Mobile Sink Wireless Underground Sensor Communication Monitor

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Abstract. Mine disasters claim thousands of human lives and cause millions of property loss every year. The safety of the mine worker is of paramount importance in any underground environment. Advances in the development of Wireless Sensor Networks (WSNs) for monitoring infrastructure health, and environmental conditions provide end users with the benefit of low-cost installation, maintenance and scalability. This paper will investigate the challenges around a development of a real-time mine monitoring system using wireless sensor nodes to prevent mine disasters such as gas explosions or mine collapses. We propose a mobile, real-time gateway that will be able to process data collected from static wireless sensor nodes monitoring underground infrastructure, to prevent underground disasters.

Keywords: Wireless sensor network; mobile sensor network; underground mobile processing; underground mobile sink communication monitor.

1 Introduction

Drill and blast mining operations conducted on underground mines can cause explosions and tunnel collapses resulting in loss of life of mine workers, extensive property damage and reduced productivity. To improve the safety of the mine worker and minimize damage to mine infrastructure it is important to monitor the underground environment in real-time and collect data about the current state of the system. The disadvantages of using wired networks include costs (both labor and capital), inflexibility in adapting to changing environmental conditions and the requirement for a readily available power source. Wireless sensor networks (WSNs)are cheaper both in terms of labor installation and capital costs, more flexible and easily adaptable to changing environmental conditions and easily and rapidly deployable in environments where there is no or limited power and communication structures. Wireless communication systems in underground mines and tunnels are influenced by harsh environmental conditions, tunnel length and width, and the layout of the tunnel walls and ceilings [4].Radio frequency (RF) waves in underground systems do not propagate well in due to the bounding effects of the tunnel infrastructure [5] and experience high attenuation of the transmitted signal power [2]. These problems present serious difficulties in using WSNs for tunnel infrastructure

monitoring. This paper proposes a mobile real-time wireless gateway node, which will collect data from static infrastructure wireless nodes. The mobile node communicates with static nodes strategically placed within the underground tunnel and processes the received data in real-time to determine the current strength of the surrounding infrastructure and air quality. Each mobile node will be equipped with a trigger event that broadcasts data. Any surrounding level 1 static nodes that receives a high priority message will re-broadcast the message until it is received by all level 1 nodes which will alert workers of the potential danger in that environment.
The rest of the paper is structured as follows. In Section II, related work in the use of wireless sensor nodes to monitor underground systems is reviewed. Section III provides a brief summary of the algorithm description. In Section IV, the experimental setup is described. In Section V, the results of the experiments are analyzed and Section VI provides a conclusion and discusses future work.

2 Related work

Li and Liu designed a system to rapidly detect structure variations caused by underground collapses [3]. Mohanty proposed miner tracking and detection of hazardous conditions in underground mines, using stationary wireless sensor nodes placed at selected locations throughout the mine so that each node could communicate with gateway node(s) (called “sink”) using one or more hops [6]. Bandyopadhyay et al propose a Wireless Information and Safety System for Underground Mines based on RFID for tracking miners and moveable equipment in an underground environment [2]. Akyildiz et al [1] describe signal propagation techniques for wireless underground communication networks. The channel model and signal propagation characteristics for electromagnetic (EM) waves and magnetic induction (MI) techniques in the soil transmission medium is described and the effects of various interference, noise and signal attenuation factors are discussed. A multimode channel model characterizing the wireless channel in a tunnel or a room-and-pillar in underground mines and road/subway tunnels is discussed [1].

3 System overview

Fig. 1 shows the structure implemented for monitoring hazardous conditions. The mobile processing gateway node (MP), at the lower level of the hierarchy (level 3), scans the environment to locate which static node is in communication range and stores the address in an array. After storing the addresses, the MP requests data from each stored static node address at the time in order to avoid collision messages at the MP. The static nodes, in the middle of the hierarchy (level 2), collect the data then send it to the MP, which stores the values in a second array in order to compare it to the threshold value set and to keep records. The threshold is considered as the highest level value status information of the environment. Three environmental states condition will be displayed, namely: normal, warning, and dangerous condition. The case of warning condition will be displayed when the threshold level is passed before reaching the critical point value. This condition is taken in order to make aware workers that the sensors are detecting unwanted change in the environment. When dangerous condition is detected, the mobile processing gateway node will broadcast the message to the high hierarchy or level 1 node (super node) which will send it to all super nodes then activate the alarm system. The super node (high hierarchy) communicates with each other and also scan all static nodes to check if they still functioning. When a super node cannot detect a static node, in case of battery failure or node malfunctioning, an alert message will be sent to workers informing which specific place of the node is malfunctioning.

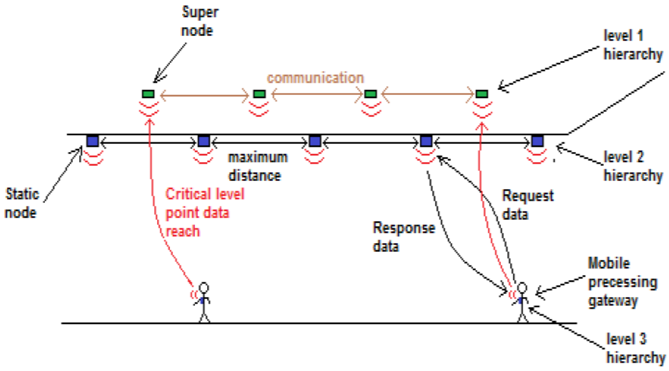

Fig. 1. Structure Implementation

4 Experimental setup

An experimental setup was conducted in a passageway at the University of Johannesburg as a representation of an underground tunnel. South African underground mines have stringent safety requirements and an actual mine tunnel in which to conduct the experiment could not be found. A node is placed on a belt at shoulder level and tested on different human heights. Static nodes are placed on the center of the ceiling the maximum communication range distance apart. The maximum range distance is divided in sectors. For each sector, a pedestrian walks toward the static wireless node from the maximum point sector and from the static wireless node to the maximum point sector. For each pattern, time is recorded. The process continues while communication between the two nodes exists. Each pattern has time and distance variables that determine the relationship among pedestrian mobility and communication. Different speed behavior is tested for specified distance in order to determine the effect of pedestrian mobility on communication reliability. At specified distance point X, an angle of communication can be determined by assuming that the communication between two nodes is in straight line condition.

5 Results and discussion

The maximum communication range between two wireless nodes in the passage way for good reliability is 30.5m. The size of the message used in the experiment is 8 and

16 bits long. A communication reliability threshold was set at 98% to test the propose algorithm structure.

A. Using 8 bit message with mobile node at height Mh = 1.44 m above ground.

Fig. 2 shows the correlation between the pedestrian velocities and the communication reliability. It was noticed that for different pedestrian velocity, the reliability of the communication was mostly good while the mobile wireless node is in the communication range but the faster the pedestrian, the communication reliability decreases. Fig. 3 shows the reliability of communication was inversely proportional to the angle, the bigger the angle means that the mobile wireless node is closer to the static node the better the communication.

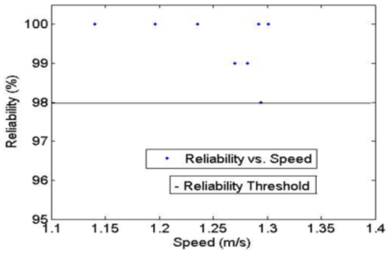

Fig. 2. Reliability vs. Speed, 8-bit, Mh = 1.44 m

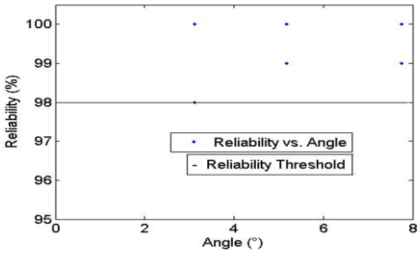

Fig. 3. Reliability vs. Angle, 8-bit, Mh = 1.44 m

B. Using 16 bit message with mobile node at height Mh = 1.44 m above ground.

Fig. 4 shows the correlation between pedestrian velocities and the communication reliability. Fig. 5 shows the correlation between angle and the communication reliability. The result shows that most of the data collected was above that threshold.

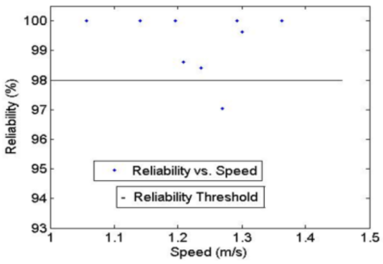

Fig. 4. Reliability vs. Speed, *16 bit, Mh = 1.44 m*

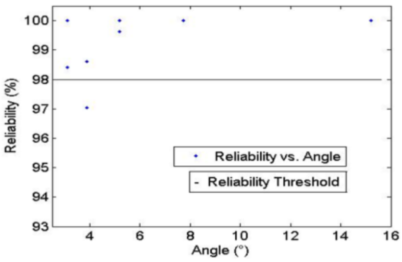

Fig. 5. Reliability vs. Angle, *16 bit, Mh = 1.44 m*

C. Using 16 bits message with mobile node at height Mh = 1.47 m above ground.

Fig. 6 shows the signal strength drops to 93.5% for high speed and is 100% for slow speeds. It was also noticed that at a distance between nodes greater than 15 m the average signal strength is 98%. Fig. 7 shows the correlation between angle and the communication reliability.

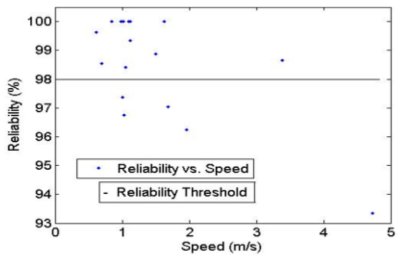

Fig. 6. Reliability vs. Speed, *16 bit, Mh = 1.47 m*

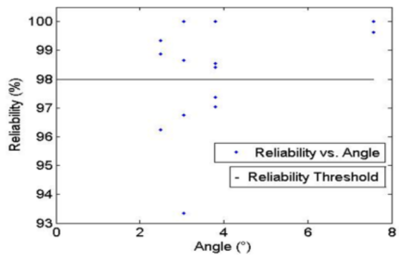

Fig. 7. Reliability vs. Angle, *16 bit, Mh = 1.47 m*

6 Conclusion

The effect of pedestrian mobility on communication reliability in a WSN is analyzed. A node was placed on the ceiling and a node gateway on a pedestrian. The packet loss rate was measured with different movement speeds and patterns for specified distances between nodes. Pedestrian mobility and do have a small effect on the communication reliability which can be neglected when both wireless nodes are sharing data within communication range because the lowest rate obtained was 93.5% for a 16 bit message. This indicates that a mobile data communicator (sink) can be placed on a pedestrian to collect environmental behavior.

Acknowledgments

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