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Research Article

A Novel Cognitive Opportunistic Communication Framework for Coal Mines

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The dynamic advancement and harsh environment of coal mines often result in intermittent or regional wireless connection between sending nodes and receiving nodes and then lead to the decrease of transmission success ratio and even failure. To solve this problem, the environmental cognition and best-effort transmission are both demanded. Here we proposed a novel communication framework for coal mines based on a cognitive opportunistic concept to address the wireless network communication problems in coal mines, which consists of the node mobility model in coal mines, cooperative cognition of the time-varying communication environment, and the opportunistic routing of intermittent or regional connection scenarios. To realize this framework, real time neighbor discovering mechanisms and mobility perceiving strategies, called environment cognition, must be deeply investigated to predict the trends of node movement. The obtained results of environment cognition are then used to analyze current channel characteristics in order to determine and set optimum communication system parameters and reduce the probability of intermittent or regional connection. To address those unavoidable situations of the intermittent or regional connection, the opportunistic routing mechanism is brought forward to provide relatively stable data transmission. Finally, as an example of cognitive opportunistic mine communication of this framework, personnel evacuation under an emergency is discussed.

1. Introduction

Coal production and consumption has been playing an important role in the energy industry of China. It is crucial for the safe and efficient production to monitor environmental parameters, equipment status, personnel information, production situations, and security status and send these parameters to the ground monitoring center in real time via the ubiquitous mine internet of things (MIoT). A mine roadway, comprised of rough coal, rock, and bolt-beam-mesh, has extensive branches and bending with narrow and long space. At the same time, a mine roadway is full of metal supports, large production equipment, transportation vehicles, and steel rails, resulting in strong multipath effects, serious fading, and significant interferences of radio wave propagation. Particularly, all equipment in a coalface must keep advancing throughout the mining process, which causes dynamic changes of the communication space [1]. Due to the aforementioned mine roadway characteristics, wireless communication systems used in mines face unique difficulties compared to those used on the surface, such as the following: (1) communication nodes may be damaged by coal, rocks, or humans, resulting in intermittent or regional network connections; (2) the time-varying physical communication space forces wireless channels into a time-varying state, resulting in intermittent network connections; and (3) the great amount of dust produced during the coal cutting process and the presence of large, moving metal equipment result in poor adaptation to wireless communication systems, whose main effect on communication systems is also regional or intermittent node connection.

To address the wireless communication problem of intermittent or regional connection in mine roadways, two critical difficulties must be resolved: adaptation ability of communication systems to the changing environmental parameters and the relatively stable transmission ability under an inevitable unstable condition of intermittent or regional connection. This paper proposes a novel cognitive opportunistic communication framework for coal mines to enhance the ability of the MIoT to adapt to the mine roadway environment and ensure that monitoring signal will not be interrupted by the harsh time-varying transmission environment, supporting and guaranteeing the construction of digital and intelligent mines. Compared to existing communication frameworks for ground applications, our framework includes components specific to coal mines to address the special communication difficulties met by the roadway. Compared to existing communication frameworks for coal mines, our framework includes models specific to special roadway sites and emergency situations based on opportunistic and cognitive technologies to deal with communication problems introduced by regional or intermittent connection.

Our major contributions are summarized as follows:

(1) We reviewed the state of the art of the wireless communication technologies in coal mines and revealed their characteristics and key challenges. Besides, we also analyzed the reasons why communications systems used in surface environments cannot be directly utilized in coal mines

(2) We proposed a cognitive opportunistic mine communication framework, which can adapt to the dynamic advancement and vulnerability of mining nodes and is thus of great significance to guarantee the successful communication

(3) Some key technologies were deeply investigated, such as the node mobility model in coal mines, cooperative cognition of the time-varying communication environment, and the opportunistic routing of intermittent or regional connection scenarios

(4) An application example of personnel evacuation under an emergency scenario was explored to demonstrate the effectiveness of the framework

The remainder of this paper is organized as follows. Section 2 surveys some typical wireless communication systems and their challenges in mines and proposes a cognitive opportunistic mine communication framework. Section 3 details the three key technologies involved in the proposed framework, namely, the construction of the node mobility model, cooperative cognition of the time-varying communication in the mine roadway, and the opportunistic routing of intermittent or regional connection scenarios. As an exemplary application scenario, Section 4 discusses the application of cognitive opportunistic mine communication for personnel evacuation in an emergency. Section 5 concludes the whole paper.

2. Cognitive Opportunistic Mine Communication Framework

2.1. State of the Art of Wireless Communication in Mines. Existing investigations into wireless mine communication have generally focused on the propagation characteristics of a wireless signal, network models, network protocols, and communication system development.

2.1.1. Propagation Characteristics of a Wireless Signal. Typical research methods in this field are ray tracing, waveguide theory, and experimental testing. Ray tracing is a method to investigate the transmission characteristics of a wireless signal by tracing the path of rays [2], which is often inefficient because of the strong multipath characteristics present in most mines. The waveguide method regards a mine roadway as a waveguide in order to study the transmission characteristics of a wireless signal [3]; however, the complex mine environment often produces significant differences between results obtained by a waveguide theoretical model and those obtained by practical testing. Experimental testing is a method often used to obtain such statistical characteristics as path loss and delay spread of roadways by conducting field investigations [4]; experimental conclusions are often closely related to the experiment locations and signal frequencies.

2.1.2. Network Models. Typical mine network models include chain models and mesh models. The chain model deploys wireless nodes linearly along a roadway corresponding to its linear characteristics [5], but it is more likely to form energy holes. In a mesh model, some nodes such as access points act as backbone nodes, interconnecting with each other to form a mesh network [6]; some access points which have accessibility to the wireless sensor networks are referred to as gateways. Thus this type of network is essentially a mixed network composed of wireless and wired components which requires support from transmission cables [7].

2.1.3. Network Protocols. The purpose of protocol design is typically to expand network coverage, improve success ratio of message transmission, and reduce energy consumption or transmission delay. Network coverage is primarily implemented by studying different node deployment methods [8], which must take into account the relationships among the coverage model, the roadway width limit, and node redundancy. Success ratio of transmission and network energy consumption are often the greatest challenges to successful wireless network communication [9]. In particular, some nodes in a chain network model will not work any longer once their energy becomes depleted [10]. Finally, transmission delay is related to the type of data and the method of relay node selection [11].

2.1.4. System Development. Primary types of wireless communication systems in mines include ultra-low-frequency, through-the-earth communication, medium-frequency induction communication, leaky feeder communication, personal handy-phone, ZigBee, and Wi-Fi systems [12]. These systems are typically transplanted from ground systems without consideration of the special difficulties presented by the mining environment. Many systems are unable to adapt to the complex, changing communication environment of mines and may only prove to be effective in a part of a mine or roadway, but ineffective in the overall mining environment [13].

The reason why wireless communication technologies on ground cannot be directly applied to mine roadways is that communication systems must be able to perceive the complex and changing environmental characteristics around them and tell these results to their communication partners in

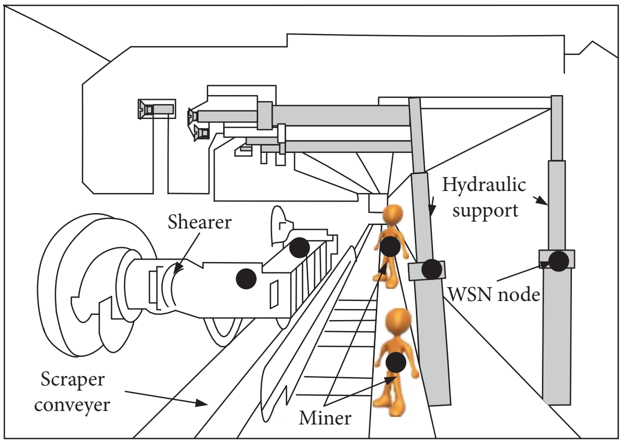

Figure 1: Coalface and its WSN deployment.

a timely manner, so as to increase the cooperative communication abilities. Traditional wireless communication systems which utilize relatively fixed parameters such as communication frequency, modulation method, and bandwidth are often unable to adapt to the aforementioned dynamic and various changes in a mining environment. Additionally, in a complex environment like the mine roadway which contains many devices as well as various geological structures and roadway interconnections, data transmission and reception between wireless communication nodes must follow a suitable routing protocol to be dynamically adaptive to the environment.

Take the coalface, the forefront of coal production, as an example. To enable the coal cutting, roof supporting, and coal transporting, all miners and mining equipment (such as the shearer, hydraulic support operator, and scraper conveyor operator) must cooperate closely. The dynamic advancement of the equipment at the coalface forces the communication space into a time-varying state, making it impossible to lay additional wired communication cables in a timely manner. Under these conditions, wireless communication must be flexible to deploy and easy to extend as the mining face advances. For this purpose, wireless sensor network (WSN) nodes can be deployed on the hydraulic supports, shearer, and miners (Figure 1) [14]. These nodes move along with the equipment and miners, leading to a linear (chock-type support) or bilinear (chock-shield support) topology based on the linking conditions. Because of the extensive existence of the reliable wired/wireless networks in tailgates or headgates, the wireless sensor network at the coalface can easily transmit its messages to access points in gateways and then to other regions of the mine or ground information center. That is, these access points will be the sink nodes of the WSN in a coal mine.

Unfortunately, the information at the coalface cannot always be transmitted to the sink node due to the intermittent or regional connections, which is a frequent situation encountered in mine roadways. For example, coal production may make some network nodes occasionally damaged and sudden accidents can also induce network coverage failure in some areas. The most common method to maximize the network coverage in mine roadways is to increase node density, which can not only result in increased costs of system construction and operation, but also lead to increased network management complexity. Therefore, it is imperative to investigate new paradigms of wireless network design for use in mines.

2.2. Cognitive Opportunistic Communication Framework for Coal Mines. Actually, intermittent or regional connection does not mean absolute or permanent failure of communication between the transmitting and receiving nodes [15]. The negative effects of unstable link quality will be substantially offset by a communication system with the ability to dynamically cognize environmental features and self-adaptively adjust communication parameters based on the results of cognition [16], reducing the probability of intermittent or regional connection. Considering that node movement creates a meeting opportunity for nodes located in different regions, data can be transmitted to other nodes that are more likely to meet the target node even in the case of intermittent or regional connection; such information can then be stored, transported, and forwarded for delivery to the target node [17]. An opportunistic communication network based on cognition of the mine environment can adapt to the dynamic advancement and vulnerability of mining nodes and is thus of great significance to improve successful communication.

At present, few studies have been reported which investigated self-adaptive mine communication based on opportunistic communication. Ji Luo conducted a study on delay-tolerant communication in coal roadways [11], in which the tramcar in the mine roadway was used as a mobile sink node, and the sensors deployed in the roadway remained stationary; the tramcar moved along the deterministic path in the roadway to directly collect data from sensor nodes, thus avoiding multihop transmission. However, this study only considered the specific circumstances of a moving tramcar and stationary nodes, while practical applications must also take into account the moving nodes which represent underground miners. The reported study also failed to consider the effects of dynamic changes in the physical communication space and did not address the environmental self-adaptation problem in mine roadways, thus failing to address the challenges posed by intermittent or regional connection.

Three key problems must be addressed in order to implement cognitive opportunistic mine communication:

(1) The establishment of the node mobility model based on the node movement characteristics and spatial constraints of mines: this model will serve as the basis for cognition of the mine environment and the implementation of opportunistic communication. The difficulties implementing this model include the state transition mechanism and performance bounds of the model, its concordance with actual motion, influential factors, and their interaction mechanism of the model

(2) The dynamic determination of optimum parameters for communication links to reconfigure the communication

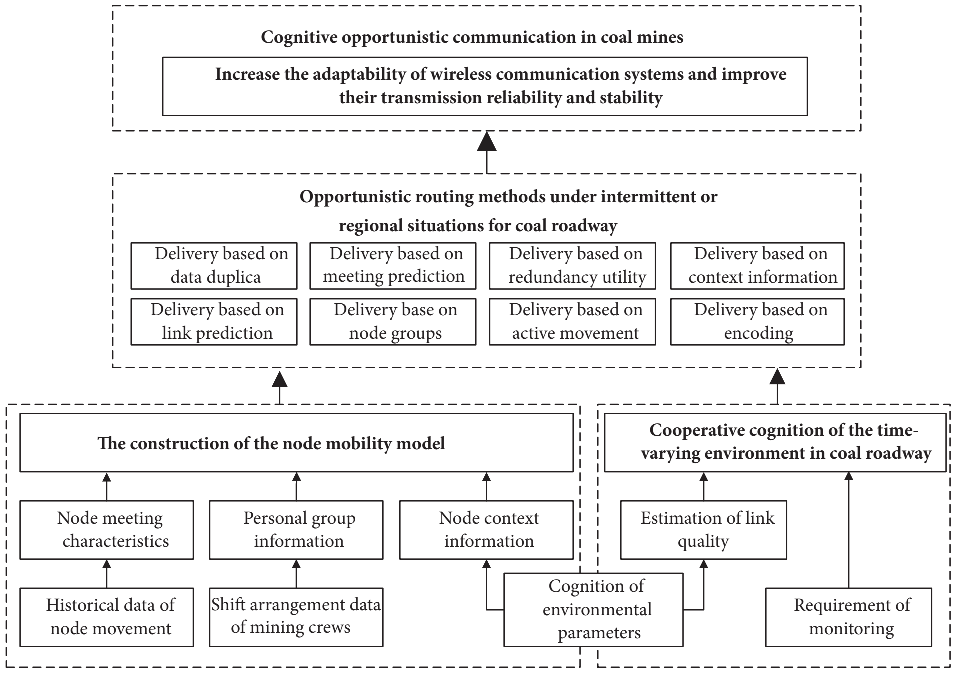

Figure 2: Cognitive opportunistic communication framework for coal mines.

system automatically: this is essential to the environmental self-adaptation of wireless communication systems for mines and to the reduction of intermittent or regional connection. The main challenges are the modeling of the joint optimization in order to dynamically determine and configure the optimum communication parameters

(3) The design of opportunistic routing algorithms accurately reflecting the characteristics and requirements of mines based on the influential factors of transmission performance and their operational mechanisms: this is necessary to relatively stable data transmission of wireless communication systems for mines under intermittent or regional communication conditions. The challenge presented by this problem is that there are too many various factors which must be considered when designing such type of algorithms

Here an opportunistic mine communication framework is proposed; see Figure 2. First, historical data of node movement achieved by positioning systems are used to determine and analyze node meeting characteristics such as the interval and duration of node meetings. The work arrangement of mining crews is utilized to investigate the groups to which different personnel belong. The cognition results of environmental parameters are exploited to obtain contextual information regarding the node circumstances. The analyses described above as well as the physical roadway structure make it possible to construct the node mobility model. Second, a node timely determines the available channels between itself and its neighbor nodes according to the perceived environmental parameters. Based on the monitoring requirements of the ground monitoring center and channel estimation results of mine roadway, the communication system parameters are adjusted to implement its self-adaptation to the mine environment. Finally, based on the established node mobility model and the results of communication environment cognition, the opportunistic communication mechanism of mine roadways can be investigated and effective opportunistic routing algorithms can be designed to implement stable data transmission under regional or intermittent connection conditions.

To address the challenges faced by the proposed architecture, Section 3 will discuss the construction of the mobility model for moving nodes in mine roadways, as well as cooperative cognition of the time-varying communication environment and the opportunistic routing of intermittent or regional connection scenarios.

3. Key Technologies in Cognitive Opportunistic Communication in Mines

3.1. Construction of the Mobility Model for Mobile Nodes in Mine Roadways. Data transmission in a mine roadway is primarily affected by transmission distance, the node mobility model. and neighbor scanning frequency [18]. Additionally, much data is closely related to the contextual information of nodes and demonstrates strong temporal or spatial characteristics [19]. Therefore, discovery of neighbors, the perception of node mobility, and construction of a mobility model serve as the foundations for environmental cognition. The synchronous neighbor discovery methods are not appropriate for a mine roadway because the assumption of one node transmitting and one node receiving does not necessarily hold true, particularly in a coalface. Besides, it is essential to carefully investigate the scanning frequency of neighbors to make a trade-off between energy consumption and information timeliness.

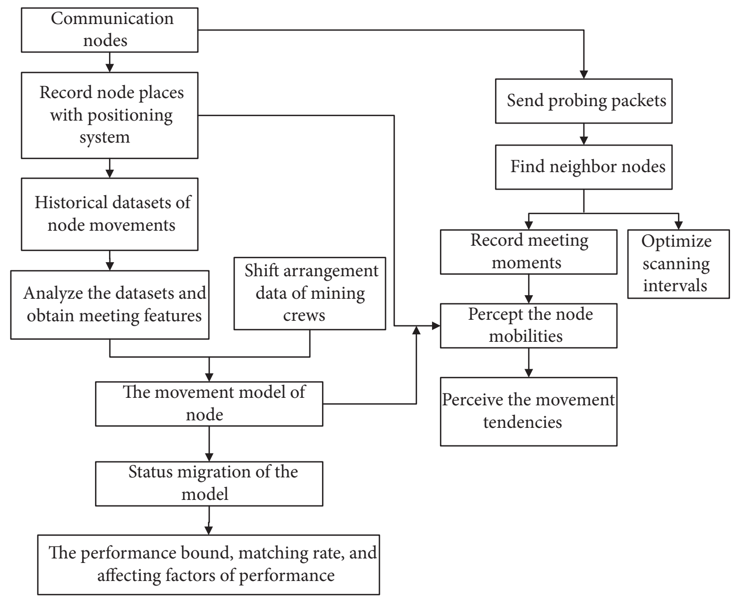

Figure 3: Construction of the mobility model for mobile nodes in mine roadways.

Mobility models are the basis for movement perception and the design of a routing algorithm. Current studies of mobility models have primarily focused on discovering the distribution characteristics of meeting intervals and durations [20] and the establishment of network sequential diagrams reflecting changes of network topology [21]. Experimental data have also been used to study the characteristics of information transmission paths in order to determine the temporal-spatial correlation between nodes [22]. Traditional mobility models based on random movement assume that both destination and velocity are random; this is characterized as Brownian motion, such as that employed by the random waypoint model (RWP) and random walk model (RWM). This type of mobility model facilitates the theoretical derivation of performance bounds; it is very flexible and its movement characteristics can be extended by making changes to the model parameters. However, this type of model cannot capture the actual movement patterns of moving objects in mine roadways. The tramcar, shearer, and hydraulic support in a mine roadway move according to a highly regular pattern, but the movement of a miner is both regular and random due to the constraints of their job types and working hours. Existing mobility models cannot fully reflect these characteristics, and further study must be conducted to explore the mobility models of nodes based on the characteristics of mine roadways to provide guidance for the design of opportunistic routing algorithms.

First, the existing positioning system is used to collect the location and time information of the moving nodes in the mine roadway in order to obtain historical datasets of node movement (Figure 3). The status distribution and meeting intervals and durations of nodes at a given moment reflect the temporal and spatial characteristics of opportunistic networks, which are of great significance to data transmission. These studies help solve [23, 24] (1) which nodes frequently meet the current node and are thus candidates for relay selection; (2) which nodes have social and group connections which may indicate a greater willingness to communicate cooperatively; and (3) how long a meeting lasts, in which an optimal time value will allow complete yet efficient communication.

A mobility model can then be designed based on the obtained statistical characteristics. For example, the movement of nodes in a mine roadway can be modeled as a temporally correlated Markov process, which is then validated by experimental data. If the states of a message located at node i and node j are called current state and next state, respectively, then its transition from the current state to the next state corresponds to a data transmission scenario. The period of time spent awaiting the transition from one state to another represents the meeting interval, and the period of time spent in the designated state represents the meeting duration. Different states correspond to different mine locations, and state transitions correspond to location migration. Transitions into and out of the same state demonstrate identical movement characteristics, while transitions between different states demonstrate different movement characteristics. A feedback mechanism can be introduced to the state transition process in order to mitigate the fluctuation of motion patterns in different locations. Node mobility can thus be perceived and node movement can be predicted based on the node mobility model and node discovery mechanism.

3.2. Cooperative Cognition of the Time-Varying Communication Environment of Mine Roadways. Due to the dynamic changes in the physical space and the harsh working conditions of mines, the wireless links in mine roadways are subject to sudden, significant changes, which can result in the loss or increased delay of data. Environmental cognition helps enhance the adaptation of communication systems

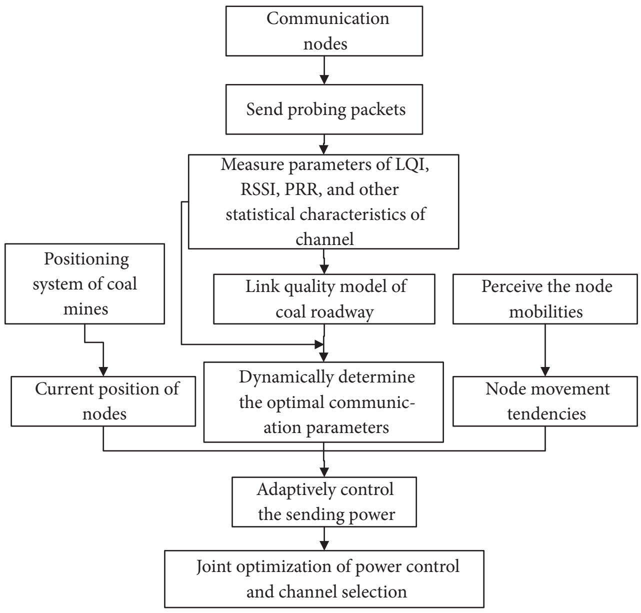

Figure 4: Cooperative cognition of the time-varying communication environment of mine roadways.

to environmental changes. Once link quality reduces, the communication system can adjust its parameters to adapt to the current surroundings in order to avoid intermittent connection. For this purpose, it is essential to estimate the link quality in real time [25] in order to adjust the communication parameters to optimum values in a timely manner. For example, the power of transmission systems can be improved to increase the one-hop transmission distance in order to improve the success ratio of data transmission under poor link quality or relay failure conditions.

However, higher transmission power also results in greater energy consumption and leads to greater interference to neighbors on the same frequency [26]. A self-adaptive power control algorithm may be designed to reduce energy consumption (Figure 4) and to enable nodes to establish and maintain connection using minimum power requirements. Power control and channel selection must be jointly optimized in order to reduce interference [27] and must be designed as a distributive, dynamic algorithm which may employ game theory or the machine learning method based on local node information such as local signal-to-noise ratio. Both environmental cognition and parameter adjustment require that nodes engage in explicit or implicit information exchange when they meet [28], leading to a cooperative mode based opportunistic cognition and adjustment.

To implement environmental parameter cognition, nodes must effectively perceive the communication environment and adjust parameters based on the environment, user goals, and node capabilities [29]. However, it must be noted that environmental cognition cannot be equated with environmental perception; the latter simply involves parameter acquisition, while the former involves decision-making based on perceived information [30], even in situations in which the acquired environmental information is incomplete.

Next, algorithms can be designed to achieve the collaborative reconfiguration of communication parameters based on link estimation, the current optimum parameters of the link characteristic model, and the monitoring requirements for mines in order to appropriately adjust the communication system parameters such as encoding schemes (i.e., differential binary phase shift keying (DBPSK), differential quadrature phase shift keying (DQPSK), and complementary code keying (CCK)). These algorithms may consist of three engines: an environmental cognition engine, an application interface engine, and a calculation and decision engine. The environmental cognition engine is used to perceive environmental information, the application interface engine receives monitoring requirements from users, and the calculation and decision engine is used to reconfigure node parameters based on the environmental information and the user requirements. Link estimation and scheduling must be characterized by passive scheduling and triggered by changes in communication parameters; active link scheduling can also be implemented based on user requirements.

3.3. Opportunistic Routings of Intermittent or Regional Connection Scenarios in Mine Roadways. If the decline of data transmission performance does not result from the link degradation but from link interruption, the studies described above will not be enough to ensure data transmission. As a possible solution, node movement characteristics and the spatial constraints of mine roadways must be explored in order to design an efficient opportunistic routing method. In the field of opportunistic routing, existing studies have extensively focused on the forwarding mechanism based on a message replica. This forwarding mechanism creates a balance between transmission delay and resource consumption by controlling the number of copies [31] or calculates the probability of node meeting based on historical information and link prediction before forwarding the data to the nodes that are more likely to meet the destination node [32].

Node movement in a coal mine consists of highly correlated cooperative movement that seeks to accomplish production goals. In the coalface, a shearer driver operates the shearer to cut coal, and the hydraulic supports advance to support the roof during the mining process. The mined coal is then transported to the belt via the scraper conveyor and then lifted onto the ground after transportation via the belts or tramcars. This overall process involves driving, mining, transportation, ventilation, and drainage and thus requires a great number of personnel and lots of equipment. The movement of the equipment and personnel includes both regular movement (such as that exhibited by the shearer, hydraulic support, and tramcar) and mixed regular and random movement, such as the movement of the operators. Overall, the majority of node movements in mine roadways is characterized as regular movement. With the help of mobility models, opportunistic routing algorithms can be designed based on meeting prediction, copy distribution, and context distribution mechanisms; see Figure 5.

Additionally, nodes in a mine roadway often transmit data in a linear, directional manner. For example, the data

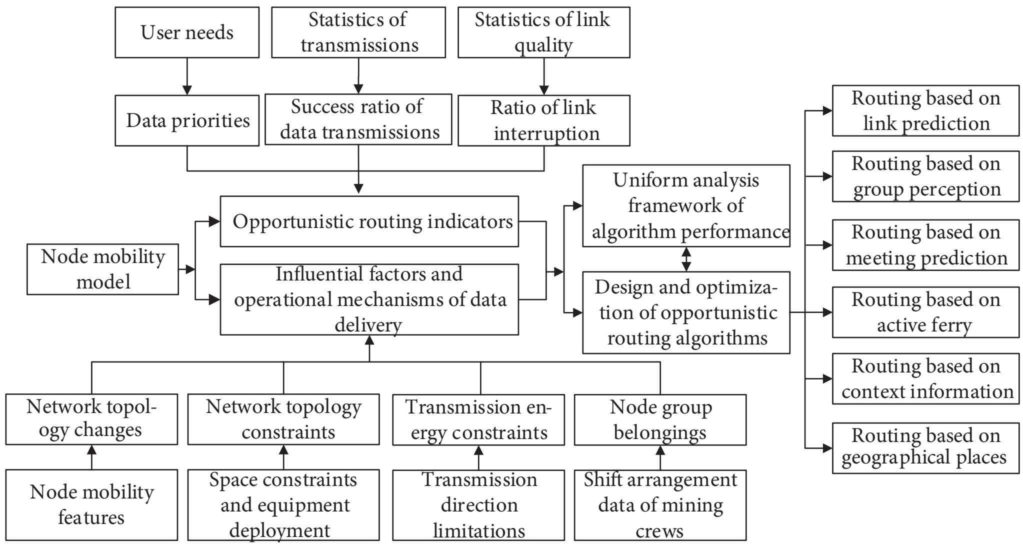

Figure 5: Opportunistic routings of intermittent or regional connection scenarios in mine roadways.

transmission of the coalface always heads to the sink node in the headgate or tailgate. Therefore, it is appropriate to design an opportunistic routing algorithm based on geographic locations. The tramcars and personnel which partake in cyclic reciprocating motion provide opportunities for data transmission between nonadjacent equipment and personnel which can serve as the ferry node between disconnected nodes. Furthermore, the established node mobility model incorporates historical meeting information and node meeting characteristics. Based on these various characteristics, different utility indicators can be designed for opportunistic transmission. According to the results of communication environment cognition, a set of relay candidates can be determined for the current node in order to implement opportunistic transmission based on link prediction. The success of message transmission as well as the energy consumed by transmission is greatly affected by the number of nodes in a mine roadway, the number of messages to be transmitted, and message size. Finally, the parameters of the physical layer, link layer, and network layer can be combined [33] to design cross-layer opportunistic routing algorithms.

4. An Exemplary Application: Personnel Evacuation Based on Cognitive Opportunistic Communication in an Emergency

Cognitive opportunistic communication is of great significance to the mobile acquisition of mine environmental information as well as the continuous monitoring of miners' health information, particularly to disaster prevention and reconstruction of a mine internet of things designed for ordinary activities. As an example, this section discusses the application of cognitive opportunistic communication to the transmission process of disaster information in an emergency, such as a coal mine flood, the presence of excessive gas, and production accidents. In case of an emergency, the sensor node (carried by a person) which first perceives the emergency must quickly transmit the information about when and where the accident took place and the urgency degree of the accident to nearby personnel and instruct personnel to evacuate as quickly as possible, as shown in Figure 6.

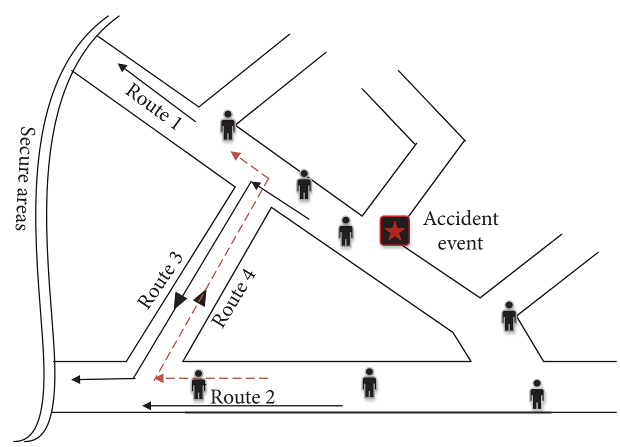

Figure 6: Personnel evacuation under emergency scenarios.

However, some nodes in the accident region may not be in normal working status as a result of the emergency, making the accident information incapable of being transmitted. However, the sensor nodes carried by moving objects (e.g., personnel or vehicles) can detect the accident information and subsequently transmit the information through cognitive opportunistic communication during evacuation.

(1) The first person who perceived the emergency will first evacuate from the area of danger. As more people are met during the evacuation and information is exchanged,

more people will evacuate. In this way, information is diffused during the evacuation process

(2) A vehicle typically moves in a periodic motion along a determined path at a determined rate in order to transport goods or personnel. If no person is in the vehicle, the vehicle will continue to move until it meets a person to which it will forward information regarding the accident. If a person is present in the vehicle, the person can choose to evacuate by the vehicle continuously or get off and evacuate on foot

Emergencies that occur in a mine roadway often affect one or more areas of the roadway rather than a single place, such as in the case of a coal mine flood or the presence of excessive gas. Therefore, personnel must move toward a designated safe area. For example, as shown in Figure 6, there are four designated evacuation routes. Following route 1, a person can evacuate directly along the upper oblique straight roadway; following route 2, a person can evacuate directly along the lower long straight roadway; following route 3, a person can evacuate along the lower roadway after passing through the upper roadway and the middle roadway; following route 4, a person can evacuate along the upper oblique straight roadway after passing through the lower roadway and the middle roadway. In an actual mine roadway, different roadway combinations may generate many escape routes; a person can evacuate quickly and safely only by following a designated optimum path.

As the popularity of the mine internet of things increases, personal terminals used for perception in mines have developed increasingly diverse functions and strong computing capabilities [34]. A roadway map can be stored in personal terminals and advice about best escape routes can be offered in case of an accident, based on the perceived information of the accident scenario. A circumstance in which all personnel evacuate along the same route should be avoided in order to avert congestion or collision, and the cognitive opportunistic abilities of the communication system can recognize the mine environment in real time in order to plan, guide, and proactively evaluate optimum escape routes and to ensure balanced traffic distribution. This indicates that cognitive opportunistic mine communication is of great importance to accident information spread and evacuation path optimization in an emergency.

It must be noted that all personnel who follow the feasible escape routes from the accident location to the pithead must receive information about the accident. However, personnel in roadways that are positioned directly opposite the escape paths cannot receive information about the accident because they cannot encounter any moving objects with the event information. This problem can be addressed from the following perspectives:

(1) Mine trunk roadways are typically covered by wired industrial networks, while some of these roadways are also covered by Wi-Fi wireless networks and opportunistic communication is typically implemented at the endpoint of a coal mine such as the coalface. If an accident occurs at the endpoint of a coal mine, personnel nearby will see or hear the accident, prompting themselves to shout to warn others of the accident. As a result, all personnel in this region can quickly evacuate, prohibiting a circumstance in which the location of the accident cannot be communicated

(2) If an accident occurs in an area covered by a traditional wireless network (such as a Wi-Fi, 3G, or 4G network) resulting in damage to some aspects of the wireless network, personnel in the underground coal mine will form an opportunistic network during evacuation, while personnel located behind the accident location can receive accident information via the mixed network

(3) If a person is evacuated to a region effectively covered by a network, the accident message can be transmitted to the ground control center via the backbone network, which then notifies all underground personnel of the accident situation via voice broadcast or direct transmission of the message to personal terminals. Of course, if an area of a roadway collapses, the miners behind the area of the roadway cannot evacuate and must wait for rescue no matter whether they have perceived the accident situation or not

5. Conclusions

The communication parameters of wireless mine communication systems, such as communication participants, signal transmission environment, and node mobility model, greatly differ from those of ground wireless communication systems. Cognitive opportunistic means, therefore, play crucial roles there, because their self-adaptive recognition mechanisms for mine environments and the opportunistic communication abilities keep communication systems informed about the time-changing environmental or communicational parameters. Keeping this issue in mind, we proposed a novel wireless communication framework for coal mines based on the cognitive opportunistic communication of the internet of things, which includes three key elements, namely, the node movement model constructing, the cooperative cognition of time-varying communication environments, and the opportunistic routing of intermittent or regional connection scenarios. Eventually, an example of personnel evacuation under an emergency scenario was explored to validate the usage of this framework. Subsequent studies will involve the theoretical investigation and field experiments based on the movement data collected from mine nodes, as well as the design of practical node mobility models, routing methods, and the system prototype of the cognitive opportunistic communication system for mines.

Data Availability

All data included in this study are available upon request by contact with the corresponding author.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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