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# Node deployment of band-type wireless sensor network for underground coalmine tunnel

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A B S T R A C T

Proper node deployment is the first step to build a Wireless Sensor Network (WSN) system. Therefore, a detailed study on mathematical 3D node deployment is carried out in this paper with the purpose of increasing the coverage efficiency of WSN in underground coalmine tunnel. Firstly, a 3D band-type node deployment model is proposed and in which part, several important characteristics of node deployment are discussed in detail, such as radio features, sensing efficiency, redundancy principles and coverage features. Secondly, a targeted node deployment algorithm is brought up and the core method of interval computing is put forward, thus the node interval can be computed accordingly. Thirdly, we use simulated annealing method to optimize the deployment algorithm proposed. The results show that the characteristics of node deployment in coalmine tunnel affect the network coverage dramatically. Moreover, comparing with the current deployment strategies, the optimized deployment provided by us can promote the coverage efficiency markedly.


## 1. Introduction

Impactful monitoring systems, such as environment monitoring, miner location and machine condition monitoring are used to diagnose equipment faults and provide early disaster warning in coalmine. Wireless Sensor Network (WSN) is adopted to build these robust monitoring systems as it has many characteristics which adapt to the working conditions in underground coalmine, such as mobility of nodes, ease of use, low-cost power consumption, scalability to large scale of deployment. Node deployment is the first step to build a WSN system. According to the manner of node placement, current deployment approaches can be classified into three categories, which are random deployment [1], incremental deployment [2–8] and movement-assisted deployment [9–13]. All this work has brought great progress to node deployment. However, they cannot be used in coalmine directly as the limits of geographical conditions.

Fig. 1 shows a common used monitoring network in coalmine, which consists of both wireless and wired networks. The wireless part is used to gather the data of distributed sensors, and the wired part is used to forward the massive sensor data. As the position of the wired relay nodes are determined by the position of the interface of Coalmine Industrial Ethernet, the most important factor that affects the monitoring system is the deployment of wireless sensor nodes.

## 2. Related works

So far, researches on node deployment in underground coalmine tunnel are scarce. ZHU et al [14,15] have deployed a 2D band-type wireless sensor network in coalmine. Comparing to the random node deployment strategy, the strategy proposed in this work can prolong the lifetime of the network by two times. WU et al. [16] have proposed a holistic routing approach for underground coalmine by considering different node deployment strategies. Li et al. [17] have deployed a mesh WSN for mining workface. Wang et al. [18] have proposed a node deployment strategy for achieving high-accurate localization and high-reliable communication in coalmine.

These achievements lay a great foundation for deploying a WSN in coalmine, and parts of them are mainly supporting technologies of WSN in coalmine, such as routing protocol and localization algorithm, parts are about approximate deployment in 2D plane. Currently, a much more accurate node deployment model of WSN in coalmine is eagerly needed. Therefore, a detailed research on a mathematical 3D band-type node deployment model which is proposed on the foundation of a more actual situation in coalmine is presented in this paper.

This paper is organized as follows: Section 3 gives a detailed model of 3D deployment in coalmine tunnel including radio features, sensing features and coverage features. A node deployment approach and its optimization are proposed in Sections 4 and 5.

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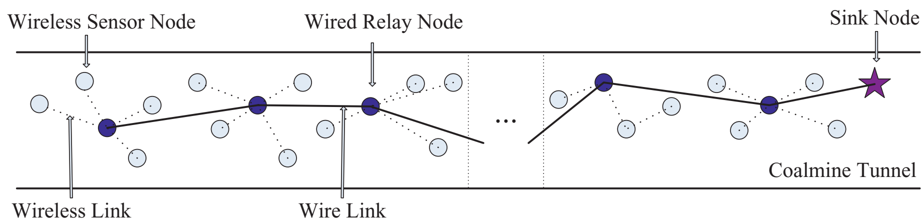


**Fig. 1.** Monitoring network in coalmine.

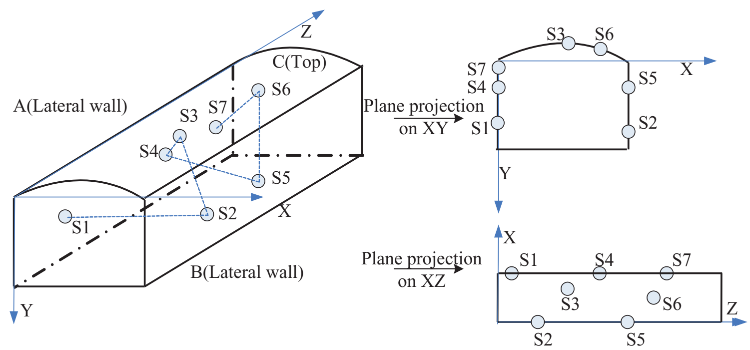


**Fig. 2.** Sketch of wireless sensor node deployment in underground coalmine tunnel.

Section 6 presents the performances of deployment approach. And Section 7 makes a conclusion for this paper.

## 3. The 3D band-type node deployment model in coalmine tunnel

### 3.1. Overview of the node deployment model

For building the model of 3D band-type node deployment in coalmine tunnel, a few reasonable assumptions are given as follows:

**Assumption 1.** All the sensing nodes are isomorphic.

The nodes have the same physical structure in WSN, that is, all the nodes have the same sensing properties and communication capabilities.

**Assumption 2.** The sensors carried by wireless nodes are omni-directional.

WSNs in underground coalmine tunnel mainly focus on monitoring environment, positioning and tracking personnel and equipment, and most sensors are omni-directional. Therefore, the sensors carried by nodes are assumed to be omni-directional in this paper.

As shown in Fig. 2, the wireless sensor nodes can only be deployed on the Top and two Lateral walls (the bottom surface is the working area) in coalmine tunnel. From the perspective of the topological graph, nodes are all located in three sides of the XY projection plane and in the internal of the rectangular of the XZ projection plane. Let parameters $L$, $H$ and $D$ denote the length, height and width of the coalmine tunnel respectively, $r_s$ denotes the sensing radius of a single sensor node, $K$ denotes coverage degree. Our goal is to obtain the optimal coordinates of all nodes based on the parameters ($L$, $H$, $D$, $r_s$ and $K$).

### 3.2. Radio features

Both the sensing and communication radii affect the node deployment in WSN. As the communication radius is determined by the radio channel, radio features in coalmine tunnel should be evaluated. In this section, the characterization of the radio channel for ISM 2.4 GHz WSN in coalmine tunnel is presented.

**Table 1**
3D Ray launching simulation parameters.

| Parameters | Value |
|---|---|
| Transmitted power level | 18 dBm |
| Frequency | 2.4 GHz |
| Receiver sensitivity | −85 dBm |
| Resolution (cuboids size) | 50 cm × 50 cm × 50 cm |
| Number of reflection | 3 |

For the assessment of the impact generated by the topology and the morphology of these environments on electromagnetic propagation, a 3D ray-launching method [19,20] has been used. A typical coalmine tunnel has been considered for the simulations as depicted in Fig. 3. The length, width and height of the coalmine tunnel are 100 m, 5 m, and 3.5 m. There are 12 miners and 2 mining cars with railway in the tunnel. As shown in Fig. 4, 12 antennas have been distributed in the coalmine tunnel, considering the real antennas properties, where A$i$ ($i = 1,2,..,6$) denote the transmitters and B$i$ ($i = 1,2,..,6$) denote the receivers. The parameters defined for the simulations are shown in Table 1.

Fig. 5 shows the obtained received power planes at height 2 m, when the transmitter is placed at the A$i$ ($i$ = 1,2,..,6) shown in Fig. 4. Fig. 6 presents the average received power. It indicates that the position of transmitting antenna produces less influence on received power. As the receiver sensitivity of the most receivers under 2.4 GHz, such as Zigbee Mote, is lower than −85 dBm, the propagation distance of 2.4 GHz radio is larger than 80 m in main tunnel.

Fig. 7 shows the received power at each of receiving antennas B$i$ ($i = 1,2,..,6$), when the radio is transmitted from A1. It illustrates that the average receiving power is −55.91 dBm when the propagation distance is 70 m, and the position of the receiving antenna produces less influence on the received power in coalmine tunnel.

From the analyses made above, we may come to the conclusion that 70 m is a trusty propagation distance in main coalmine tunnel. Some experimental studies [21,22] have also proved this conclusion. On the other hand, in respect of sensing, the working radii of the sensor carried by nodes are less than 10 m in the most applications of coalmine. As the sensing radius is much less than the