kinds of sensor information was integrated and analyzed without pretreatment, which is a low-level fusion. The main advantage of this fusion is to provide the field data information as much as possible. In this paper, we take Kalman filtering algorithm to pre-process the mine data of the sensor nodes and eliminate the data noise (including ordinary noise and abnormal data) from the original sensor data. It is helpful to provide accurate basic data for the feature-level and decision-level fusion.

In feature-level fusion, the feature information was first extracted form the sensor data and then be analyzed and processed. Feature-level achieved considerable information compression and benefited the real-time processing. Since the extracted feature is directly related to the decision, the fusion results will give the useful feature information needed by the decision information. The feather-level fusion in this article realized in the router nodes. The router node extracts feathers of the sensor nodes nearby the cluster head and provide valuable information about the characteristics of the decision-level fusion.

The decision-level fusion is a high-level fusion. The results provide a basis evidence for decision. Therefore, the decision-level fusion must attach importance to the mine situation and take full advantage of the various extracted features. The artificial neural network simulates the

thinking of the human brain, has a strong self-learning and association functions, and also takes advantage of the expert knowledge better. But the drawback of the artificial neural network is that it can not handle and describe fuzzy information, and can not take good use of existing experience and knowledge. Fuzzy system requires little samples relative to the neural network and takes effective utilization of expert knowledge. While at the same time there are some shortcomings, such as more manual intervention, low accuracy and difficulty in adaptive learning function [16]. In order to improve the utilization of multi-sensor data, we combined the fuzzy control technology and artificial neural network technology in the decision-level fusion, which took full advantage of redundancy and complementarity of multi-source information, and thereby enhancing the reliability and improving the warning performance of the mine monitoring system.

7. Software Design

7.1. Software Program of the Gateway Node

The gateway node is composed of CC2530, MSP430F2419 and CS8900A. The MSP430F2419 act as application processor and CC2530 act as Zigbee protocol processor. CC2530-ZNP uses the SPI transport mode and the power-up procedure is as follows.

(1) MSP430 processor and CC2530 power up.
(2) MSP430 processor sets CC2530 RESET_N pin low, holding CC2530 in reset.
(3) The MSP430 processor sets the optional CC2530 CFG0 and CFG1 pins.
(4) MSP430 processor initializes its SPI interface.
(5) MSP430 processor sets CC2530 RESET_N pin high and CC2530 starts operation.
(6) MSP430 processor receives the SYS_RESET_IND message using the POLL command. CC2530 will set SRDY low to indicate the message is available and the application processor should retrieve the message.
(7) MSP430 processor receives the SYS_RESET_IND message.

After executing the power-up procedure, the application processor must call some mandatory APIs before executing any APIs that invoke ZigBee over-the-air messaging. Then the CC2530 scans for the available channels and establishes a Zigbee network, waiting for the sensor nodes to join the Zigbee network and performing the binding procedure, then collects the original data from each sensor nodes (barometric pressure, wind speed, gas, CO sensor) and storages them. While connectting to the remote monitoring computer through CS8900A, the gateway packages the original data according to TCP data format and then establishes a TCP connection to send the data packets to the monitoring center database.

7.2. Sofware of the Information Monitoring Center

In this system, the information monitoring center is mainly responsible for data collection, storage and analysis, also provides a way of data exchange and publishing. The information monitoring center is equipped with the database server and web server. The database server adopts SQL Server 2008, runs the database application management software. The application management software receives the original data from gateway, realizes the function of user management, data management, system parameters configuration, Algorithm design, search, printing and etc. Web server software is developed by Apache and JSP, publishes a variety of information on web page, such as display of the mine parameters, curve shows of the historical data and alarm information, the clients can access and analyze the data on the server through IE browser.

8. Conclusion

In this paper, we describe the structure of the mine environment monitoring system and some key points in the system design, such as sensor node design methods, wireless sensor network routing protocols, data fusion methods, etc. With the advantages of strong robustness, flexibility and practicability, the monitoring system can provide decision-making for guidance of mine production and can be applied to mine safety production.

Acknowledgements

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