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Review

Overview of wireless underground sensor networks for agriculture

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In recent years, many applications have been proposed for wireless sensor networks (WSN). One of these is agriculture, where WSN can play an important role in the handling and management of water resources for agricultural irrigation and so on. The WSN suffer from intensive human involvement and delay of information. This paper shows that the wireless underground sensor networks (WUSN), which communicates in the soil is different from the terrestrial WSN. WUSN devices are deployed completely below ground and do not require any wired connections. Each device contains all necessary sensors, memory, a processor, a radio, an antenna and a power source. Here, the WUSN architecture for agriculture information system is introduced. The framework to deploy and operate the WUSN is developed. Based on the framework, WUSN in different frequency, buried depth and volumetric water content of soil are tested and results are discussed.

Key words: Wireless sensor networks (WSN), information collection, agriculture, wireless underground sensor networks (WUSN), buried depth, sensor node.

INTRODUCTION

Wireless sensor networks (WSN) in agricultural information are composed of most integrated sensors deployed in the area of the farmland, these sensors cooperate with each other to perceive and monitor real-time soil and weather information of crops (Baronti et al., 2007; Camilli et al., 2007; Carle and SimPlot-Ryl, 2004; Shih et al., 2001; Erich et al., 2006; Aqeel et al., 2011). Moreover, information perceived is transmitted to diagnosis decision center through the random self-organization wireless communication network, which receives the remote monitoring and management of the agricultural environment and the crops information (Sheth et al., 2005). Unfortunately, traditional WSN techniques cannot provide real-time data and hence, cannot fully meet these requirements. Moreover, the use of wired sensors, that must be installed and removed frequently, increases the total cost of the solution and decreases the density of sensors for a certain area (Agnelo et al., 2010).

Wireless underground sensor networks (WUSN) consist of wirelessly connected underground sensor nodes, communicated through soil and have the potential to impact a wide variety of novel applications (Li et al., 2007; Akyildiz et al., 2002, 2009; Akyildiz and Stuntebeck, 2006). In particular, agriculture uses wireless underground sensor networks to monitor soil conditions such as water and mineral content. WUSN has several remarkable merits, such as strong concealment, ease of deployment, timeliness of the data, reliability and potential for coverage density (Akyildiz and Stuntebeck, 2006). Besides monitoring static parameters of soil, the wireless underground sensor networks can also be used

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Abbreviations: WSN, Wireless sensor networks; **WUSN,** wireless underground sensor networks.

for monitoring soil motion, landslide, earthquake, debris flow, movement of underground ice and volcanic eruptions also can be predicted (Sun and Akyildiz, 2008).

Currently, research and promotion of the terrestrial WSN in agriculture application is quite extensive and advanced, but WUSN is a new subject, which has no definite results while in the stage of research. In this work, however, we considered WUSN buried underground which communicates through soil. The main difference between the well-established techniques in terrestrial WSN is the communication medium, which prevents a straightforward characterization of underground wireless channel. Moreover, we presented existing research of WSN and WUSN in agriculture which provides deployment of underground nodes. The results obtained from this study reveal that underground communication is severely affected by frequency and soil properties, especially, the volumetric water content of soil. Accordingly, important considerations for the deployment and operation of WUSN are discussed.

RELATED WORK

Existing research on the WSN technology in agriculture

Recent developments in communication techniques for WSN have resulted to a vast amount of applications in agriculture. WSN is used mainly for management decisions of irrigation water resources, storage management of agricultural products, time determination of the crop harvest, characteristics of crop growth, forecast of fertilizer demand (Berman et al., 2004) and so on.

Wireless sensor technology has been tested for agricultural land use to improving precision agriculture (Bogena et al., 2007). The temperature change in different position of feed warehouse was monitored through wireless sensor networks which were introduced (Green et al., 2009). Wireless sensor networks was applied successfully for monitoring of soil water content, temperature and salt in a cabbage farm of Spain semi-arid regions, Murcia (Lopez et al., 2009). The wireless sensor networks were applied in information monitoring of water saving irrigation systems (Feng et al., 2007). Communication of the greenhouse wireless monitoring system was realized through wireless sensor networks based on ZigBee (Zhang et al., 2008). The wireless sensor network was a kind of network whose energy was limited, reasonable clusters were determined and the energy model used in communication was given according to the number of nodes and characteristics of regional distribution (Li and Wen, 2008). Collection node system of farmland information based on WSN was designed (Cai et al., 2009).

Existing research on the WUSN technology in agriculture

WUSN has been investigated in many contexts recently. Research reports on WUSN in agricultural application are few, though the present study include mainly path loss, bit error rate, maximum transmission distance, test error of water content of path transmission of the electromagnetic wave under the main influence factors; these factors are soil types, volumetric water content of the soil, depth of nodes buried, internodes distance, the range of frequency, etc.

In the laboratory, wireless signal attenuation of ZigBee wireless transceiver module of the 2.44 GHz frequency was researched by using soil column in different soil types and the water content (Bogena et al., 2009). Network system structure of wireless underground sensor networks system aiming at intelligent transportation system and maintenance of the near surface soil was designed (Li and Wen, 2008). The performance of the wireless underground sensor networks which was influenced by propagation of electromagnetic waves in the soil, underground channel model, electrical characteristics of soil and deployed solutions of wireless underground sensor networks nodes was also studied (Li and Wen, 2008). Agnelo et al. (2010) studied the influence of the communication performance between the terrestrial nodes and the underground nodes in some factors, including antenna bandwidth of WSN nodes in 433 MHz frequency, the buried depth of nodes in the soil and water content of the soil. The near surface WUSN system used for golf course was developed and the acquisition node, relay node and gateway node were designed (Coen et al., 2009). It has been shown that rainfall and stormy weather environmental conditions, the soil compactness, soil density and vegetation cover degree, topology structure parameters of wireless underground sensor networks, sampling time and sampling density had great influence on the distortion degree of the soil moisture acquisition signal (Xin and Mehmet, 2010).

SYSTEM ARCHITECTURE OF WUSN NODE

The design of the wireless sensor node uses the modularizing design method. The architecture of WUSN is shown in Figure 1. The system structure of the entire nodes is composed of sensor module, processor module, wireless communication module and energy supply module.

This design takes digital sensor DS18B20 to collect soil water content. DS18B20 is produced by Dallas Company of the United States, which is one of the single line digital temperature sensors. It has many advantages such as miniaturization, low power consumption, high

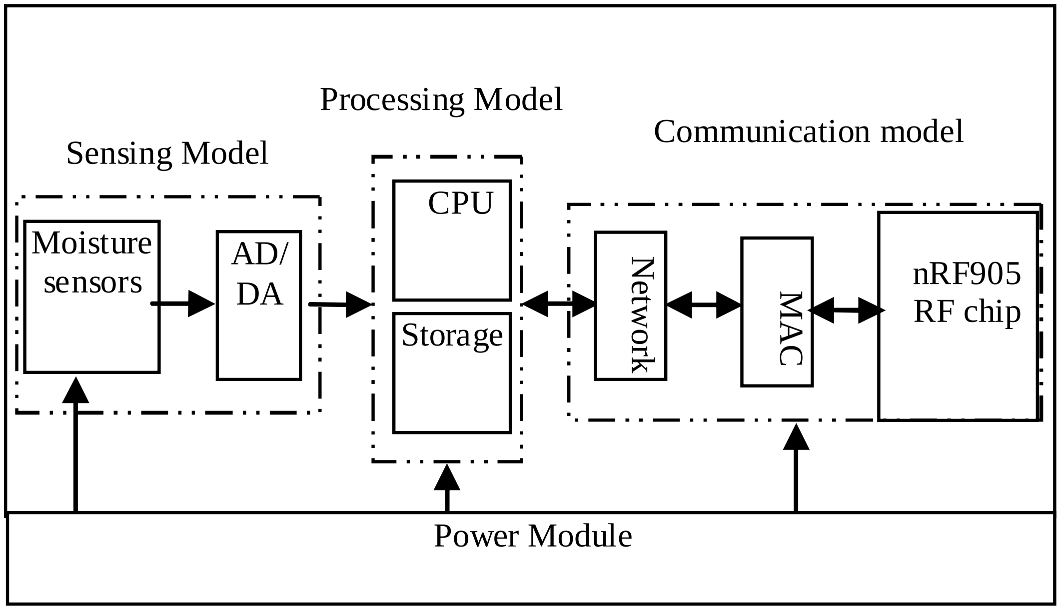

Figure 1. Architecture of wireless sensor network node.

performance and strong anti-interference ability and is an easy to match microprocessor (Zhang et al., 2005). The microcontroller adopts 16 bit series MSP430 launched by TI Company. It has a unique advantage in low power applications. MSP430 has very high levels of integration. This microcontroller has many functions, such as cost-effective, strong anti-interference ability. WUSN uses nRF905 wireless chip to complete information collection and transmission. In addition, sink node has the same architecture as the WUSN node.

In this work, sink node is only laid on the ground in WUSN, all nodes in underground will transmit data eventually to the terrestrial sink node, which can make the whole network have better concealment. WUSN node set depends on the specific application. It can be displayed in the same depth, can also be displayed in different depth and can even be set as different layer. The sink node is fixed or movable, which keeps it in the range of communication, the topological structure as shown in Figure 2.

CLASSIFICATION OF WUSN AND DEPLOYMENT STRATEGIES

Although a novel area, a detailed classification of WUSN is necessary since several different scenarios with very specific issues, are presented under WUSN. As shown in Figure 3, communication of the WUSN can be mainly classified into two: topsoil wireless underground sensor networks and subsoil wireless underground sensor networks.

Soil subsurface is classified into two regions: the topsoil region, which refers to the first 30 cm of soil, or the root growth layer, whichever, is shallower, and the subsoil region, which refers to the region below the topsoil, that is, usually the 30 to 100 cm region. Accordingly, as shown in Figure 1, WUSN can be classified as a function of the deployment region: topsoil WUSN, if the WUSN is deployed in the topsoil region, or subsoil WUSN, if deployed in the subsoil region.

To the best of our knowledge, we particularly consider agricultural applications of WUSN, which usually require burying depths greater due to plowing and similar mechanical activities occurring in the soil. Accordingly, the majority of the experiments consider a better burying depth. Here, sensor nodes are buried under cultivate layer, so that the soil water content in real time can be gotten. The deployment of wireless underground sensor network node is shown in Figure 4.

EXPERIMENT SETUP AND RESULTS OF WUSN

In this trial, we assumed the clay percent as 15%, the silt percent as 35%, the sand particle percent as 50%, the bulk density as 1.5 g/cm^3 and the solid soil particle density as 2.6/cm^3 unless otherwise noted. WUSN nodes are buried in certain depth of soil, resulting in propagation of wireless electromagnetic wave in the soil by two ways, one is penetrating soil directly to the ground, and the other is the transmission method of the communication between WUSN nodes.

Through design and test of the WUSN node, this paper

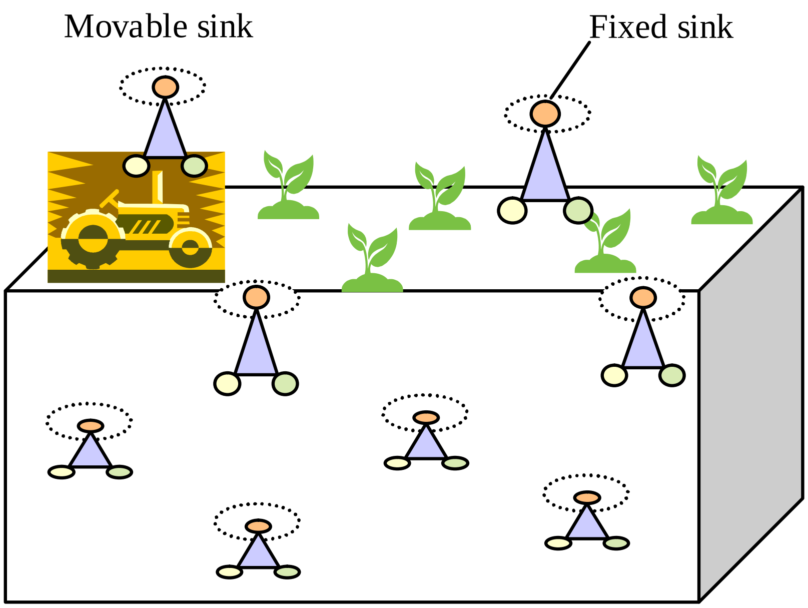

Figure 2. Topology structure of wireless sensor network.

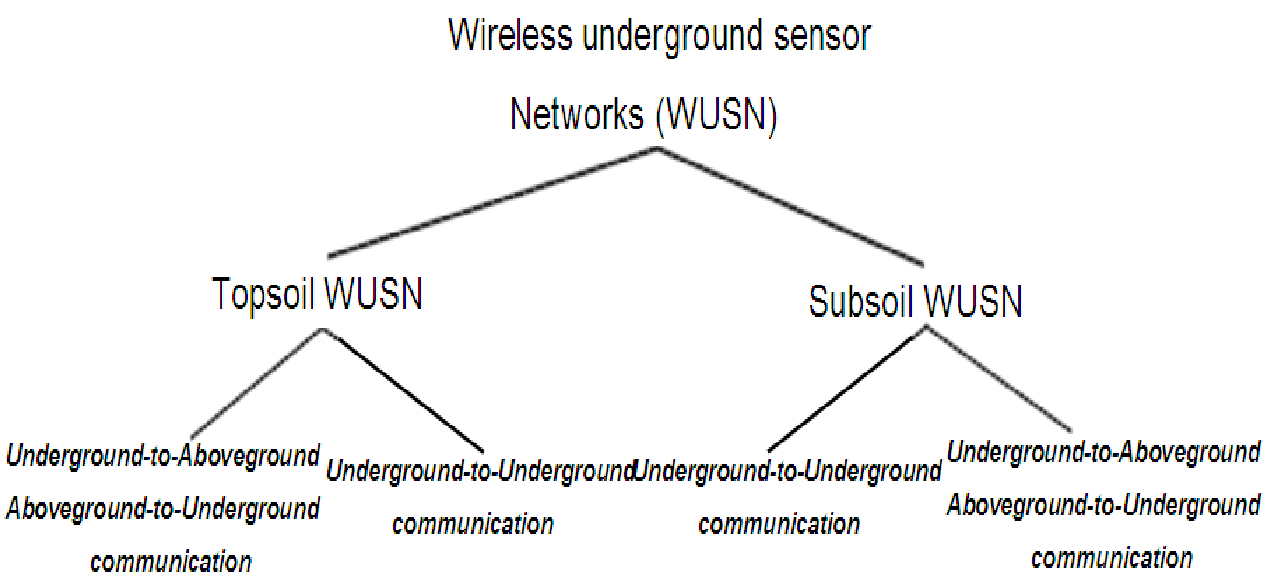

Figure 3. Classification of wireless underground sensor networks.

needs to study the characteristic relationship between volumetric water content of soil, node depth, the signal frequency and attenuation in the process of the transmission and get applicative conclusion. It is expected that this will be of great help for developing the wireless underground sensor networks system. The results are presented considering how some important parameters affect the wireless underground sensor networks communication: the burial depth, the nod frequency and volumetric water content of the soil.

Path loss is the difference in value between real signal strength received and source signal strength level, namely the signal attenuation extent; it reflects directly the efficiency of wireless electromagnetic signal transmission. Figure 5 describes the path loss of the wireless signals caused by soil volumetric water content change in different frequencies. In Figure 6, the path loss is shown as a function of burying depth, for various operating

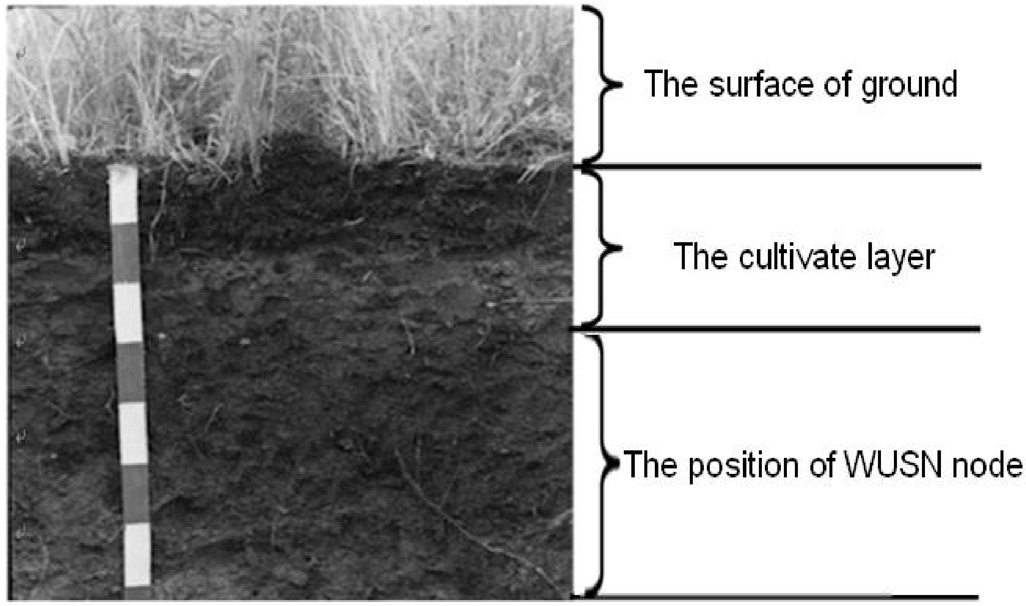

Figure 4. Schemes of WUSN nodes deployed.

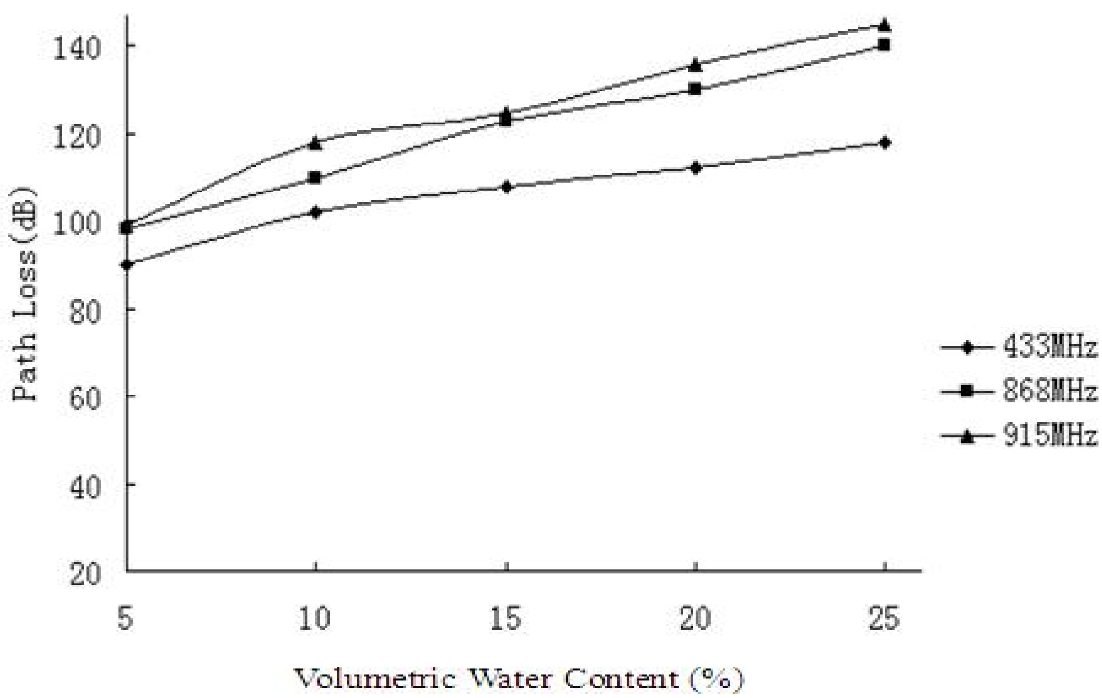

Figure 5. The relationship between path loss, operating frequency and volumetric water content.

frequencies.

As shown in Figure 5, an increase in node frequency as well as increases in the path loss is expected. The path loss is the least when frequency is 433 MHz. Moreover, the volumetric water content of soil is also an important factor that affects the path loss. So, the signal attenuation increases with the increase in water content. It can also be observed in Figure 5, that the path loss of 915 and 868 MHz RF frequency node is nearly the same when the volumetric water content is 15%.

The experiments show that a higher burying depth also implies an increase in the soil path and higher attenuation

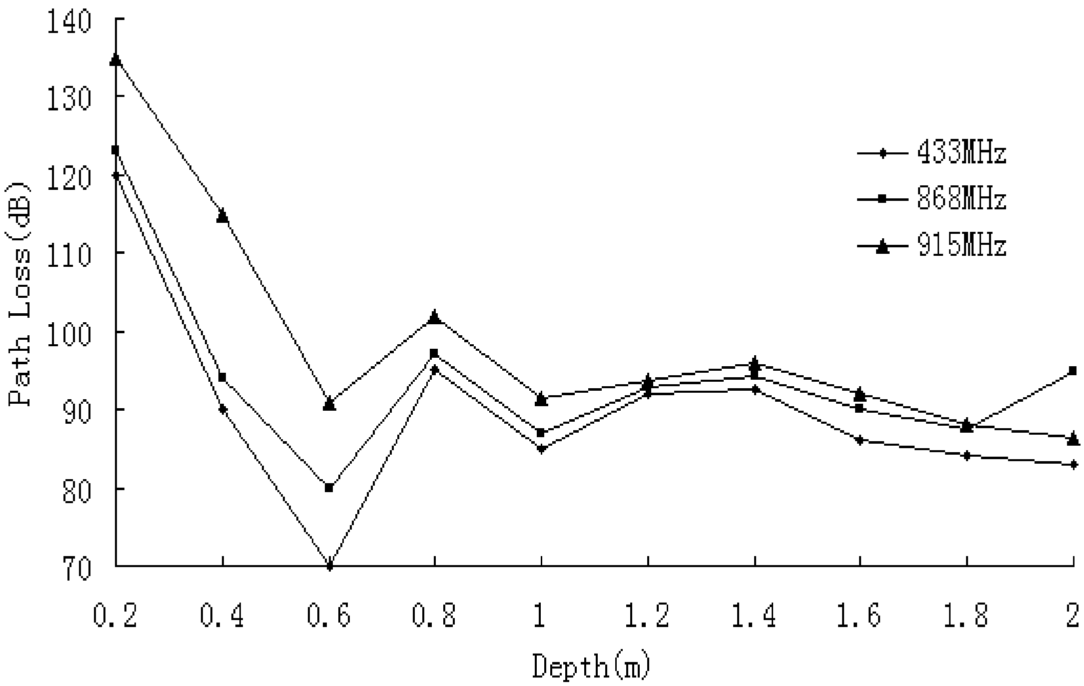

Figure 6. The relationship between path loss, operating frequency and burial depth.

is observed at higher depth. It is well known that EM waves that propagate from a medium with a lower dielectric constant such as air to another one with a higher constant such as soil are highly reflected. Consequently, the air-soil interface causes an additional attenuation. Moreover, a shallower burying depth of the node can significantly enhance underground communication. As shown in Figure 6, the loss path changes with node frequency and burial depth. Note that the path loss is the lowest (70 dB) when the buried depth of node is 0.6 m and node frequency is 433 MHz. Therefore, for a given node deployment, there are many suitable frequency and burying depth in the hybrid wireless sensor networks.

CONCLUSIONS

In this paper, we proposed a classification of wireless underground sensor networks and presented experimental results for WUSN communication. The work provides insight into communication through soil using wireless sensor networks.

The results of the experiment reveal the feasibility of WUSN in agricultural application. Firstly, the results show that the burial depth is important for the WUSN tests due to the effects of reflected rays from the underground-air interface at the surface. Moreover, we have shown that the volumetric water content of soil plays an important role in the communication of WUSN. The results reveal that a 20% increase in the soil moisture increases the path loss by more than 30%. In addition, the wireless underground channel has been found to exhibit extreme temporal stability, which is important in the design of routing and topology control protocols.

As compared to that in air, the underground communication exhibits significant challenges for the development of wireless underground sensor networks. Among these challenges, the attenuation caused by the soil is the most important aspect of underground communication and has to be completely characterized. Through experiments, it is shown that in the zone of 400 MHz frequency band, the path loss can be limited to a degree supporting feasible communication. The results of this work lay the foundations of underground communication and will help in the future research and applications of wireless underground sensor networks, which is a promising application area for wireless sensor networks.

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