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# Radio transmission characteristics in tunnel environments

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**ABSTRACT**

Radio communication is becoming more widely used in underground mining, although it is still a challenge to achieve good quality and reliable coverage. This research provides information to assist mining professionals in designing voice or data communication systems that operate underground by transmitting along mine tunnels. This has been achieved by presenting a simplified model for predicting the propagation of microwave signals and supplementing this with the results of an extensive experimental study aimed at understanding how the performance predicted by the model differs from real-world performance. The results validate the model under ideal conditions but additional signal attenuation is shown to occur when operating close to a wall, behind a partial obstruction or in a side tunnel. Experimental results indicate the typical magnitude of such additional attenuation. Also, long- and short-range fluctuations to the predicted average is demonstrated and their typical magnitude shown. A system planning approach is outlined.

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## Introduction

The use of radio in underground mines – in the form of wireless sensor networks, Wi-Fi networks and voice links, and utilised in the areas of monitoring and control, personnel or asset tracking and person-to-person communication – is not nearly as well established as in many other industries, despite its advantages compared to wired links. This is due, in part, to the fact that radio propagation along tunnels is not as fully understood as in other environments despite ongoing research.

The propagation of radio waves in tunnels has been extensively studied by several researchers during the last 40 years at a range of frequencies from LF to microwave. For example, extensive studies were reported in (Emslie et al. 1975; Legace et al. 1975), involving UHF and microwave frequencies. The main conclusion drawn was that, at the higher UHF and microwave frequencies, tunnels act as lossy dielectric waveguides.

A recent review of approaches for modelling the propagation of radio signals in tunnels is presented in (Hrovat et al. 2014). Four main techniques were identified: numerical solutions to Maxwell's equations, ray tracing, empirical two-slope modelling and modal analysis.

Maxwell's equations, that define the variations of electric and magnetic fields in space, can be solved by several numerical methods such as FDTD (Finite Difference, Time Domain) modelling. (Ramirez et al. 2011; Zhou & Jacksha 2015a) have described how the FDTD approach can be used for modelling radio propagation in tunnels but the technique remains highly computationally intensive.

Modelling based on ray tracing is able to characterise tunnel propagation with a high degree of accuracy, e.g. (Mahmoud & Wait 1974; Hwang et al. 1998; Choudhury & Jha 2011). Modern software simulation packages rely on accurate models of the tunnels in order to predict the tunnel propagation using the geometrical ray technique. However, the necessary geometrical models of the tunnels have to be obtained using 3D surveying techniques such as laser scanning, which can be onerous. This is especially true in mines that could contain many kilometres of passage and where the characteristics of the passages can change on a day-to-day basis. Such changes occur due to moving machinery and vehicles plus the fact that the process of mining, by definition, alters the physical dimensions and architecture of some parts of a mine. This limits the value of ray tracing techniques for practical system planning.

The two slope model considers the tunnel to be split into two regions, the rate of signal attenuation in the region close to the transmitter being greater than that in the more distant region. This model has been used in a purely empirical fashion by Klemenschits and Bonek (1994), although this does not result in a high level of accuracy. Other researchers have described more than

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