Mine Monitoring System using Wireless Sensor Networks

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ABSTRACT

For the importance of monitoring system in mine, this paper describes the application of wireless sensor networks for mine safety monitoring. Schemes for clustering and mobile node based on the characteristics of mine wireless sensor networks are proposed in roadway. The simulation results show that the clustering and mobile node schemes achieved in this paper can meet the requirements of mine, and reduce energy consumption of both mobile nodes and other nodes. So these schemes successfully improve the practical ability and stability of the wireless senor networks, which are more suitable for coal mine monitoring system.

Index Terms—Coal mine, Wireless Sensor Networks, Clustering, Mobile Node

I. INTRODUCTION

As we know, the environment and work condition of coal mine are bad, at the same time there exists various disasters underground. Especially in recent years, coal mine disasters occur frequently, which results in great casualties and economic losses, so the safety problems of coal mine is very serious in our country. The present mine monitoring systems [1] tend to be wire network systems, which are not suitable for all the parts of coal mine. It is not easy to wire there. Moreover, wire systems can not be moved with the moving of mining area. The most important one is that it is inconvenient to carry out emergency rescue during mine disaster. Therefore, it is necessary to adopt effective technology to mine monitoring system.

Wireless sensor networks [2] are promising research fields with applications in several areas. Wireless sensor networks are composed of large numbers of tiny, inexpensive and low-power sensor nodes, which are battery powered, and with limited on processing and storage capabilities. With the developments of sensor technology, electronics, modern network and wireless communication technology, wireless sensor networks are designed and developed to be more feasible for mine monitoring. In contrast with existing mine monitoring networks, wireless sensor networks have the characteristics of self-organizing, easier for deployment, wireless transmission and low-cost. Many scientific researches are focused on wireless sensor networks in the recent years, but a few are made to meet the requirements of mine monitoring.

In this paper, the application of wireless sensor networks in coal mine monitoring is described. The paper is organized as follows. Section 2 is a brief introduction to the application of wireless sensor networks. In Section 3, we propose a method of clustering for wireless sensor networks in roadway. In the section 4, we present t mobile node of wireless sensor networks, which focus on the actual demand of mobile devices monitoring at mine face. Finally, we get the conclusions of the paper.

II. WIRELESS SENSOR NETWORKS IN MINE

Based on the characteristics of coal mine, the application of wireless sensor networks in mine is designed.

A. Application Area of Wireless Sensor Networks

Wire network is effective in many parts of coal mine for its powerful and high rate. For example, mine-used optical fiber is characterized by large capacity, no electromagnetic interference, wide frequency band, water proof and unrepeated long-distance transmission. However, it has disadvantages for certain places where have complex topographic features and equipments layout, such as the face and the goaf of coal mine. Limited by complex conditions underground, data transmission is more suitable to use wireless sensor networks. Wireless sensor networks can be densely embedded and sense the environment situation in these areas [3], which is fit for mine face. It can satisfy complex environment and nodes frequent mobility with no cabling. But its anti-interference ability, transmission distance and channel capacity is inferior to wired network.

So we use optical fiber in the main shaft, placing wireless sensor networks in the branch roadway [4]. So it has large capacity and mature technology of fiber network, as well as the features of wireless sensor networks, which improves the system performance. Underground of mine, nodes of wireless sensor networks self-organize rapidly, and sense the concerned object in bad environment. These tiny nodes process and send data to sink node with mobile communication modules, which combines wireless sensor networks and other networks. Then data is transmitted to fiber backbone, which bridges to aboveground management center through Internet or satellite. So

the system is sufficient to guarantee the monitoring requirement of mine monitoring. Wireless sensor networks applied in the environment of mine roadway are shown as Figure 1.

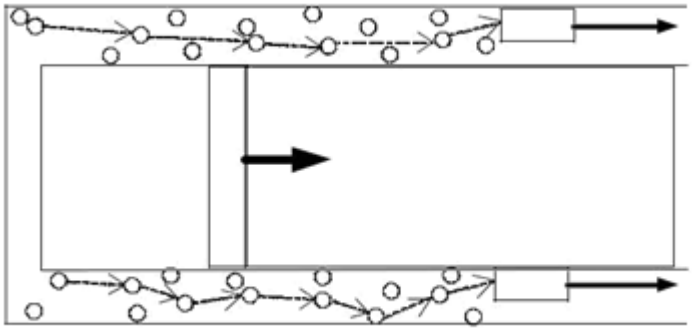


Figure 1.Wireless sensor networks applied in roadway

B. Monitoring Functions of Wireless Sensor Networks

Any safety parameters of coal mine can be obtained by wireless sensor networks. According to monitoring requirements of mine and China "Coal mine Safety regulation", monitoring functions of wireless sensor networks are as the followed aspects.

• Temperature of the air: The temperature of mine face air is no more than 26 ℃ , while temperature of electromechanical chamber is no more than 30℃.

• Wind speed of roadway: Wind speed not only affects radiating of worker, but also impacts on the safety production in mine. So there are explicit stipulation in mine, the minimum wind speed is 0.15m/s, whilst maximum is 15m/s.

• Gas concentration: Gas disaster is one of the main disasters which threaten the security of mine, so sensor nodes should mainly monitor it. For example, the concentration of CO is 0.0024, and NH3 is 0.004.

• Mine drainage: Networks should monitor the water level of roadway.

• Recognition of worker card: Networks need to recognize and send the data of every worker's card information.

• Monitoring of equipment moving speed: Nodes can go with the moving equipment, so the speed can be measured.

• Image extraction: Some nodes can get images or even video form CCD camera, so people aboveground can know the situation underground.

III. PRACTICAL TEST OF COMMUNICATION DISTANCE

MICAZ node produced by Crossbow Company is tested in roadway. MICAZ node has routing function, and can be connected to gas sensor, pressure sensor, temperature sensor, and other kinds of sensor module [5]. Crossbow Company provides MIB600CA node as the sink node, which has 10 ／ 100 Base-T Ethernet interface. The network in practical test has 1 MIB600CA node and 5 MICAZ nodes, and the carrier frequency of node is 2 ． 4 GHz, and the maximum data transmission rate is 250 kb ／ s. From the test we get the result of practical communication distance of node in different environments. Tests are taken out in ordinary building and roadway in Yan Zhou Mine. In ordinary building, we test the straight corridor and corridor with corners. Straight corridor has no corner. The test roadways are classified into two kinds, one is the main roadway and the other is crossheading. The test is based on the packet loss rate is 10%, and part of the results of communication distance are shown in Table I.

TABLE I. communication distance of node

Communication distance (m)	**Packet loss rate *10%***	**Average Value**
Straight corridor	32.0	31.3
	31.5	
	30.5	
Corridor with corners	13.5	13.7
	13.5	
	14.0	
Main roadway	12	11.7
	11	
	12	
Crossheading	22	20
	21	
	23	
Normal area	60-150 [6]	

So we can know that the communication distance of node is over 100 m in normal environment, while in roadway it is much smaller. So we set the communication radius of node of 30 m in the later discussion and simulation. It should pays attention to some aspects of mine network. For example, it needs to locate redundant nodes as relaying node at the corner of roadway. The redundant nodes can reduce the blind area, which can have no sensor module to be a simple structure and low cost.

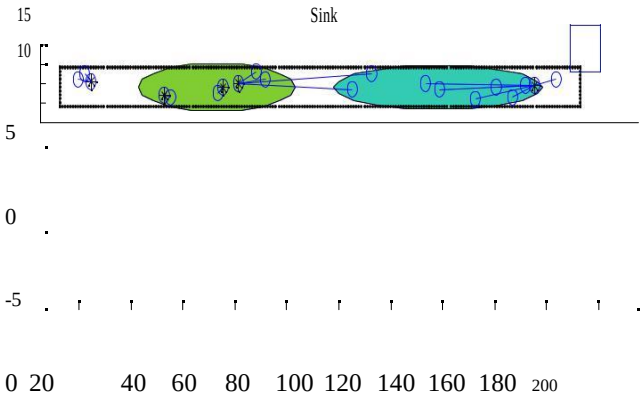
IV. REQUIREMENTS OF MINE

The environment of mine is special for its high loss and interference, which leads to high and imbalanced energy consumption. These problems can be solved by replacement of node, data fusion [7] and effective routing [8]. But we need to concern the work condition and requirement of Coal mine. For example, in roadway, the neighboring nodes may work for different mine face and monitoring demands. But wireless sensor networks in normal occasion do not pay attention different part inside of the network. The mine equipments are always moving, while normal networks have not considered it. So the mechanisms of Clustering based on working area and mobile node are put forward.

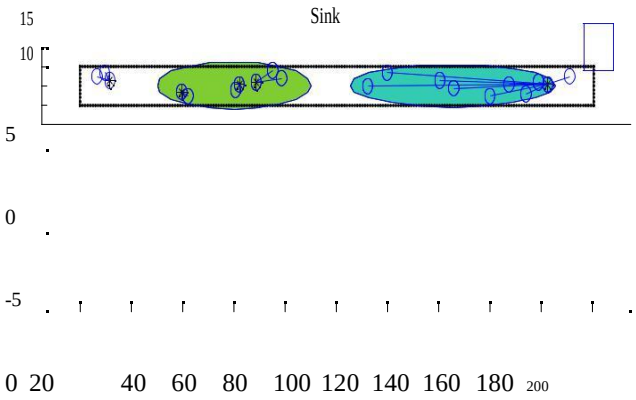
A. Clustering based on working area

The roadway is so long that it may have different working areas. In different working areas, the network may concern different monitoring aspects. As Figure 1, there are two large elliptic in the monitoring area. The left elliptic area is mainly focus on the fluctuation of temperature, while the right elliptic area pays more attention to the gas concentration.

The normal clustering algorithms are mostly based on residual energy of nodes, routing distance, and signal intensity and so on. So the result of normal clustering algorithms [9] is that nodes in working area are often in the same cluster, just like Figure 2 (a). We design a clustering algorithm based on signal intensity and working area. The attribute of nodes' working area can be set by manual-adjusting platform, and the node can perceive the nearby nodes' attribute of working area automatically. The result of clustering based on working area is shown as Figure 2 (b).



(a) Clustering based on distance



(b)Clustering based on working area Figure 2. Clustering of roadway

Figure 2 (a) shows the normal clustering result, nodes with different monitoring demands and sensor modules are divided into the same cluster. So the data dependence is small in different working areas, which goes against data fusion and analysis. Figure 2 (b) shows clustering based on working area; one cluster is in only in one working area. So the data gathered by one cluster has significant correlation, which is helpful to data fusion and information analysis. So the clustering based on working area fits the requirement of mine monitoring.

B. Mobile node in roadway

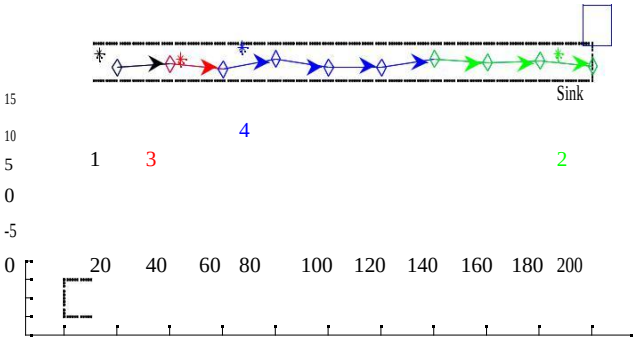
Coal face and some equipment are moving, so it is necessary to make move mechanism for node in mine wireless sensor networks. Move mechanism is on the demand of mobile monitoring. For example, worker in mine can take node with himself around the concerning area to meet the real-time monitoring request.

Mobile node enters and exits cluster when the equipment moves. For wireless sensor networks in normal environment, the motion directions of nodes are complex, and there are many choices of the next cluster which the mobile node will enter. But the movement of node in mine is simpler: First, the width of roadway is small, and the length is long, so the motion directions of nodes in roadway are almost horizontal. Second, the next cluster which the mobile node will enter is his former one or post one. Entering and exiting of mobile node cost much energy, so it needs to avoid entering and exiting cluster frequently. The effective way to control the energy consumption of mobile node is to choose optimum next cluster. The methods for next entering cluster based on nearest cluster and farthest cluster are compared.

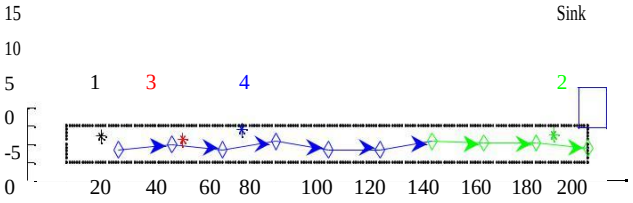
• Nearest cluster algorithm for mobile node entering (NCM): When the mobile node is out of the transmission range of its present cluster head, it exits the present cluster. Then it chooses the nearest cluster head to enter, and updates its related information.

• Minimum entering clusters algorithm (MECM): When the mobile node is out of the range of its present cluster head, it exits the present cluster. Then based on Dijkstra algorithm, it finds the path which has the minimum hops to the end of the network. On that path, the cluster head which is the farthest on it motion direction and within the transmission range of mobile node is the next cluster. At last updates the related information of mobile nodes.

Figure 3 compares Nearest cluster algorithm and Minimum entering clusters algorithm for mobile node entering, a mobile node move from 0-200 m in roadway.



(a) Nearest cluster algorithm



(b) Minimum number of entering clusters algorithm Figure 3. Mobile node

From the result of Figure 3, we can know that Nearest cluster algorithm makes mobile node enter and exit four different clusters, and Minimum entering clusters algorithm makes mobile node enter and exit two different clusters.

The result indicate that mobile node of NCM enters and exits clusters frequently, while mobile node of MECM enters and exits less clusters. So the Minimum entering clusters algorithm can maintain the present cluster of mobile node. Once the mobile node needs to change cluster, Minimum entering clusters algorithm choose the farthest cluster head on it motion direction. In such way, the next cluster of mobile node can be maintained as far as possible. Reduce the number of entering and exiting cluster [10] can save energy and make better topological stability. So it is useful to adopt Minimum entering clusters algorithm for wireless sensor networks in mine.

The residual energy of mobile nodes and other nodes in network based on these two algorithms are compared. The simulation is based on the assumption that all the nodes cost no energy, except the energy consumption caused by mobile nodes' entering and exiting. So the residual energy of all nodes is the effect of mobile nodes without other factors. The velocity of mobile node is 20 m/min, and the mobile node moves in a roadway with the length of 400 m. The residual energy of NCM and MECM are shown in Figure 4.

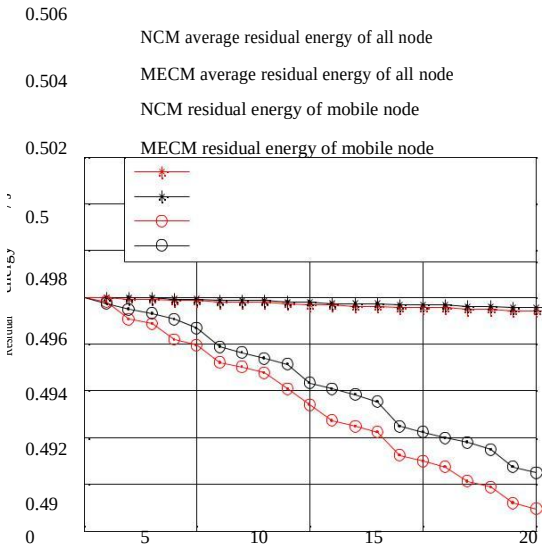


Figure 4. Residual energy of mobile node and clulter head

In Figure 4, the residual energy of all nodes in network is dropping with the increasing of running time, so mobile nodes cost much energy. We can see that Minimum entering clusters algorithm have more energy than Nearest cluster algorithm. So Minimum entering clusters algorithm can reduce number of entering and exiting, and save energy for all nodes. So it is useful to adopt Minimum entering clusters algorithm for wireless sensor networks in mine.

Further more, to guarantee the monitoring requirement of the whole coal mine, wireless sensor networks applied in mine can adopt some efficient approach as follows.

- K-fold spare nodes: when there are active nodes, the spare nodes keep sleeping. While when there are no active nodes, the spare nodes are started up.
- Local Data storage: data is local preserved for the fails is temporary. When link is recovered, the data is sent to sink node.
- Multiple sink nodes [11]: use more sinks nodes to converge data of network sectionally.

V. CONCLUSIONS

Based on the theory and normal researches of wireless sensor networks, we analyze its application in the high loss and interference area of mine and simulate the networks in roadway. The wireless sensor networks used in roadway adopts clustering based on working area and mobile node, which makes it more suitable for mine. The simulation results verify

that clustering based on working area is more reasonable for mine situation. MECM of mobile node can save energy for both mobile nodes and other nodes. So these schemes of this paper successfully improve the practical ability and stability of the wireless senor networks in mine.

Monitoring system is the most important aspect in China coal industry safety. It is obviously that wireless sensor networks will be a guarantee of the safety production, high efficiency and sustainable development in coal mine. The further research will be focused on the anti-interference and explosion-proof hardware.

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