The Performance Parameters Of Wireless Sensor Networks In Underground Mines

Sinan UGUZ

Abstract: In recent years, underground mines have increasingly remained on the agenda with both difficult working conditions and problems such as collapsed and firedamp explosion in our country and in the world. In terms of life safety of miners and their health, mine sites are required to be continuously monitored and controlled. This is difficult to achieve with existing wired systems due to the topography of mine sites. The applications have increased with the development of wireless sensor networks (WSN) technology in mine sites in recent years. This case has also caused an increase in studies on improving WSN performance. Especially, energy efficiency is very important for the WSN hardware with a low energy source. In this study, information about things to consider while using WSN technologies in underground mines and studies on their performance has been provided.

Index Terms: Antenna, Energy efficiency, Monitoring, Network topologies, Routing, Underground mines, Wireless sensor networks

1 INTRODUCTION

Underground wireless sensor networks (UWSN) are referred as types of WSNs operating under the soil surface. The hardware creating this network is located either as completely buried underground or in the underground open areas such as mine, metro, sub-sea tunnel, etc. [1]. UWSNs have a variety of application areas such as environment and infrastructure monitoring, location detection of objects and security. Applications in the area of agriculture and mining can be given as an example of the environment monitoring category. Monitoring in terms of water, mineral, etc. of the soil during irrigation and fertilizing, or the applications of landslide prediction can be shown among UWSN studies in agriculture. Furthermore, studies such as the measurement of air quality in mines, the detection of miners via voice sensors or wearable sensors in case of an emergency that may occur at the mine site can be assessed in this group. Monitoring of structural parameters such as stress and strain in the sections remaining underground of many structures such as dams, bridges, buildings, etc., and the observation of many infrastructure systems such as channels, electrical wiring, and liquid storages tanks underground are the application fields of UWSNs. UWSNs can be used to detect the location of people remaining under the collapse because of the disasters such as an earthquake, etc. in debris. The detection of intruders entering the borders of living spaces with pressure, sound, or magnetic sensors settled under the soil can be considered as other application fields of UWSNs. The developing technology of UWSN is very important in terms of underground mines. It is required to perform a detailed examination of mine sites and decide on the best network topology for the site before performing UWSN applications in mines. Underground mines are the work areas with difficult conditions and complex geography. It is required to constantly monitor environmental factors, miners, and devices used in mines that contain blind spots and narrow tunnels for dozens of kilometers. The data of environmental factors including water, gas and dust levels from very different areas in mines should be monitored and checked to ensure safe working conditions [2]. Monitoring and control systems are realized through wired or wireless systems.

• *Sinan Uguz, Department of Software Engineering, Suleyman Demirel University, Isparta, Turkey. E-mail: sinanuguz@sdu.edu.tr*

A typical wired data monitoring and control system can be considered as a system that operates depending on industrial network standards such as Fieldbus, Canbus, etc. These systems consist of substations and the data coming from the sensors located at each substation are delivered to the main system. To use a cable system in the complex geography of mines causes some disadvantages such as high costs and installation difficulty. Since mines are ever expanding by nature, monitoring and control systems to be installed are required to have the modular structure. Installing UWSN to form a mine with the modular structure is more suitable compared to cable systems. It is possible to increase the productivity and reliability as well as reduce operating costs through the use of UWSN in mines. [3]. Different UWSN technologies are used for the monitoring and control systems in mines. Table 1 shows the properties of short-range UWSNs used in mines. According to Table 1, Bluetooth can be considered as a technology that has limited applicability for mines due to the low network capacity and short distance communication features. Ultra-wideband (UWB) technology has limited applicability due to short distance communication. Since Wi-Fi nodes have high power consumption, access points with a constant energy supply are needed. This situation takes place among disadvantages of Wi-Fi technologies with a high cost. ZigBee is separated in a positive way from other WSNs in terms of the appropriateness of the communication distance between nodes, low energy consumption, and wide network capacity. The data transmission speed of ZigBee is considered to be low for multimedia systems such as audio, video, and picture [4].

TABLE I

COMPARISON OF UWSNS WIDELY USED IN MINES

Properties	Bluetooth	UWB	Wi-Fi	Zigbee
Distance (m)	10	<10	50-100	50-500
Frequency (GHz)	2.4	3.1-10.6	2.4 or 5	2.4
Data Rate (Mbps)	1	100-500	11	250×10^{-3}
Network Capacity (Node)	7	10-500	32	65,536
Power Consumption (mW)	1-100	30	500-1000	20-40
Complexity	High	Medium	High	Low

This article is organized as follows. The networks topologies in mines are examined in Section 2 and the performance parameters of UWSN are examined in Section 3.

2 The Network Topologies In Mines

The difficult conditions and the complex geography of mines which have many passageways and the shape of the ore body require the use of different topologies on mine sites. Nowadays, underground mines are mined by using methods such as room and pillar, cut and filling, and long-wall methods [5]. If an ore body has a flat structure, the room and pillar method is used, if it has a steep slope, the cut and filling method is used, and if has a wide and thin veins structure, the long-wall method is used. In each method, as long as the mine expands, the mine site transforms into different shapes.

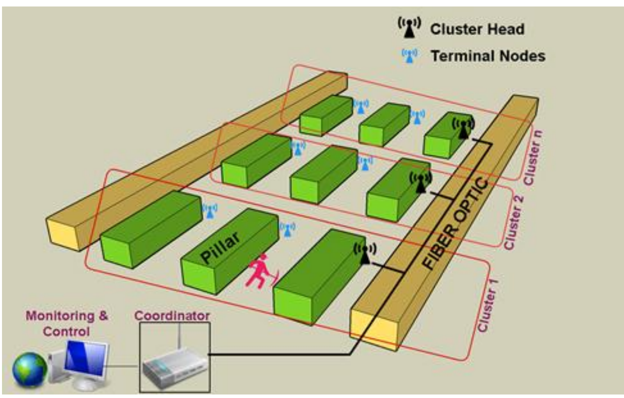

Fig. 1 *The cluster-tree topology of a mine site*

The cluster-tree topology structure of a mine site where production is made with the room and pillar method can be seen in Figure 1. In this method, the pillars are composed to balance the load on the mine that is formed during the production of ore and production is carried out from the rooms remaining between pillars. In Figure 1, the areas within the mine site are divided into clusters. A cluster head node and a large number of terminal nodes can be found basically in each cluster. Terminal nodes can have sensors reading factors such as temperature, humidity, coal gas, CO_2, air velocity, water, fume, etc. and they can also detect the location information of miners. The terminal nodes which are found within each cluster transfer the data obtained through sensors to the cluster head node. Cluster head nodes also transfer the data received from the nodes in their clusters to the coordinator. Each cluster head node must be connected to the coordinator in a reliable and fast way. Wired communication methods such as CanBus, FieldBus, etc. can be used for the connection of clusters to the coordinator and transmission between clusters. The coordinator realizes the communication of the monitoring & control unit with the mine site. The real-time monitoring of the mine site and intervention if necessary are ensured with the software in the monitoring & control unit. Monitoring & control unit software can be either SCADA based software or software with a graphical interface, written in programming languages such as Java, C#, Delphi, etc. The instant transmission of warnings to the appropriate locations in case of emergency can be provided online with web services in the monitoring & control unit [6].

3 The Performance Parameters Of Uwsn

A dynamic expansion of mine sites causes a numerical increase of UWSN nodes. A numerical increase in nodes will be a burden in terms of cost. Therefore, nodes are generally produced as low cost and small size devices. This situation causes various hardware problems and limited power supply for nodes. Limited memory and processor capacity can also lead to software problems in a node. Because of these reasons, to do scientific research for improving the performance of the network in UWSN applications in mines is important.

3.1 Energy Efficiency

Sustaining a long lifetime of a network is one of the vital points for mines. When the energy of the sensor nodes in the network is consumed, they are disconnected from the network. To replace the power supply of the nodes consuming power is a difficult and time-consuming process due to geographical conditions. Therefore, the energy efficiency of nodes is vital for the sustainability of the network. While the energy efficiency is provided, a cost increase and the size of the nodes emerge as the most important problems. The studies carried out at this point focus on power-efficient hardware and communication protocols. The duty cycling is one of the important concepts for energy efficiency [7]. When nodes in a network are constantly in the position of receiving or sending data, they consume already limited power resources. For this reason, they remain passive in the period when they do not data exchange, namely they pass to the sleep mode. That nodes are in the active position during the data transmission of radios and are in the sleep mode in other cases creates a loop called the duty cycle in the network. As the number of nodes in the network increases, the duty cycle will become difficult since the simultaneous operation of nodes will also become difficult. Therefore, when UWSN is designed, the network scalability must be considered. Another factor having an impact on the performance of the UWSN energy efficiency is the design of the MAC (Medium Access Control) protocol. The main task of the MAC protocol is to develop strategies which prevent the collision of data packets during communication between nodes [8]. Since data transmission is not realized as a result of the collision of data packets, the node will waste energy. Another issue examined in the MAC protocol is the size of data packets sent by the nodes. The more information a data packet contains the more energy consumption of the node will be. Therefore, to reduce the packet overhead plays an important role for energy efficiency. Idle listening that can be expressed as the moment when the radio is ready for data communication while designing the MAC protocol is among other important performance criteria. If a node takes a data packet which it does not own from the channel in the vacant listening position, it is overhearing. In such a case, the node wastes its energy. Therefore, a node must take only the data packets which are transmitted to it. The nodes obtain an ID number to be separated from the other nodes in the network. Increasing the number of nodes causes the growth of the ID number. Increasing the data packets will cause more energy consume since ID numbers are the information carried by data packets. This case is one of the performance criteria that must be addressed by the MAC protocol.

3.2 Optimum Routing

Transmitting the data in the shortest time, through the shortest path and completely is the most desired criteria during transmission of the data obtained from the nodes to the monitoring & control in UWSN studies. This need is becoming more important in the applications related to the detection of an emergency in mines. At this point, it must be performed by using the correct routing algorithms of communication in the network. The most important issues to be considered in the studies to be performed are the amount of energy of the nodes in the network. Because nodes are small hardware in terms of the size, power supply on them can be depleted rapidly. If correct routing is not performed, the power of nodes with a critical role will be quickly consumed and the network will be unavailable [9]. As can be seen in Figure 2, the closest nodes are preferred in order to transmit the data to sink from the node with number one. Since the same route is followed continuously in such an application, a more rapid reduction will occur in the energy of the nodes on this route. Another problem in such a communication is that node No.2 is the closest node to sink. Therefore, since the data coming from other nodes will be also transmitted to sink node through node no.2, the energy of this node will be exhausted quickly and the network will become unavailable. In Figure 2, nodes grouped close to each other are separated in two clusters in such a way that they are in the same clusters, and red cluster head nodes are created for each cluster. The task of cluster head nodes is to transmit the data received from other nodes in the cluster to sink node. In such a network structure, the rapid decrease of its energy and the continuous use of the cluster head node can be an important problem. By means of different algorithms developed for this, different cluster head nodes are determined in each cycle. The cluster head nodes can also provide a curative effect on the performance of the network by reducing the size of the data to be sent with data compaction.

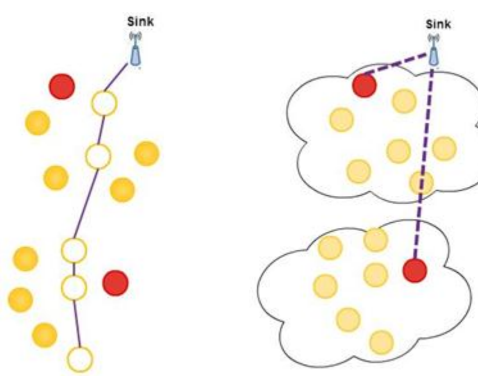

Fig. 2 *Routing in nodes*

3.3 Antenna Design

UWSNs can be placed in the multi-storey depth to ensure connectivity and coverage. A deeper node and another node close to the surface can exhibit different behaviors in terms of broadcasting in the horizontal or vertical direction [10]. The nodes arranged by multilayer architecture must have three-dimensional communication capability of the antennas. Since the radiation pattern of omnidirectional antennas is not suitable for vertical communication, the use of one omnidirectional antenna is not suitable for such a structure [11]. Therefore, UWSN can be designed by using two antennas for both horizontal and vertical communication, or smart antennas which have the ability to dynamically change the radiation pattern can be used according to the communication needs. The communication environment of UWSN includes many difficulties by the nature of the soil. While electromagnetic waves radiate along soil and rocks, the moment propagation is realized at lower frequencies, less signal attenuation can be observed [12]. Therefore, the use of low frequencies is more convenient for communication. However, conventional electromagnetic antennas are very large in size at low frequency. The choice of appropriate modulation schemes, as well as this problem, is another performance criterion studied. The use of lower transmission frequency and low bandwidth bring positive results for data transmission. For this reason, a lower data rate can be used in the UWSNs compared to terrestrial WSNs. The excessive channel loss affects the data rate for UWSN. These issues also affect the performance of the network.

4 Conclusion

In this study, the performance criteria to take into consideration in the implementation of the WSN technology in underground mines which replaces wired communication in many fields in recent years are discussed. Furthermore, network topologies which may vary according to the types of underground mines are mentioned, and the application manner of the cluster-tree topology at a mine site where ore is extracted with the room and pillar method is explained. The rapid depletion of the power supply of nodes and not an easy replacement of their batteries due to the structure of mine sites increase the importance of establishing an energy efficient network in UWSN technologies. The configuration of the network to run in the duty cycle loop of nodes will contribute to the creation of an energy efficient network. Another important point is MAC protocols trying to minimize the lengths of data packets that send nodes to each other. MAC protocols also include algorithms which prevent collisions by regulating the shapes of sending the data packets of the nodes in the network. Another important issue which is studied and affects the performance of UWSN is routing techniques. The most important issue to be considered while transmitting the data packet in a node to sink with different routing algorithms will become to be able to provide homogeneous consumption of the energies of all nodes in the network. The antennas have a great importance in the design of UWSN. Upon considering the fact that many factors affecting the spread of electromagnetic waves are found underground, antenna selection is important for the improvement of network performance.

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