Tunnelling and Underground Space Technology 73 (2018) 127–138

Contents lists available at ScienceDirect

Tunnelling and Underground Space Technology

journal homepage: www.elsevier.com/locate/tust

Development of wireless sensor networks for underground communication and monitoring systems (the cases of underground mine environments)

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ARTICLE INFO

Keywords:
Underground mine
Monitoring and communication system
Wireless sensor network
ZigBee network

ABSTRACT

The challenges of maintaining safe workplaces and improving operations and services in underground mines are unique. These have largely been mitigated by implementing new technology of wireless sensor networks (WSNs) in the last few years. Establishment and development of a reliable monitoring and communication network through such hostile environments are still major concerns. In this study, a more comprehensive monitoring and communication system for underground mine environments using ZigBee network are developed. To this regard, experiments with real systems and prototypes are applied. The controllable and uncontrollable parameters of both underground environment and network for the establishment of ZigBee network are also assessed. Then, a practical method to design a model of an underground mine monitoring and communication system is proposed. This model was verified by testing system functions and applications for example, temperature, humidity and illumination readings, text messaging, and controlling ventilation fans throughout an underground mine in Western Australia. The monitoring and communication systems operated successfully and it demonstrated the reliable outcomes of their function and application for underground mines.

1. Introduction

The development of a wireless sensor network (WSN) model is hugely beneficial for the practical design of underground mine monitoring and communication systems. This is mostly owing to the large variety of networking variables, the rapid technological advancement of sensor nodes, and considerable changes in environmental parameters from one mine site to another one.

Thus, a recognition of entire variables is a key component for the evaluation of the reliability of the WSNs' functions and applications in an underground mine. Ben Maissa et al. (2013) emphasised the necessity of investing in WSNs' performance, based on model analysis and validation, before handling more critical functions. Stanley-Marbell et al. (2008) observed the impact of the WSNs' operation taking into account the variables of the hardware, software and physical limitations. They focused on the importance of recognising the uncontrollable parameters of the environment and run-time parameters in order to develop a more realistic model and evaluate the performance of WSNs under a system model. This work attempted to provide models of WSNs which predicted system properties and challenges associated with cost and time effectiveness on a real project. This study will demonstrate a practical system design for establishing a reliable WSN for required underground functions and applications in underground environments. In particular, it shows that how the confirmation and calibration of a WSN model using ZigBee network is developed based on the field investigations. The controllable and uncontrollable parameters of both the network and underground environments are considered so as to establish and further develop wireless monitoring and communication systems in underground openings.

The procedure of establishment and development of a WSN in an underground mine is illustrated in Fig. 1. The specification of the underground network should be first drawn up in order to design a monitoring and communication system which could be utilised for communication, environment monitoring, tracking or any combination of these. Consequently, the determination of required stationary or/and mobile sensors contributes to an evaluation of the controllable and uncontrollable parameters through the network as well as underground environment. Then, a model of the system is designed. This is experimentally analysed for the verification of the network setup and the reliability of the functions and applications. In the event of satisfactory results, the generalisation of the model is very likely to establish a reliable monitoring and communication system between a control room and levels of an underground mine.

The remainder of this paper is organised as follows. The effective

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https://doi.org/10.1016/j.tust.2017.12.015
Received 24 July 2017; Received in revised form 5 December 2017; Accepted 13 December 2017
0886-7798/

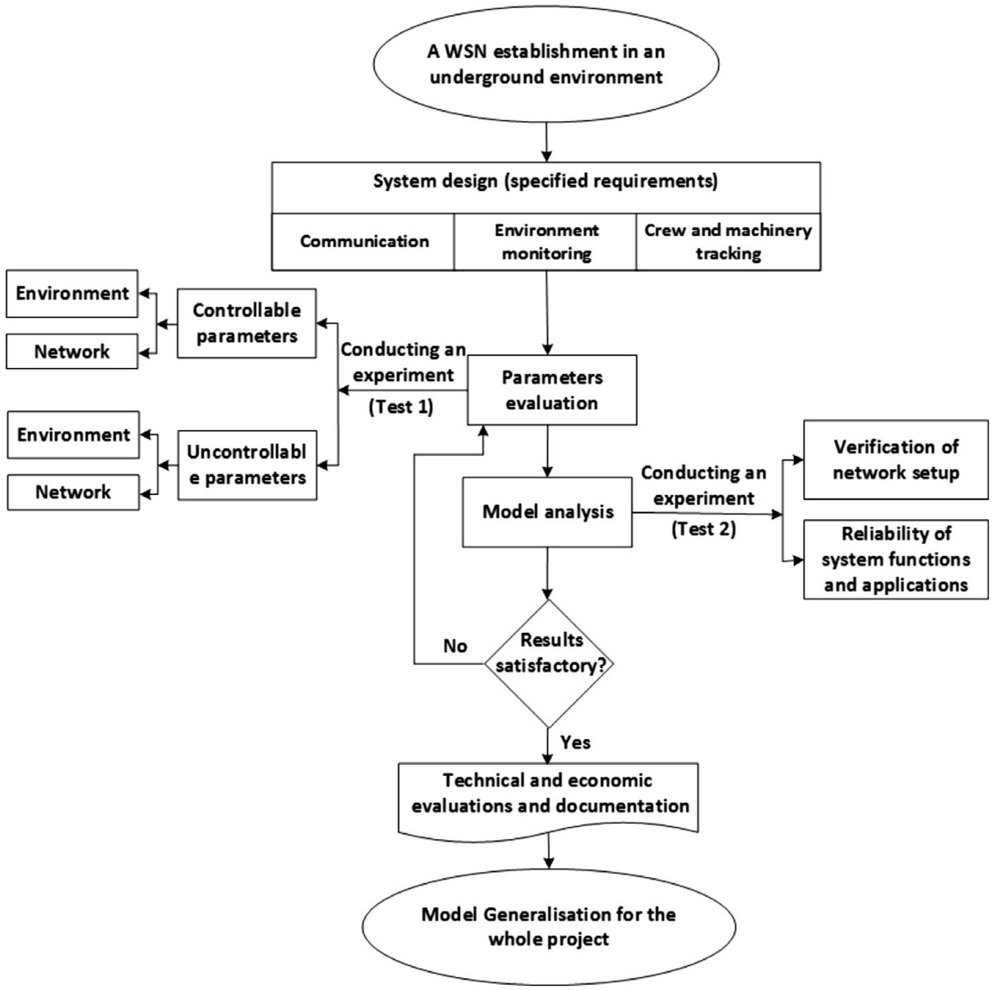

Fig. 1. Procedure of establishment and development of a WSN in underground mines.

parameters for the establishment of a ZigBee network in an underground mine is first evaluated. Then, a system design and model is developed based on the classification of results from an experiment undertaken at an underground mine in Western Australia. Following that, another experiment is conducted to physically verify the reliability of the proposed ZigBee network model in this particular mine. This is performed by testing the system's functions and applications including messages texting and controlling ventilation fan operations as a model. Finally, the results of experiments are discussed with a subsequent of the directional line of sight and non-line of sight and the position of the nodes.

2. ZigBee network modelling in underground mines

In order to implement an underground monitoring and communication system, building a model is necessary for the assessment of technical and economic evaluations. This is based on determining required functions and applications, and the recognition of the variables of network metrics and environmental variables in the specified environment.

2.1. Parameters evaluation

Moridi et al. (2014) selected and simulated ZigBee networks for monitoring and communication in underground environments and concluded that recognising and assessing the effective parameters is crucial in a network design. Zarei et al. (2013) posited a method for assessing the principal parameters of tunnels water inflow. Accordingly, the controllable and uncontrollable parameters of a ZigBee network and the surrounding environment are illustrated in Fig. 2.

There are a considerable number of uncontrollable parameters which contribute to the complexities of any model simulating the real world. Some parameters of a ZigBee network (Fig. 1) such as the arrangement and localization of nodes and the network metrics are adjustable for better data telemetry in underground mines. The uncontrollable parameters are the number of hops, network congestion and infrequent failures in the reception of data packets. It might be possible to render these parameters controllable within confined spaces. There are also environmental variables of tunnels that are uncontrollable in ZigBee network design as opposed to the known or controllable parameters of tunnel geometry, layout and employed system support. Such uncontrollable parameters include the rate of water inflow fluctuation, the degree of wall surface distortion and roughness, the radio frequency interferences of operating and communication systems, obstacles like dump trucks, boggers, and air compressors, as well as the variation rate of permeability, dielectric constants, and conductivity in the surrounding rock mass along openings.

Therefore, a ZigBee network can efficiently be established after determining the underground effective parameters that influence ZigBee communication signals, and finding the maximum reliable communication distance between nodes in different underground openings with all variables considered. Thus, quantifying all of the above parameters is a prerequisite for the design of a reliable ZigBee network for underground openings.