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Research Article

A Network Communication Frequency Routing Protocol of Coal Mine Safety Monitoring System Based on Wireless Narrowband Data Communication Network

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In recent years, the coal industry has been expanding the scale and output of coal mining in China, yet the safety in production is faced with great challenge. Communication system in coal mines plays a significant role in production safety, and wireless narrowband data communication network technology is a new-type advantageous measure to construct wireless network security monitoring system for coal mining. Here, a coal mine monitoring signal transmission method based on bus technology and wireless data transmission technology suitable for coal mines is proposed. The corresponding monitoring system is designed, and the system is able to collect the gas concentration and mechanical operation status of the mines. Wireless sensor network nodes are used for the RF communication module. The communication performance of this system in coal and rock medium and the roadway along the goaf is simulated, and the quantitative relationship between the attenuation coefficient of different communication frequencies and the effective communication distance is obtained. Hence, the results show that the protocol has good performance in terms of route establishment, maintenance, and data transmission hop count for the positioning of coal mine employees.

1. Introduction

In recent years, the coal industry has been expanding the scale and output of coal mining in China, yet the safety in production is faced with great challenges. Various accidents and mine disasters are threatening the personnel and the mines. Communication system in coal mine system plays an important role in both production safety maintenance and emergency rescuing. Therefore, reliable long-distance communication in coal mines is desired. Conventional coal mine monitoring system uses fiber transmission as the backbone to construct a coal mine integrated communication network, which has the characteristics of strong anti-interference ability and stable signal transmission [1]. However, considering the actual situation of coal mine production, the complex production environment largely limits the functions of the wired communication system [1,2]. Wireless narrowband data communication network is a novel technology, which is proposed and popularized in recent years [3,4]. Multiple schemes can be adopted in this work; for example, up to four baseband processing units can be connected under one radio network controller [5]. According to the load of the digital signal processing of the overall device digital signal process (DSP), the specific planning of the network of 20 fiber-optic remote base stations can be processed according to the actual situation [6]. In the underground coal mine safety monitoring and personnel positioning system, the personnel portable node is at the outermost node and is not responsible for transmitting data, and these nodes cannot communicate with each other. Their main function is to achieve target positioning and environmental monitoring by combining the location information of fixed nodes in the surrounding coal mine roadway [7]. In 2013, the measurement of medium

frequency propagation characteristics of transmission lines in underground coal mines was proposed [8]. Now, the underground wireless sensor network environment comprehensive monitoring system was proposed [9–11].

In the previous studies on narrowband communication, it is proposed that direct current (DC) coefficient reflects the measure of the mean value of the pixels in the subblock. If the responding node contains a route to the source, it is sent directly using the route; otherwise, if the network link is symmetric (bidirectional link), it can be reversely transmitted using the discovered route [12]. The spectrum selector can collect the spectrum information of the spectrum analyzer and select a range of available frequency bands according to the rules of the system [13]. Narrowband communication mainly includes sensor technology, wireless communication and networking technology, distributed data fusion and aggregation technology, data management technology, node location technology, and time synchronization technology [15]. The main function of wireless sensor networks is to collect and transmit data, so sensor technology is the basis of many technologies in wireless sensor networks [16]. Cognitive wireless ad hoc networks and on-demand routing only initiate routing discovery when the source node intends to send data to the destination node. Low routing overhead is more suitable for cognitive wireless ad hoc networks [17]. The core idea of this hierarchical topology model is to consider the cognitive radio network topology as a set of interfaces for cognitive nodes and a mapping of its spectrum opportunities [18]. In this way, a set of nodes, respectively, detect the spectrum opportunity to form a complete set of possible relationships of the topological relationship and obtain a hierarchical layered topology with node mirroring.

However, to date, the feasibility of multiple node connection and processing have not been fully verified, and the potential application of narrowband communication has not been fully developed. Here, a coal mine monitoring signal transmission method based on bus technology and wireless data transmission technology suitable for China's coal mines is proposed. The corresponding monitoring system is designed, and the system has the function of collecting the gas concentration and mechanical operation status of the mines. As a key factor in this system, a network communication frequency routing protocol is proposed and investigated.

The rest of the paper is organized as follows: Section 2 is based on design and structure of the system, Section 3 explains the result analysis and discussion, and Section 4 concludes the paper.

2. Design and Structure of the System

The coal mine integrated monitoring system in this paper is developed for monitoring the production and operation status of underground equipment and gas concentration [19]. As a load, the information is encapsulated in a data format that can be transmitted on the public network. The data are unpackaged at the interface between the destination LAN and the public network, and the load is removed. The logical path through which encapsulated packets are transmitted over the Internet is named a "Tunnel." Proper communication protocol is vital to encapsulate, transmit, and de-encapsulate data smoothly. It is the core control factor of the whole private network system. According to the protocol stack process, the communication function of the private network is realized by using modular software architecture (using the original communication network element as the function module of the equipment). To guarantee the function of private network products, the modular design shall optimize the composition of the system and reduce the auxiliary equipment. This is very important for the realization of communication under complex conditions in coal mines.

When a problem occurs in a module, the system shall be able to sense and take positive measures in time. It is unacceptable to cause crash of the entire system due to the failure of one module. For this purpose, the individual functional modules are required to be relatively independent and mutual influence between them shall be prevented. When coal mine disasters occur, conventional communication equipment is often destroyed, causing disruption of communication between the mines and the ground, resulting in survivors trapped in the mines losing contact ground personnel or rescue personnel. Low-frequency ground-to-ground communication can reliably understand emergency rescue communication and realize communication between underground trapped personnel and ground personnel or rescue personnel. The limit communication frequency of each medium is shown in Table 1. The protocol stacks on the control plane are all implemented in the device board SCTA, as shown in Figure 1. The specific protocol stack structure is no longer given. When the RNC and SGSN/GGSN transmissions are integrated, the message is transmitted through an internal custom message.

The available frequency bands of cognitive radio network nodes are affected by the primary user, so they change at any time [20]. Special MAC and link layer protocols can be used to shield the impact of dynamic bands on the upper layer of cognitive radio networks. By observing historical data, the parameters of coal mine monitored by sensors can be analyzed, and the normal operation of equipment and experimental results can be understood. Historical data query module includes form code design and database query code design. A method of discovering neighbors on public control channels uses link layer protocols; data communication uses other channels, and these data channels change over time. But shielding itself can lead to inaccurate decision-making or performance deficiencies. So, the node hardware technology is the key research technology of the network. One sensor node is a chip with embedded operating system, which enables the node to carry out data calculation and network communication.

Multipath protocols may not be as simple as single-path protocols in terms of network throughput and data packet transmission rate. Simultaneous transmissions of data by multiple paths can improve the reliability of data transmission in the network. Multipath routing protocols provide two different methods for data concurrent transmission.

Table 1: Limit communication frequency of medium.

	Frequency (MHz)
Lignite	0.29
Fat coal	2.00
Coking coal	2.62
Lean coal	4.89
Anthracite	0.18

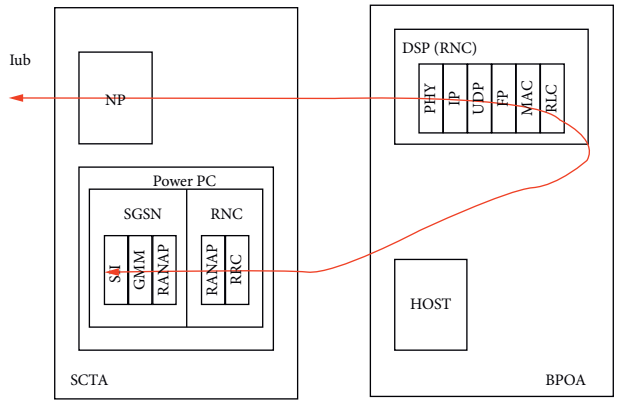

Figure 1: Packet domain signaling stream.

One is to use multiple paths to transfer backup information of packets. The other is to split the data information into different data packets using different paths for data transmission. The transmission format is shown in Table 2. The change of the working frequency band will also be caused by the change of the environment, which will affect the stability of the link. Therefore, the improved protocol integrates the entire wireless environment when establishing path and route maintenance, and selects a relatively stable frequency band to ensure that the path is not affected by the node frequency switching as much as possible. A comparison of the four short-range wireless communication technologies is shown in Table 2.

The wireless transmission process of coal mine gas acquisition data includes the following:

(i) Coal mine gas data are collected by special equipment (acquisition terminal). The collected data include gas concentration, temperature, ventilation, fan working conditions, and so on.

(ii) The collected data are transmitted to the system computer on the well through the monitoring network of the coal mine.

The structure of the data system at the time of the communication is shown in Figure 2. The underground equipment mainly includes underground intelligent nodes, sensors, repeaters, etc. The intelligent nodes of monitoring substations are installed in the necessary locations of underground mines. Intelligent nodes can connect all kinds of sensors. The dependence of the performance requirements of each module of the sensor node is shown in Table 3 and Figure 3. As RAM and program memory are connected with CPU through the same address bus and data bus, program code can be loaded into RAM or run in RAM. This provides

Table 2: Transfer message format.

		Data (kbps)	Time (s)	Packet loss
Single path	Port	1028	8	12
Multipath	Port A	254	2	0
	Port B	254	2	0
	Port C	254	2	1
	Port D	254	2	0

great convenience for debugging the program. All instructions have a byte or word operation. However, the operation of the stack and the PC is performed on the word width, and the address must be aligned to the even address. So, the choice of processor is critical in sensor node design. The processor used by the sensor network node should meet the following requirements: the shape is as small as possible, the integration is as high as possible, the power consumption is low, and the sleep mode is supported. The speed should be as fast as possible. There must be enough external universal ports and communication interfaces. The cost should be as low as possible, and the security should be guaranteed. At the time of mining of this working face, there is already a certain degree of oxidation. In addition, the mining period is long in the adjacent working face, the ventilation route is long, the porosity along the airside is large, and there are many air leakage passages, which is easy to form a smooth air leakage. The loose coal body continues to oxidize under such air leakage conditions. When the heat generated by the oxidation of the coal body is greater than the heat dissipation amount of the coal body, the heat is accumulated and the temperature of the coal body is increased. Therefore, the coal spontaneous combustion monitoring information is accurately collected at the possible ignition sites with a high degree of spontaneous combustion along the air side, and the degree of ignition is accurately grasped.

In coal mine safety system, due to the limitation of transmission bandwidth, the requirement of video compression rate is high. If the motion vector is searched in the traditional spatial domain, the prediction error is transformed and the entropy coding is carried out. Under the condition of high compression ratio, the recovered image has block effect. In traditional wireless networks, all nodes work in a fixed and unified frequency band, and it is easy to establish and maintain connections between nodes. In cognitive radio networks, there is usually no such fixed and unified frequency band. Each node detects its own SOP independently, so the operating frequency band of the node selection may be different. The nodes need to detect their SOP in the first step and then select the frequency band from the available spectrum. Therefore, any node or link failure will only affect this path and will not affect other paths. Node disjoint routes are superior to other routes in the use of network resources in high aggregation. It is difficult to find multiple node disjoint paths because of randomly deployed sensor nodes. A link disjoint node means that some nodes may intersect but no link is intersected. When a node fails, all paths linking this node will fail. In the eyes of cognitive users, the use of frequency bands is intermittent, and the connections

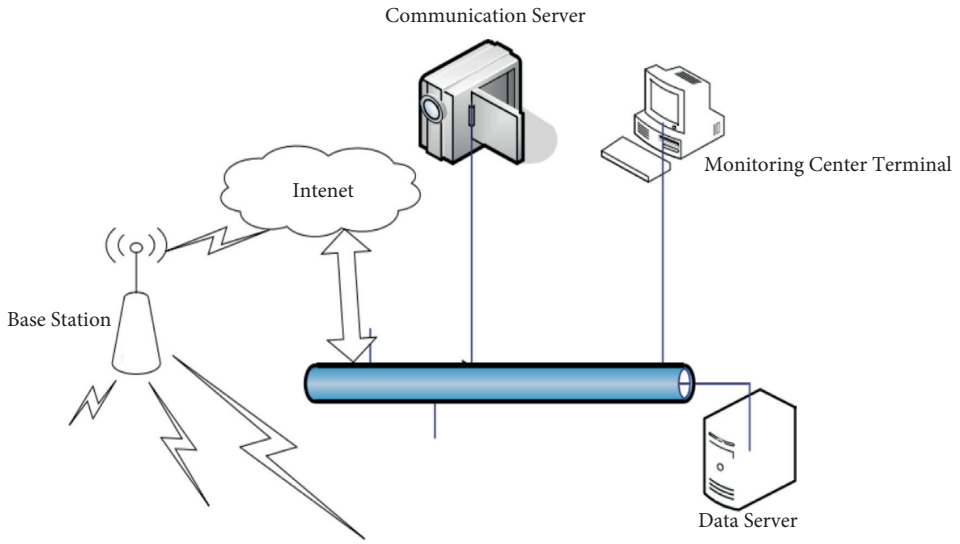

Figure 2: Data system architecture in communication.

Table 3: Dependence of performance requirements of sensor node modules.

CPU main frequency (MHz)	Data (bits)	Communications frequency (Mbps)
8	8	64
12	8	96
32	8	256
48	8	384
72	8	576

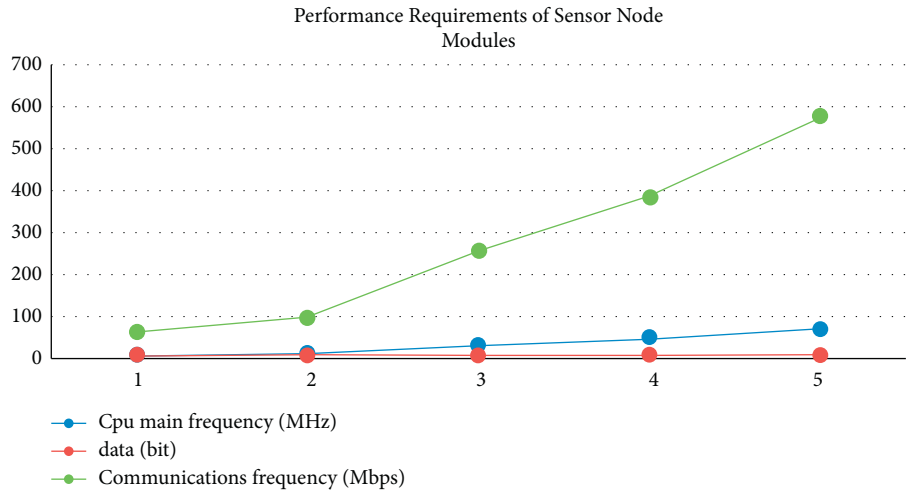

Figure 3: Dependence of performance requirements of sensor node modules.

established between nodes are therefore intermittent. When the link between nodes is disconnected due to spectrum unavailability, the connection is selected when it continues to wait for the spectrum to be available. Whether to choose other spectrums or to choose other paths to complete data communication is an issue that shall be taken into account in an improved routing protocol. The investment in wireless spread spectrum is quite economical. The use of WLAN not only reduces the need for cabling and some of the wiring-related expenses, but also provides users with more flexible and more mobile information acquisition methods.

3. Result Analysis and Discussion

Nodes are the receiving and sending stations of information on the network. There are two types of nodes in the bus system: nonintelligent nodes without microcontroller and intelligent nodes with microcontroller [21]. The so-called intelligent node is composed of microprocessor and programmable control chip. Coal mine data acquisition line and transmission part: Coal mine will collect all kinds of safety data from the underground to the coal mine transmission terminal, through the CDMA wireless network transmission to the telecommunications company network center PDSN equipment. If they are equal, UDP communication will be realized step by step; if they are not equal, prompt information will be displayed in the interface of Super Terminal. Then, all configuration information is displayed, and the program rechecks, putting the correct check value into the 1000H address space. Users can configure DTU based on prompts.

There are many underground equipments, which are complex and have different shapes. They can have influence on wireless transmission. It is difficult to analyze and verify them both theoretically and experimentally. At present, the more consistent conclusion is that the adverse effect of locomotive on wireless transmission is greater than that of wooden damper, and that of steel-wood hybrid damper is even greater. The steel damper can block the wireless transmission of the temporary wind wall, which has a small adverse effect on the wireless transmission, and the permanent wind wall has a large adverse effect. A part of the energy is reflected on the wall of the roadway, and a part of the energy is scattered due to the scattering of the rough surface. There is also a part of the electromagnetic wave energy being refracted by the consuming medium, resulting in rough loss. Thus, the multipath fading phenomenon is very serious. At present, due to the complexity of the wall surface roughness, research on this issue is relatively rare. The Kirchhoff method is used to study the rough surface with relatively gentle undulation, and the electromagnetic propagation problem of the rough surface whose surface mean square height is much smaller than the wavelength can be studied by the perturbation method. The loss when there is a turn during propagation is shown in Table 4 and Figure 4.

The loss of electromagnetic wave propagation in free space is shown in formula (1), where Lbs is the loss of free space defective parts, unit: DB; F is frequency, unit: MHz; and D is distance, unit: km.

$$\text{Lbs} = 32.45 + 20\lg F\,(\text{MHz}) + 20\lg\, D\,(\text{km}). \tag{1}$$

The transmission attenuation formula of electromagnetic wave in roadway is calculated, and the transmission loss of electromagnetic wave in back roadway is simplified as follows:

The transmission loss of electromagnetic wave in rock medium is LS, unit: DB; the size of attenuation coefficient β and electromagnetic wave angular frequency ω; rock conductivity σ; rock permeability μ; rock dielectric coefficient ε; and β the attenuation coefficient.

$$\text{LS} = \beta \times L = L\omega\sqrt{\frac{\mu\varepsilon}{2}\left(1 + \frac{\omega^2}{\omega^2\delta^2}\right) - 1}. \tag{2}$$

In the actual gob-side roadway, due to the need of production, there will be a large number of mechanical and electrical equipment and transport equipment, and many conductors are laid in the roadway, such as power supply and communication network (the main interference factor), water supply pipeline, locomotive rails, and electromechanical power equipment. The existence of these conductors will make the electromagnetic characteristics of the entire roadway change dramatically. Therefore, we the information shall be coded with motion vectors and sent to the cache. The quantized prediction residuals are then inversely quantized, and the forecasted image is summed up as the restored image of the current frame and put into the frame buffer as the reference frame of the next frame. At the decoder side, the reference frame in the buffer uses the decoded motion vector to compensate the motion and then adds the predicted residuals.

When the number of available bands is small, data transmission conflicts and interference between nodes are the main factors affecting throughput and distribution rate. When the available frequency band increases, the conflict and interference of data transmission between nodes decrease, and the band switching of nodes becomes the main factor affecting the throughput and distribution rate. The position coordinates in the fixed nodes of the roadway are obtained according to the longitude and latitude of the roadway map of the coal mine and are written into the nodes together with the node control program. The large amount of data that a message transmits in the network increases the possibility that it can reach the destination node correctly.

Finally, for multipath routing protocols with the purpose of effectively utilizing network resources, priority is given to the overall network condition, node energy consumption, and current packet transmission amount when performing route discovery and path selection. Thereby, it improves network performance, such as bandwidth allocation, congestion control, guarantee, and the like. The available frequency band information of all the previous nodes included in the packet and its available frequency band information are used to calculate the optimal frequency band, and the CRREP containing the path optimal frequency band selection information is unicast back to the source node. Of course, in order to ensure the time of route establishment, the packet will be discarded when the time of processing the packet CRREQ exceeds the defined time.

As a comparison of routing schemes, this section uses the original DSR protocol without SMM. In order to eliminate queuing delay and electromagnetic wave propagation delay interference, the queue length and bandwidth of each node are set at the same level. Time measurements are established for fair access to routing. In fact, wireless sensor networks do not necessarily provide higher data transmission capability by using all construction paths in a single channel due to the wireless interference between nearby nodes. However, data transmission through several paths may not take advantage

Table 4: Loss at a turn in propagation.

	Transmission (DB)	Loss (%)
Turn loss	6.38	11.02
Longitudinal conductor	5.92	9.13
Conductor and roadway	7.15	4.95

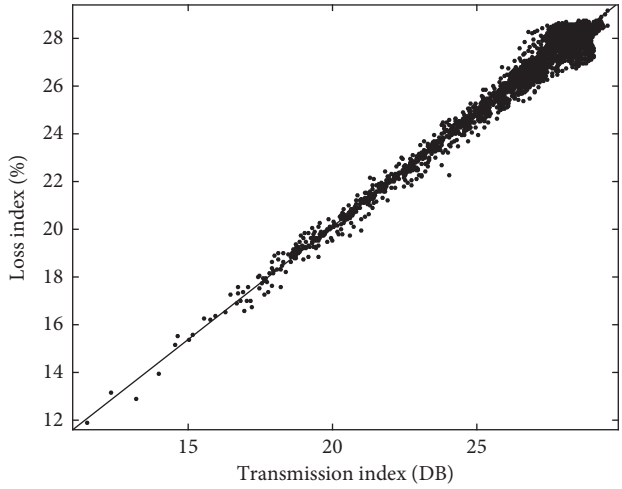

Figure 4: Loss at a turn in propagation.

of potential network resources. Once a set of paths is selected, the multipath routing protocol needs to decide how to allocate the selected paths. The data packet may be generated by the upper protocol of the node or the data sent by the previous node. If the data packet is generated by the node itself, it means that the node is the source node and initiates a routing discovery process. If the data of the previous node are received, then the available frequency band is selected to continue forwarding until the destination node receives the data. It is also the most complex part of the network protocol, where controller plays the core role. It is a combination of logic circuits on a programmable chip to achieve these functions. It provides a physical line interface to the microprocessor. By programming it, one can set how it works, control its working state, send and receive data, and build the application layer on top of it.

The real-time data acquisition node and the field interface layer nodes are monitored to form a distributed architecture. It has good effects in coal mine testing and application. After appropriate expansion and modification of software and hardware, it can also be applied to environmental monitoring, monitoring and control of oil extraction equipment, and monitoring of crop growth conditions. In the system design, the choice of the sensor is crucial because it is the premise and basis for monitoring the environmental characteristics, directly related to the life safety of the miners and the interests of the mining enterprises, taking into account the accuracy of the monitoring, the complexity of the installation, the external disturbances, and the size of the volume and other actual conditions. The server monitoring center data receiving flowchart is shown in Figure 5.

Location technology refers to the mechanism of determining the location of other nodes in the layout area and establishing spatial relationship between sensor nodes by relying on the limited location of known nodes, so as to calculate the movement of monitoring targets. When the number of available frequency bands increases, the source node and destination node will have more paths to choose. Choosing a better path can reduce the communication delay of the network. When there is only one available frequency band, the communication delay of the network will be long. Due to resource constraints of sensor nodes and high dynamic and low-power wireless links, the path is very prone to make errors. Therefore, path reconstruction can degrade performance. This is the main task of the multipath maintenance phase.

Path discovery can be divided into three different situations: one active path fails; all active paths fail; and a series of active paths fail. If the node monitors the data packet in the receiving band, it begins to prepare to receive the data message. If the node hears that the transmission band is busy, it indicates that other nodes are using the transmission band. If the node still insists on sending, it may cause transmission conflict. Therefore, the node does not send the datagram in this time slot and actively avoids collision. The signal is first split into high-pass and low-pass portions and subsampled; then, the previous step is repeated for the low-pass signal and cycled. The lifting scheme makes full use of the similarity between the high-pass filter and the low-pass filter to speed up the calculation. In some cases, the number of arithmetic operations can be reduced by a factor of two. The disturbance signal propagates directly into the node through the atmosphere of the roadway, and the attenuation

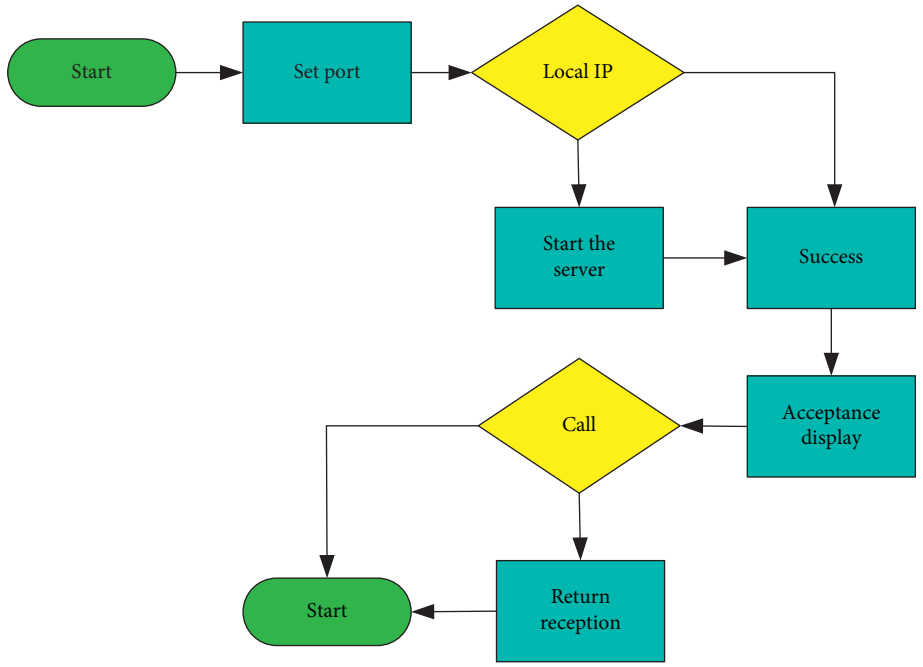

Figure 5: Data receiving flowchart of server monitoring center.

of the electromagnetic wave of the interference source is small, so the interference to the monitoring signal is large in this case. In another case, the receiving point is far away from the interference source, the interference signal enters the receiving point after being absorbed and dissipated by a relatively long path, and the interference effect is relatively small.

4. Conclusion

According to the characteristics of wireless sensor network, the wireless sensor network technology is applied to the underground mine safety monitoring and personnel positioning system. A set of wireless sensor network information acquisition, transmission, and location system suitable for coal mine environment is designed. The overall design and key technologies of the upper computer software of the mine safety monitoring system are as follows:

(i) Design and analysis of the software system include demand analysis, target requirements, and performance requirements

(ii) Overall architecture of the host computer software implementation

The propagation process is affected by three main factors: electrical parameters of the sealed wall, the compactness of the wall, and the thickness of the wall. Electromagnetic signal transmission along goaf roadway belongs to limited space transmission. The propagation process mainly depends on the electrical parameters of surrounding rock, the supporting form of roadway, the size of cross section, the inclination and roughness of roadway wall, the curvature degree of roadway, dust/mist droplets, and multifactor electromagnetic interference. If the transmission range of each frequency band is inconsistent, it is still necessary to study how to select the control frequency band or control the frequency band set to cover all neighbors. If different control bands are selected in different neighboring domains, the protocol needs to ensure that control messages between the two neighboring domains can reach each other. Considering the possibility of congestion in a control band, an algorithm can be designed so that the network can select the control band used in real time on several nodes' common frequency bands according to the perceived situation. In the management phase of the route, spectrum sensing, selection, and access are controlled in the program. If spectrum awareness can be increased, it will make the cognitive network better fit the actual situation.

4.1. Future Work. This network communication routing protocol which is designed for coal mining safety can be further optimized for future cases. It can be extended up to another level. The coal mining monitoring signals can then be used for a number of mines simultaneously. Similarly, the communication between different coal mines can be made much better by using such kind of protocols.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by JinHao Zhang, Min Chen, YaHui Liu, and PingJian Yao. The first draft of the manuscript was written by JinHao Zhang, and all authors commented on previous versions of the manuscript. All authors have read and approved the final manuscript.

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