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RESEARCH ARTICLE

Optimization of Environmental Data to Improve Safety in Coal Mine using Wireless Sensor Networks

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Abstract

Objective: Design and implementation of an intelligent system to exploit the safety of Coal mine employees using wireless sensor Network. **Methods:** In this work, we collect environmental data such as harmful gases, temperature/humidity data, earth pressure, vibration, and groundwater level in the mine, by using Wireless Sensor Networks (WSN). A real time environmental data is continuously being monitored and analyzed to handle the current situation of the mine. Moreover, safety alert system can be activated in time to minimize the risk of the mine workers. Here we make use of location-based energy efficient routing protocol to minimize the delay, optimizes the energy between end nodes and a mat lab as simulation tool to compare the results. **Findings:** The presented system finds an extensive use in coal mine industry to provide the safety of employees. However, the designed system can also be employed in railway and road tunnels to check the continuous real time environment conditions of the tunnel and accordingly desired actions have to be taken place. Moreover, the designed system can provide the new base to the research community to precede the research in this field. **Novelty:** The presented approach is simple to operate, cost effective, energy efficient when compared to the existing approaches i.e., B. Vinodh kumar, Banda Srikanth and Kishore V (Please refer figure 6, 7 & 8 for comparisons with different parameters) and has a dynamic control mechanism based on current situation.

Keywords: WSN; Zigbee; environmental data; sensors; WPAN

1 Introduction

Ensuring safety and a healthy environment at the workplace in underground coal mines is very important as it is directly related to the life and health of the workers. There have been unfortunate accidents in which casualties occurred due to explosions and burial mine accidents in the human race. In particular, major risk factors related to mine ventilation include harmful gas, explosive gas, dust, temperature, humidity, and radiation. Many theories and models have been designed and implemented to minimize the coal mine accidents [1–3], however minimum attention is given towards finding the data like location, number of workers, equipment, and real time environmental data such as gas, wind speed in the mine, temperature, and humidity in the mine. So effective and efficient system need to be addressed that can provide the safety against serious accidents in the Coal Mine. Nowadays wireless sensor networks (WSN) are being widely used to secure health and safety in mine operations since it is autonomous and can be deployed quickly and easily anywhere irrespective of place, position and time. Also, it is a technology that processes and measured the data by establishing wireless connection between end nodes using sensors and also consumes less power[(4)]. Thus, by using this technology in underground mine one can detect or predict accidents. Li et al[(5)] presented a review paper in which the authors discuss the safety issues of coal mine employees and the importance of information technology in the coal mine. B. Vinodh Kumar et al., & Komuro N and Suzumaru R[(6,7)] presented IoT based Underground Coalmine Safety System, in which the authors use different types of sensors and a microcontroller to explore the situation inside the coal mine, however, this approach may not be the optimum in real-time application as no real-time data has been taken to investigate the current scenario and accordingly formulate the decision, also the circuit is complex and improves the delay. The authors of[(8,9)] proposed different models to improve the safety measurements of coal mine. But the requirement of huge data storage makes the system model the least effective and cannot be used effectively in coal mines to tone down the issues of risk assessment. Y. Zhu and G. You[(10)] developed a model to provide safety to the coal mine employees using WSN. In this paper, the authors set a constant threshold limit for various sensors which is not based on the mine statistical data, so as a result of which, it may pass wrong information and may not be optimum for real-time application in the coal mine, furthermore the circuitry is complex and introduces more delay which reduces its importance in real-time application. Umashankar et al[(11)] presented a model to optimize energy using WSN. In this steady, the authors try to improve the energy of the node so that lifetime of the node can be improved. This method has enormous importance in the coal mine to minimize the energy problems and enhance the life span of the node to large extent. Banda et al.,[(12)] presented a routing protocol to improve the security of coal mines using fuzzy logic, however, the generation of fuzzy rules increases the delay and reduces the throughput and may not be the optimum solution for real-time applications in the coal mine.

In domestic underground coal mines, many mines are deeply deteriorated due to over-mine. As a result of which safety-related issues may not be provided in the mine and collapses which cause accidents. In addition, pollutants such as exhaust gas generated by the movement of diesel vehicles, equipment during working hours, and post-blast gas generated after blasting work are continuously emitted in underground mines. Also, harmful gas is above the standard value due to the poor ventilation system inside the mine[(13)]. So, there is a risk of serious damage to human life, therefore it is essential to manage air quality in underground coal mines. Due to these problems, the development of a mine safety monitoring and alert system is essential. Underground tunnel communication is the main issue in coal mines, as it has a serious problem such as data transmission failure due to radio link failure. In a temporary mine environment, it is difficult to establish successful wireless communication due to various factors. Such as dust, humidity, temperature, the moving location of the workplace, the difficulty of positioning vehicle equipment, placing transmission, reception antennas, and various tunnel structures due to the mine methods. The Wireless Sensor Networks seems to be the solution of Coal mine safety in which the sensor node detects and processes the data from environmental sensors and communicates to relay nodes. The wireless technology that has been commonly used for major applications of wireless sensor networks is Zigbee, because it is a low-speed, low-power, low-cost wireless personal area network WPAN. Here the Coordinator node receives the data from the relay nodes and transmits it to the central control room. Several theories and methods have been proposed[(14–16)] to investigate coal mine safety using wireless sensor networks. Thayumanavan et al and N Sathishkumar et al.,[(17,18)] proposed IOT based security to the coal mine, however the designed algorithms are complex and increases delay, therefore may not be the optimum solution for real time coal mine. N. The Zigbee Alliance developed the PHY layer and MAC layer standard technology of IEEE 802.15.4 for Wireless personnel area networks (WPANs) and standardized higher protocol layers (i.e. Network layer, application layer), which are being used according to the application environment of the Zigbee standards. The other technologies of WPANs that can be used to develop a wireless sensor network are IEEE 802.15.2-based Ultra-Wide Band (UWB) and IEEE 802.15.1-based Bluetooth technology. IEEE 802.11-based Wi-Fi technology of wireless local area network (WLAN) is also widely used in wireless sensor networks.

Table 1 represents the comparative summary of each of the above-mentioned technologies. From Table 1 it has been observed that among all the technologies of WPAN, Zigbee has a relatively slow data transmission rate (i.e.0.25 Mbps). However, it has a wide network capacity that supports long-distance communication and is comparatively simple to build a network. The Wi-Fi method consumes considerably more power than the personal wireless communication methods, so the battery replacement is frequent; therefore, it is unfeasible for applications requiring a low-speed connection.

Establishing an environmental monitoring system using a wireless sensor network in an underground mine, with a relatively small amount of data transmission, requires long-distance communication and an extensive network in a long-extended mine shaft. Considering these aspects, Zigbee has been chosen as a communication technology scheme to investigate the coal mine steady. In this steady, a real-time model for underground coal mine has been developed to monitor the Coal

Table 1. Comparative summary

Parameters	WPAN			WLAN
	UWB	Bluetooth	Zigbee	Wi-Fi
Communication distance (m)	<10	10	50-500	50-100
Frequency range (GHz)	3.1-10.6	2.4	2.4	2.4 or 5
Data rate (Mbps)	100-500	1	0.25	11
Network capacity (nodes)	10-500	7	65,536	32
Power consumption (mW)	30	1-100	20-40	500-1000
Complexity	Mid-High	High	Low	High
Usage in Domestic Mine	O	X	X	O

Mine situation continuously using wireless Sensors and Zigbee technology. Moreover real time data from wireless sensors has been continuously analyzed to get current threshold limit of data, accordingly safety alert system can be activated to improve the safe working conditions In all the above presented approaches very less or no attention was given towards real time environmental data, No doubt few models [6,12,14] considered sensor data, however they fixed a threshold limit of data to predict accidents, which may not always true because the parameters which are responsible for mine accidents are varied with respect to environmental conditions occurred in the mine. Therefore, an information and communication system needs to be addressed which can continuously monitor the real time data in the mine and accordingly desired action has to be taken. The deep mines

The rest of the paper is organized as follows, in section 2 we describe the methodology of the proposed approach, in section 3 we present results and discussion, furthermore we conclude our paper in section 4.

2 Methodology

In the presented approach we follow Zigbee devices with a star topology to build a wireless sensor network. As each node has the advantage of being able to configure in a mesh topology that can be a router, end device, and a full-function device setting as a coordinator. The hardware used in this study consists of a coordinator, a router, and an end device. First of all, the coordinator is a network manager that has only one in each Zigbee network. It is located at the center point of the entire network and becomes the backbone for data transmitted from lower routers and the end devices; it stores the network information and delivers commands to the desired sensor node. So to select the appropriate sensor and process the date between end nodes, three different sections have been chosen to achieve the goal of coal mine safety i.e. i) Selection of Sensors ii) Hardware Configuration and iii) Software Configuration

2.1 Selection of sensors

The sensors used in the Zigbee end device module were selected by referring to the Mine Safety Technical Data Standards and the sensor performance. Various Sensor characteristics that play a critical role in coal mine safety are summarized in Table 2.

Here the selection of sensors is based on the requirement for the safety of working people in the mine. So keeping various safety issues in mind the sensors used to measure activity are noxious gas types such as carbon monoxide (CO), carbon dioxide ({CO_2), Hydrogen sulphide (H2S), and oxygen (O_2) sensors. In addition, temperature, humidity, earth pressure, and water level sensors are also installed in the module.

As a sensor selection criterion, it is chosen to measure more than the allowable concentration of harmful gases. Currently, only TLV-TWA is selected as the standard in domestic safe technology standards, which is the allowable concentration for 8 hours. Table 3 represents the maximum permissible concentration of various gases present in the mine, The standards considered here were referred to as Short-term exposure concentration (TLV-STEL) and maximum permissible concentration (TLV-C) [19]. In accumulation, humidity and temperature sensors are also chosen, since the mine has a high humidity condition due to the inflow of groundwater.

2.2 Hardware configuration

In the presented approach we use a coordinator node, a router node, and an end device. Here the coordinator node acts as a network manager in each Zigbee network [20] and is located at the center of the network to cover the entire range efficiently, furthermore acts as the backbone for data transmission between end devices and routers. Also, it plays the role of storing

Table 2. Datasheet of sensors connected to end-device Module

Parameters	CP-11		BW Max XT II		
	CO2	Temp & Hum	CO	O2	H2S
Working voltage (V)	3.4~6.4	4.5~5.5	3.5~5.5	3.5~5.5	3.5~5.5
Working Temperature (°C)	-30~40	-30~50	-30-50	-30-50	-30-50
Working Humidity (RH%)	15-85	15-90	15-90	15-90	15-90
output method	analog voltage signal	digital signal	analog voltage signal	analog voltage signal	analog voltage signal
Measuring range	0-50 PPM	Temp: -40~80°C Hum: 0~99.9 RH%	0-100 PPM	0-80%	0-100 PPM
Resolution	part per billion (ppb) Scale	1ppm	part per billion (ppb) Scale	0.1% Level	part per billion (ppb) Scale

Table 3. Exposure limit of mine gases

Gases	TLV-TWA	TLV-STEL	TLV-C
Carbon dioxide (CO2)	0.5%	3.0%	1.5%
Carbon monoxide (CO)	0.005%	0.04%	0.02%
Hydrogen sulfide (H2S)	10 ppm	15 ppm	15 ppm
Oxygen (O_2)	>19.5%	-	-

network information, delivering commands to the desired sensor nodes. Figure 1 represents the Zigbee coordinator module along with a network interface and is integrated with 3G Modem & Antenna (HSDPA, EDGE, and GPRS), quad-band Ethernet. USB 2.0 transmits and receives data through serial communication with the monitoring program in the PC via the USB port.

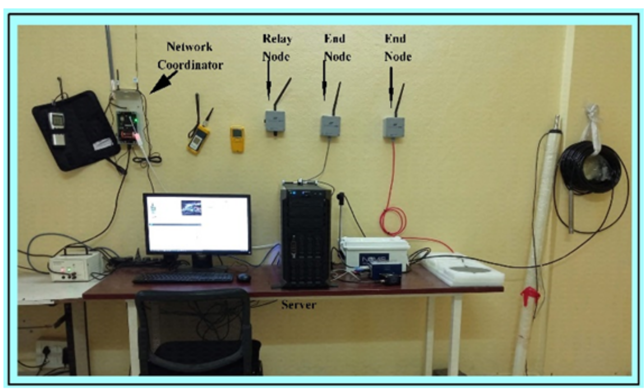

Fig 1. The hardware setup of WSN nodes & a coordinator node

Here 3G Modem fulfills our need in all respects as per our requirement, however, one can use 4G and higher modem also by choosing compatible Trans receivers and interface devices.

The role of a router in a Zigbee network is to extend the communication range of the network by relaying data transmission or reception between Zigbee nodes. It also serves as an application that can transmit data to the coordinator node. The router node composes a module with a microcontroller (MCU) and measurement sensor. The Zigbee router module used in this study is shown in Figure 3, the end device located at the end of the entire network configuration, communicates with the coordinator or router, which is the upper node. It serves to collect actual environmental data and transfers it to the coordinator node. The sensors used in the Zigbee end device module are selected by referring to the Mine Safety Technical Standards and the performance of the sensor. The measurement sensors used here are carbon monoxide (CO), carbon dioxide (CO2), Hydrogen sulfide (H2S), and Oxygen (O2). Furthermore, temperature, humidity, and earth pressure sensors are also installed to make the system innovative and efficient.

2.3 Software Configuration

The software employed to operate the above category of hardware devices in the WSN environment is Encardio-rite software and the URL used http://162.168.0.10, in any of the browsers.

Initially, we configure different types of WSN nodes and add necessary sensors into the network to perform simulation results. Information to the added nodes can be checked under the nodes list section of the project window. Figure 3 represents the WSN with coordinate node and Zigbee technology to investigate the current scenario in the coal mine. A monitoring program that receives and processes the real-time data from the Zigbee sensor network is also represented in Figure 2. This monitoring program is a Visual Interface program that continuously receives data that is transmitted from each end device through the COM port connected to the coordinator. The transmitted data is stored in a List array and displayed in real-time through the table and graph at the top of the program (see fig. 2).

In addition, the total data stored in the program can be downloaded as a CSV file whenever required. It can be later utilized for data analysis. Collected data will be interfaced with the Lab View software, a function is developed in which the data is updated to the latest value in the string array corresponding to each sensor and automatically updated in CSV file format.

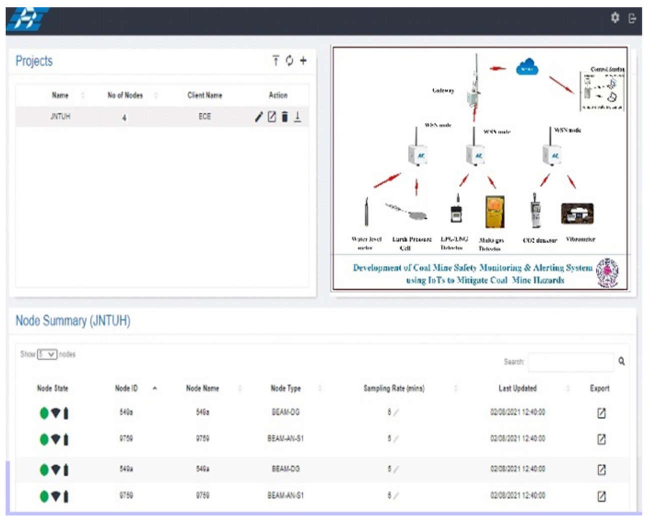

Fig 2. Software setup of WSN nodes & coordinator node

3 Results and Discussion

The data values from the environmental sensor are connected to the end nodes and are received with the monitoring interface program built into the Zigbee gateway. Here we are using LAEERP [21] protocol to find the optimum route between end nodes. In our simulated environment 21 real-time samples of data were received during measurement time (refer to Table 4), the data transmitted from the end device passes through the router node located in the middle section and is forwarded to the coordinator node, where the data is stored and taken for further analysis. The analyzed data is monitored and accordingly the threshold limit of all the sensors is set to activate the alarm system ON, if the sensor data limit exceeds the threshold limit and accordingly the safety measures have to be taken in advance. In this way threshold limit is continuously being monitored and set with respect to the real time data and dynamic operation has to be taken using lab view software.

Figure 3 represents the variation of data with respect to time. It is observed from the figure that data is varying, so a fixed threshold limit cannot maintain a real-time application.

This demonstrates the necessity of the proposed approach as the real-time data-based decision has to be taken and accordingly safety measures can be implemented in advance.

The network parameters considered for simulation are area of the network is 1500x1500 m^2, nodes taken 100, sinks 1, range 100m, packet size 1kbyte, power transmitted 18mw, power received 16mw and buffer size is 256kB.

Table 4. Measurement of Sensors data over a while

Date/time	CO Level (ppm)	CO2 Level (ppm)	H2S Level (ppm)	O2 Level (%)	Temp (°F)	RH (%)	Earth Pressure Cell (mV/V)
7/23/2021 10:16	0.57	558	3.12	20.10	73.2	70.8	0.072
7/23/2021 11:17	0.54	558	3.14	20.20	73	70.9	0.068
7/23/2021 12:18	0.58	558	3.24	20.80	73	70.6	0.067
7/23/2021 13:19	0.56	558	3.45	21.00	73	70.6	0.071
7/23/2021 14:20	0.57	556	3.11	20.40	73	70.6	0.072
7/23/2021 15:21	0.57	555	3.29	20.92	73	70.8	0.070
7/23/2021 16:22	0.57	558	3.22	21.06	73	70.8	0.069
7/23/2021 17:23	0.57	558	3.24	21.20	73.2	70.9	0.068
7/23/2021 18:24	0.57	558	3.56	21.34	73.2	71	0.072
7/23/2021 19:25	0.57	558	3.52	21.48	73.2	70.9	0.072
7/23/2021 20:26	0.57	556	3.45	21.62	73	70.6	0.067
7/23/2021 21:27	0.57	555	3.42	21.76	73	71	0.071
7/23/2021 22:28	0.57	558	3.41	21.90	73.2	70.7	0.072
7/23/2021 23:29	0.57	558	3.26	22.04	73	70.7	0.072
7/24/2021 0:30	0.58	558	3.62	22.18	73.2	71.1	0.071
7/24/2021 1:31	0.58	558	3.12	22.32	73	71	0.072
7/24/2021 2:32	0.58	556	3.14	22.46	73	70.8	0.073
7/24/2021 3:33	0.58	555	3.24	22.60	73	70.9	0.069
7/24/2021 4:34	0.58	558	3.45	22.74	72.9	71	0.071
7/24/2021 5:35	0.58	558	3.11	20.10	72.9	71.4	0.068
7/24/2021 6:36	0.58	558	3.29	20.20	73	71.3	0.068

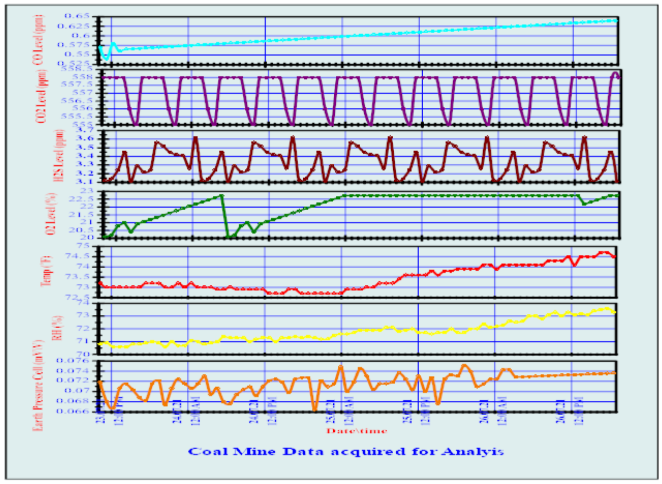

Fig 3. Graphical representation of Coal Mine data acquired over a period of time.

Figure 4 shows the localization error performance, in which we observe that the presented method shows better performance when compared with the art of work. However at some particular points, the Kishore approach is nearby to our approach, it is because at some nodes the link capacity is more and improves the performance. But if the link capacity between any two nodes within the route is marginally low it degrades the performance of the system and reduces the overall response of the method.

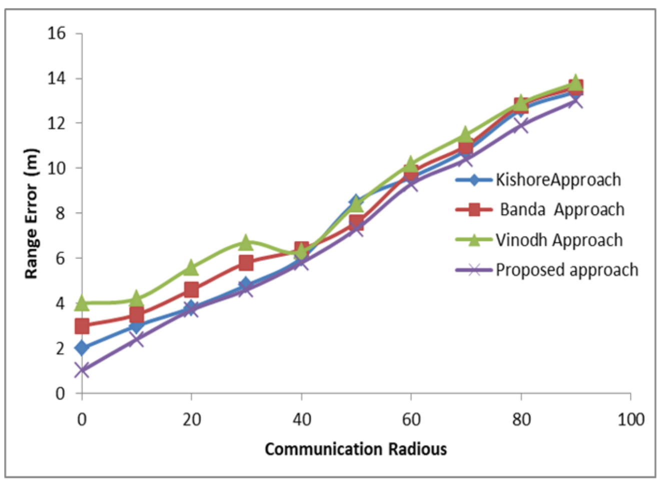

Fig 4. Localization Error Performance

Figure 5 represents the network lifetime response of the proposed approach and the art of work, from the comparative analysis it has been observed that the presented approach shows enhanced outcome when compared with the existing approaches since every node is monitored continuously for all network parameters (I.e. B.W, Energy, nodal delay and distance)

Figure 6 shows the variation of residual energy to the number of nodes, it is clear from the figure that the residual of the proposed approach is less in comparison with the existing approaches. So from the overall comparative analysis, we conclude that the presented approach has better performance when compared with the existing approaches.

The overall comparative analysis reveals that the presented approach reduces the error, optimizes the lifetime and energy of the sensor nodes, Furthermore error reduction improves the overall throughput between the end nodes and enhances the performance of the designed system

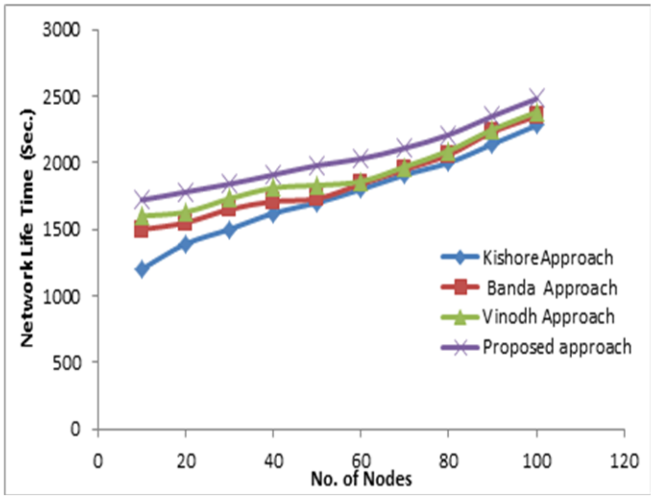

Fig 5. Response of Network lifetime

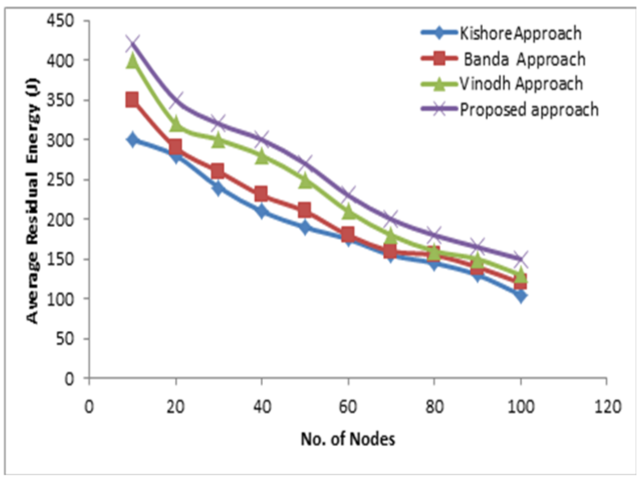

Fig 6. Variation of numberof nodes versus Average residual Energy

4 Conclusion

In this study, a real-time environmental monitoring system using the Zigbee technology model has been developed and implemented for underground coal mines, in which real time sensor data has been collected and analyzed simultaneously to get the current threshold limit of the sensed data and accordingly safety measures have to be taken in advance to reduce coal mine accidents. To run the system smoothly and efficiently a software program has been developed using Lab View software that generates an alert alarm for the working employees in underground coal mines to take desired action of safety in advance. The presented system can be used as a basic building block of the coal mine safety for the research community. The presented model has been validated using Lab View and mat lab.

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