Wireless Communication Capabilities of ZigBee Protocol and Magnetic Field Area Network (MFAN) for Developing USN Aided GIS for Underground

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ABSTRACT

One of the major implementations of GIS is the stewardship of spatially distributed infrastructures, and incorporating Ubiquitous Sensor Network (USN) into GIS has become highlighted for advanced stewardship of infrastructures. Current USN systems, which employ electromagnetic wave signals, may suffer serious attenuations when transmitting data in underground environments. In an attempt to propose an alternative wireless protocol tailored for USN aided GIS for underground, this paper presents an experimental study of wireless data transmission characteristics of two wireless protocols, ZigBee and Magnetic Field Area Network (MFAN). Wireless communication capabilities of the protocols were evaluated through soil, water and concrete wall. Test results justify the employment of MFAN for USN aided GIS for underground; the transmission of MFAN is independent on the media type while this is not the case for ZigBee.

Keywords : GIS, Ubiquitous Sensor Network (USN), ZigBee, Magnetic Field Area Network (MFAN)

1. Introduction

One of the major implementations of GIS is the stewardship of spatially distributed infrastructures. In South Korea, GIS has been successfully implemented to infrastructure monitoring and construction management (Chun et al., 2007; Sun et al., 2008).

Incorporating Ubiquitous Sensor Network (USN) into GIS has recently become highlighted for advanced stewardship of infrastructures (Hoult et al., 2009). Underground infrastructures, such as water/sewer facilities, are undoubtedly critical for public services. Accordingly, application of USN to underground environments is a challenging issue at present (Akyildiz and Stuntebeck, 2006).

However, currently available USN systems have a serious limitation to be implemented to underground; the significant attenuation of electromagnetic waves through non-air media such as soil, water and concrete. Therefore the implementation of USN aided GIS system has been limited to monitoring pipelines and tunnels where data is able to be transmitted through air (Stoianov et al., 2009).

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To overcome such limitation a wireless protocol that can transmit data even in non-air media is necessary. In an attempt to propose an alternative wireless protocol tailored for USN aided GIS for underground, this paper presents an experimental study of wireless data transmission characteristics of two wireless protocols, ZigBee and Magnetic Field Area Network (MFAN), through media composing underground environments. Wireless communication capabilities of the two protocols were evaluated through soil, water and concrete wall. Test results are discussed in terms of the potential for developing USN aided GIS for stewardship of underground infrastructures.

2. Test Program

2.1 Tested wireless protocols – ZigBee and MFAN

Two wireless protocols are selected in this study; ZigBee and MFAN. ZigBee stands for a specification for a suite of high-level communication protocols for USN. Since it uses small, low-power digital radios that require a low data rate, long battery life and secure networking, it is one of the common wireless protocols for embedded applications with low data rates and power consumption.

In this study, ZigBee protocol made in Electronics and Telecommunications Research Institute (ETRI) is used. Figure 1 shows the ZigBee board and the antenna.

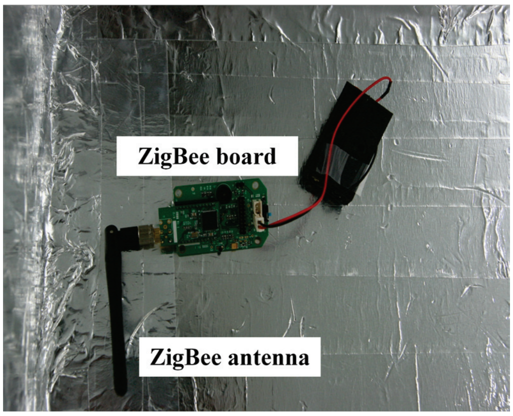

FIGURE 1. ZigBee board and antenna

MFAN is intended to be an alternative protocol of electromagnetic field wave based wireless protocols, by employing magnetic field signals for networking (Kim et al., 2009). For magnetic field signals the permeability of most material is very close (within 0.01%) to that of free space. However, the shortcoming of MFAN is severe attenuation by distance owing to that magnetic field strength in the near field falls of as $1/R^3$ whereas that of electric field falls of as $1/R^2$ (R: distance from antenna). MFAN made in Korea Electronics Technology Institute (KETI) is used in this study. Figure 2 shows the MFAN board and the antenna.

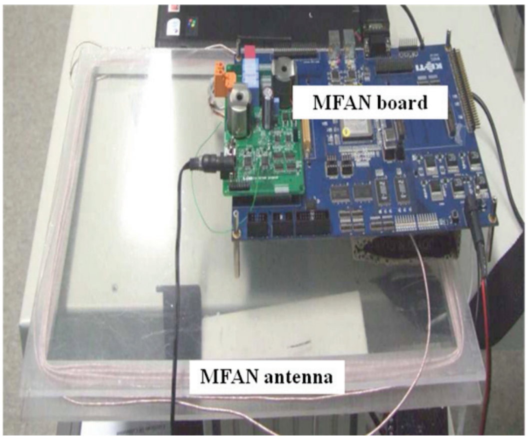

FIGURE 2. MFAN board and antenna

2.2 Test conditions

Underground environments consist of two types of media: porous (e.g. soil and rock) and non-porous (e.g. water and concrete) materials. The test program aims to estimate wireless data transmission capabilities through both types of media, therefore communication intensities were measured through soil, water and concrete.

3. Results and Discussions

3.1 Transmission through soil

Wireless transmission intensities of the two modules were measured through varying the depth of boards in ground. For the tests, the ZigBee and MFAN boards were enclosed together in a waterproof acryl box. Figure 3 shows the acryl box containing the two boards. Since ZigBee uses 2.4 GHz high-frequency range while MFAN uses 125 kHz low-frequency range, the interference between two protocols can be neglected.

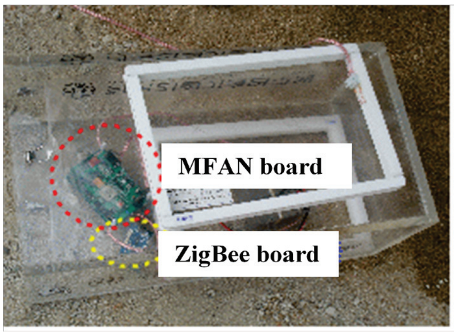

FIGURE 3. ZigBee and MFAN boards in a waterproof acryl box

The depths of boards were 0 cm (i.e. on the ground), 25 cm and 50 cm. Antennas receiving data were located at the top 50 cm of the ground for every test. The soil was granular sand which can represent a typical ground characteristic in greenfield. Figure 4 is a photograph of the transmission test through soil.

FIGURE 4. Transmission tests through soil

Table 1 presents the measured intensities of two protocols when the boards were buried in soil. Note that quantification of the intensities is different for each protocol. For ZigBee, the intensities are converted into dBm which is proportional to the communication intensity of Zigbee. On the other hand, the intensity of MFAN is quantified by a non-dimensional number which is also proportional to the communication intensity of MFAN.

TABLE 1. Transmission intensities through soil

Depth	ZigBee	MFAN
0 cm	-45 ~ -61 dBm	134
25 cm	-77 ~ -94 dBm	124
50 cm	-90 ~ -92 dBm	130

It is observed that the ZigBee can transmit data even in porous media (i.e. soil) to some extent. Nonetheless, the transmission intensity clearly decreases as the depth of the board increases. This phenomenon is attributed to that the electromagnetic signal wave dramatically attenuates as it passes through soil particles (or pore water) whose dielectric constants are much higher than those of air (≈1). Therefore, the wireless communication by ZigBee may be practically unavailable when the depth increases or pore air trapped in the wave pathways is insufficient (i.e. low porosity) to the propagation.

On the other hand, the transmission intensity of MFAN is virtually independent on the depth, since the degrees of magnetic permeability of air and soil particles are practically identical for magnetic wave signals.

3.2 Transmission through water and concrete

Besides porous media such as soils and rocks, groundwater exists in underground. Moreover, man-made non-porous materials such as concrete or metal may also compose the underground in civilized region. Therefore wireless transmission characteristics through non-porous media are also necessary to be estimated.

Wireless data transmission was measured by both protocols through water and concrete. Two boards are separated in these tests due to heavy weight of the box. Figure 5 shows the test of ZigBee in water with cased ZigBee board by a plastic bottle. MFAN was tested in a different method since it propagates data as an area network without directivity. Figure 6 shows the ZigBee and MFAN boards in a room surrounded by concrete walls. The data were continuously measured as moving the antennas to outside the room.

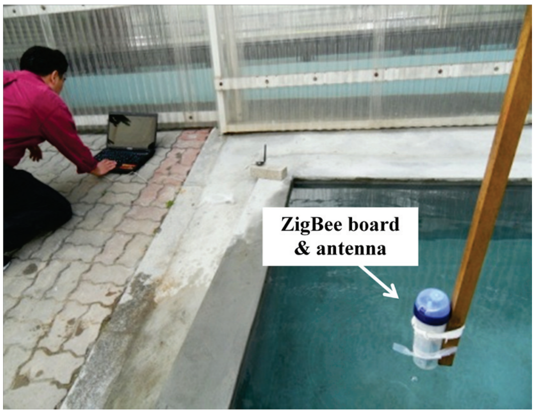

FIGURE 5. Transmission tests through water

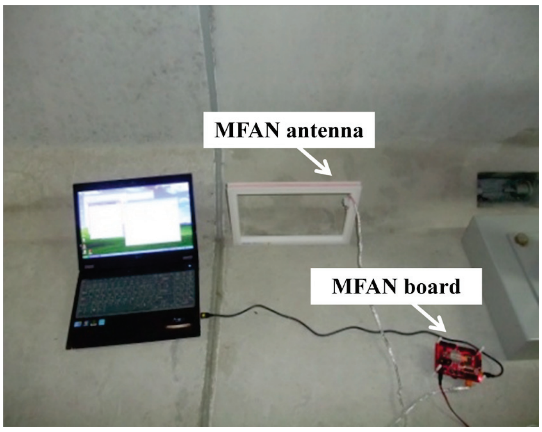

FIGURE 6. Transmission tests through concrete

Figure 7 is an illustration of the measured transmission intensity of ZigBee from the tests through concrete wall. After one of the antennas located behind the concrete wall, the intensity clearly decreased to be less than -70 ~ -75 dBm. Similar results were also obtained by the tests through water and they show more dramatic attenuation.

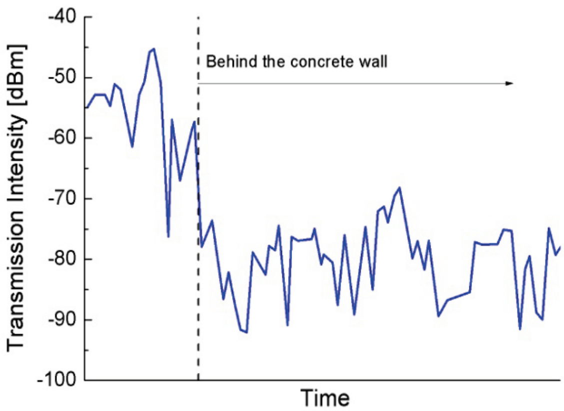

FIGURE 7. Measured transmission intensity of ZigBee in a room surrounded by concrete wall

Since the attenuation of electromagnetic wave signal is more severe through non-porous media than porous ones, test results are compared by a different criterion from the previous one. Comparisons are made in terms of the maximum transmission distances (not by intensities with distances) because the ZigBee is unable to transmit data even in shorter distances than 25 cm. Table 2 summarizes the estimated maximum transmission distances of the two protocols.

TABLE 2. Maximum transmission distances through water and concrete

Medium	ZigBee	MFAN
Water	8 cm	> 50 cm
Concrete	15 cm	> 50 cm

Test results indicate that it is practically impossible for ZigBee to comprise USN in underground, particularly when non-porous materials such as water and concrete compose the transmission media.

In sum, for the propagation of electromagnetic wave signals, a medium with low dielectric constant (e.g. air) is essential. On the other hand, the propagation of magnetic wave signals is only affected by the magnetic permeability of transmission medium so it is applicable to various environments.

4. Conclusions

This paper has presented an experimental comparison of two wireless protocols, ZigBee and MFAN, to select a proper protocol for comprising USN in underground. Wireless transmission characteristics of the two protocols are compared through soil, water and concrete which are the major compositions of underground environments. Conclusions of this study can be drawn as follows.

1) Through soil (a porous medium) the transmission intensity of ZigBee attenuates because the dielectric constants of soil particles are much higher than air. ZigBee based USN is expected to have a malfunction in deep underground or soils with low porosity. On the other hand, wireless data transmission characteristics of MFAN is practically unaffected by the existence of soil.

2) Through water and concrete (non-porous media) the ZigBee suffers more severe attenuation than soil owing to the lack of air in the medium. The maximum distances that can be transmitted by ZigBee are 8 cm in water and 15 cm in concrete. MFAN is, however, always capable of wireless communication regardless of the type of media.

3) To develop USN aided GIS for underground, therefore, MFAN is strongly recommended. Once the antenna of MFAN becomes optimized, MFAN implemented USN is expected to enhance GIS for underground infrastructures in terms of performance and economic aspect.

Acknowledgments

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