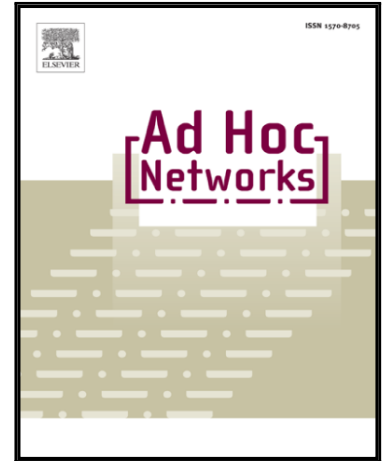


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# Connectivity Analysis of Underground Sensors in Wireless Underground Sensor Networks

Hoang Thi Huyen Trang<sup>a</sup>, Le The Dung<sup>b</sup>, Seong Oun Hwang<sup>c,\*</sup>

<sup>a</sup>Dept. of Electronics and Computer Engineering in Graduate School, Hongik University, Korea

<sup>b</sup>Dept. of Radio and Communication Engineering, Chungbuk National University, Korea

<sup>c</sup>Dept. of Computer and Information Communications Engineering, Hongik University, Korea

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## Abstract

Wireless underground sensor networks consist of sensors that are buried under the ground and communicate through soil medium. Due to channel characteristics, the connectivity analysis of wireless underground sensor networks is more complicated than that in the traditional over-the-air wireless sensor networks. This paper focuses on analyzing the connectivity of underground sensors in wireless underground sensor networks in terms of the probability of node isolation and path probability which captures the effects of the environment parameters such as soil moisture and soil composition, and system parameters such as sensor node density and propagation techniques. Throughout this paper, both qualitative and quantitative comparisons between electromagnetic wave system and ordinary magnetic induction system for underground communications are provided. More specifically, we derive the exact closed-form mathematical expressions for the probability of node isolation of these two communication systems and validate the correctness of analytical models through simulations. We also provide the simulation-based path connectivity of these two communication systems. The results obtained in this paper provide useful guidelines on the design of reliable wireless underground sensor networks.

*Keywords:* Wireless underground sensor networks, soil medium, isolation probability, path connectivity

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## 1. Introduction

Wireless underground sensor networks (WUSNs), which is one of the categories in wireless sensor networks (WSNs) [1], consist of wireless sensors buried under the ground, constitute one of the promising areas and enable many important applications such as intelligent agriculture, pipeline fault diagnosis, mine disaster rescue, oil exploration, and earthquake disaster prediction [2]. The main difference between WUSNs and the terrestrial WSNs is communication medium, which is no longer air but soil, rock, or water with electrolytes. Consequently, the buried sensor nodes can only communicate wirelessly through soil medium.

There has been a tremendous amount of researches on the channel characteristic analysis of WUSNs. In [3], [4], [5], the underground signal propagation for electromagnetic (EM) wave system has been analyzed

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\*Corresponding author

Email address: sohwan@hongik.ac.kr (Seong Oun Hwang)

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