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Full Length Research Paper

The research of an advanced wireless sensor networks for agriculture

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The advanced wireless sensor networks constitute one of the promising application areas of the recently developed wireless sensor networking techniques. It contains two parts: the terrestrial wireless sensor networks (WSN) and the underground wireless sensor networks (WUSN). The main difference between the hybrid WSN and the conventional wireless sensor networks is the aspect of WUSN, which communicates in the soil. The terrestrial WSN suffer from intensive human involvement and delay of information. There lacks a coherent system that coordinates various technologies including the terrestrial and underground sensor networks to improve the system. In this paper, the hybrid wireless sensor network architecture for agriculture information system is introduced. The framework to deploy and operate the hybrid WSN is developed. Based on the framework, research tests and results are discussed.

Key words: Hybrid wireless sensor networks (WSN), information collection, agriculture, wireless underground sensor networks (WUSN), monitoring.

INTRODUCTION

Agricultural parameter information is a kind of spatial and three-dimensional network information. The perception, processing, integration and application of the information are the main content of agricultural environment information technology, and they are also the main focus and one of the key problems in the field of contemporary international agricultural science and technology research. Because there are some characteristics in agriculture, such as the regional scattered, terrain changes, different environmental conditions etc, method that collects crop growth environment variable information accurately and rapidly is one of the primary problems to solve in the agricultural environment information technology research (Mehmet and Akyildizy, 2007).

The application of WSN technology is the main technical means to solve the problem. Wireless sensor networks in the agricultural environment 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. Moreover, information perceived is transmitted to diagnosis decision center through the random self-organization wireless communication network, which realizes the remote monitoring and management of the agricultural environment and the crops information. Recently, WSN in the agricultural environment information have been developed significantly (Slijepeevie and potkonjak, 2001; Akyildizy and Stuntebeck, 2006) and used in agricultural irrigation, cultivation, fertilizer management, and so on.

At present, most wireless sensor networks in soil environmental information belong to terrestrial wireless sensor networks system. The wireless sensor networks are usually connected to data access and wireless

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transceiver devices on the ground in the way of cable in order to avoid communicating in the soil. These devices exposed on the ground influence farming, and wireless nodes will be affected in their own wireless transmitting functions because of such natural geographical and meteorological factors. Based on these disadvantages, WUSN provide a new way for underground communication (Carle and SimPlot-Ryl, 2004; Martinez et al., 2004), it also becomes research direction of the agricultural environment information technology.

WUSN in soil environmental information is the sensor network which is constituted of wireless underground sensor devices with sending and receiving functional modules in the soil. These devices are buried completely in certain depth of soil, and data are sent through wireless means when induction module perceives data, then, the sensor networks complete the whole process of data perception and collection. The sensor networks have several remarkable merits, such as strong concealment, ease of deployment, timeliness of the data, reliability, and potential for coverage density. Besides monitoring static parameters of soil, the wireless underground sensor networks can also be used for monitoring soil motion, landslide, earthquake, debris flow, movement of underground ice and volcanic eruptions (Akyildizy and Stuntebeck, 2006) also can be predicted. Therefore, the wireless underground sensor networks have wide application prospects in agriculture, military, transportation, building industry, prediction of natural disasters (Shih et al., 2001; Akyildizy et al., 2009).

Currently, research and promotion of the terrestrial wireless sensor networks in irrigation control system is quite extensive and mature, but wireless underground sensor networks is a new subject, which has not the definite results of the study while in the stage of research (Akyildizy et al., 2002; Erich et al., 2006). WSN and WUSN are combined, which form the WSN of mixed structure. Research of the hybrid WSN is applied to the monitoring area of agriculture information will be a whole new research direction.

EXISTING SENSOR NETWORKS TECHNIQUES

The wireless sensor networks technology in agriculture

WSN has also been applied in agriculture in recent years, which 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 and forecast of fertilizer demand, and so on.

The temperature change in different position of feed warehouse was monitored through wireless sensor networks were introduced. Among, communication frequency of the sensor nodes was 433 MHz, transmit power was 10 mW. The test results showed that the temperature sensor nodes were buried in the depth 25 and 50 cm of feed storehouse could transmit reliably temperature signal to gateway node, the reliability of the signal transmission was between 98.9 and 99.4%; model was built to the temperature change in different position of feed storehouse by using monitoring results of the sensor networks, the precision forecasted is between 90.0 and 94.3%.

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. The design of the wireless sensor networks included four types sensor networks topology structure nodes deployed in the field. They were soil node, environmental node, water node and gateway node. Furthermore, the software and hardware of each node were given. The management and real time measurement of the whole system were carried by the central processing computer in the farm management office. System testing was carried in two stages, including the laboratory test and the field test. The laboratory test has analyzed mainly the function of the system devices, network performance and energy consumption; measurement range, robustness and reliability of system were test mainly in the field test.

In Feng et al. (2007) wireless sensor networks were applied in information monitoring of water saving irrigation systems. In the light of irrigation needs and characteristics of fixed pipeline spray irrigation system, the system structure of a wireless sensor networks with two layers was designed. Through the analysis of the relationship between the sensing radius of the sensor and the range of shower nozzle, in theory, the expression of the least number of sensors which could percept completely the cover field and deployment method were got. Finally, the transmission method of the data was given combined with the networks structure and nodes division, and ensured the reliability of the data transmission through the method of layered fault diagnosis.

Communication of the greenhouse wireless monitoring system was realized through wireless sensor networks based on ZigBee in. A wireless sensor network frame of dynamic star was put forward according to structure characteristics of the greenhouse. Aiming at low cost and low power consumption, mobile sink nodes formed a subnet with child nodes by using the method of timing frequency hopping, in order to shorten the distance communication among peer-to-peer. A constitution of complex communication network through low power radio frequency chip NRF2401A was realized by using the method of the frame expansion, and the communication algorithm of the sensor node, control node and sink node were given. In different working status of the sink node, the network child nodes were conducted energy consumption analysis.

In Li and Wen (2008) aiming at the wireless sensor network was a kind of network which 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. On the basis of the different layer of clusters, the number of clusters was carried on the theoretical optimization analysis and experimental methods were verified respectively. The wireless sensor networks were applied for monitoring of greenhouse environment in Zhang et al. (2008). Control terminal of system was designed based on ARM9 and embedded Linux operation system, which was used for data receiving, real-time display and storage of greenhouse environment. The control terminal communicated with remote management center through the GPRS. Data acquisition of greenhouse environment was completed based on the wireless sensor networks. The sensor networks could collect 6 channel parameters information, including temperature, humidity, CO_2 content, light intensity, substrate temperature and humidity of greenhouse, respectively.

Collection node system of farmland information based on WSN was designed in. It had developed the wireless sensor networks nodes and sink nodes combined with embedded processor system. Network nodes distributed regularly in the monitored region, were responsible for the collection of the soil moisture information. The nodes formed the network by themselves and sent the information to the sink nodes to realize the dynamic display and the large capacity storage of the information. The height of nodes antenna were set in 0.5, 1.0, 1.5 and 2.0 m respectively. Wheat seedling stage, experiment was conducted in three typical growth period of wheat, such as jointing stage and heading stage, experiment results showed that effective transmission distance of the radio signal in different growth periods of wheat and the best antenna height, which provided the technical support for the application of wireless sensor network in agriculture.

The wireless underground sensor networks technology in agriculture

WUSN is a new research subject, at present, it is in the experimental study phase and also no mature products are in the market. Research reports of WUSN in agricultural application are little, 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 of Bogena et al. (2009) wireless signal attenuation of ZigBee wireless transceiver module (Soil net) of the 2.44 GHz frequency was researched by using soil column in different soil types and the water content. Experimental results showed that increase of soil column depth and volumetric water content of the soil could lead to increase of signal attenuation, the relationship could be expressed in linear model, and the correlation coefficient R^2 is greater than 0.90.

Network system structure of wireless underground sensor networks system aiming at intelligent transportation system and maintenance of the near surface soil (such as golf courses, a football field) was designed in Feng et al. (2007). The software and hardware systems of the nodes were also designed. In addition, the collect nodes used the low performance microcontroller; the receiving nodes on the ground used the high performance and more memorial microcontroller, development and testing research of network system were not carried; Feng et al. (2007) also studied that 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. In 400 MHz frequency, sensor buried depth 0.5 m, horizontal spacing of sensor 1 m, conductivity 0.1 and dielectric constant 10 under, transmission parameters of electromagnetic wave and energy losses for different volumetric water content of the soil, different proportion sand and clay soil were analyzed through MATLAB mathematical simulation software.

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 (15 and 35 cm) and water content of the soil (volumetric water content was 9.5 and 37.3%, respectively). The field experiment showed that the ultra wideband antenna could increase the communication range by more than 350% compared to the original antennas; Volumetric water content increased from 9.5 to 37.3% leaded to the transmission distance dropped by 70%; when nodes buried depth changed from 35 to 15 cm, the transmission distance of the signal for the terrestrial nodes to underground nodes (downlink transmission) increased three times and the transmission distance of the signal for the underground nodes to terrestrial nodes (uplink transmission) only increased 0.4 times.

The near surface WUSN system used for golf course was developed and the acquisition node, relay node and gateway node were designed . Underground acquisition nodes constituted of soil moisture sensor, controller, wireless transceiver (Nordic NRF905, frequency 868 MHz), antenna, memory unit and battery power module, each collection node could connect with several moisture sensors; Sink nodes were the same as acquisition nodes except no sensors, the sink nodes collected the data of acquisition nodes and could communicate with other sink nodes and gateway nodes in the certain routing algorithm; Gateway nodes controlled data storage and transmission of sink nodes, and could connect with computer or GPRS module through RS232 interface. A gateway node could connect with 31 sink nodes at the same time, and it could be remotely controlled and visited through DDI as sink nodes. Through the experiment, operation of the system was normal, soil moisture data of the different depth could be transmitted stably and accurately to the central computer.

Xin and Mehmet (2009) study found that rainfall and stormy weather environmental conditions, and 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.

System architecture

System collects soil water content through sensors. Among, This design take 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 sensor, it has many advantages such as miniaturization, low power consumption, high performance, strong anti-interference ability and is easy to match microprocessor. WSN uses wireless transceiver module CC2430 based on ZigBee agreement to realize collection of soil information, WUSN uses nRF905 wireless chip to complete information collection and transmission. In the process of design, signal transmission frequency is 433 MHz.

The design of the wireless sensor node uses the modularizing design method, the architecture of the terrestrial WSN is shown in Figure 1, the underground WSN uses nRF905 wireless chip instead of CC2430 RF chip, the structure of the entire nodes composed of sensor module, processor module, wireless communication module and energy supply module.

This design uses mixed wireless sensor network structure of the terrestrial and underground, namely traditional WSN is adopt in underground within depth 20 cm, while WUSN is adopt in more than depth 20 cm. Sink node is only laid on the ground in WUSN, all nodes in underground will data transmit eventually to the terrestrial sink node, which can make the whole network have better concealment. WUSN node is set depends on the specific application. It can be displayed in the same depth, also can be displayed in different depth and even can be set as different layer. The sink node uses fixed or movable, which keep in the range of communication, the topological structure as shown in Figure 2.

Deployment and connectivity of nodes

The field soil water content as the main monitoring objects, signal acquisition nodes are buried in cultivate layer and under cultivate layer respectively, so that the soil water content in real time can be got. The hybrid wireless sensor network node and sensor deployed as shown in Figure 3.

Because of the unique channel characteristics and the heterogeneous network architecture of the WUSN, the connectivity analysis is much more complicated than in the terrestrial wireless sensor networks and ad hoc networks. In particular, since WUSN

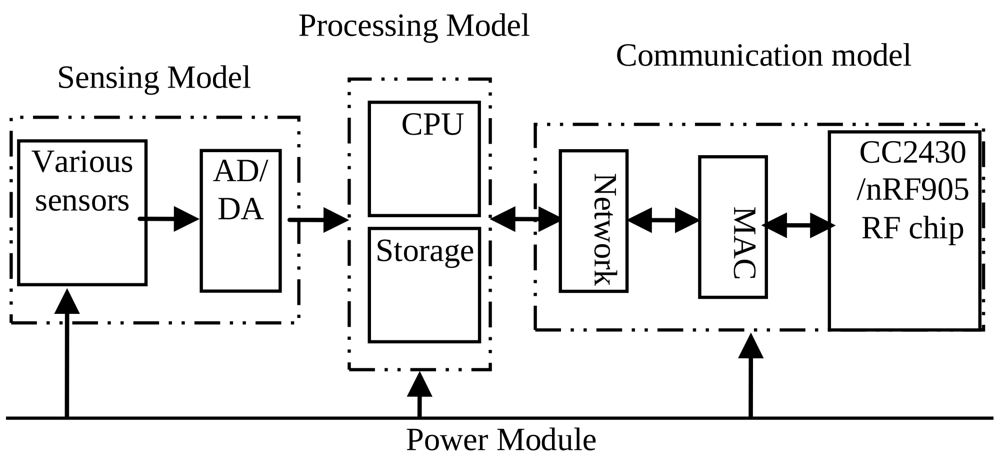

Figure 1. Architecture of wireless sensor network node.

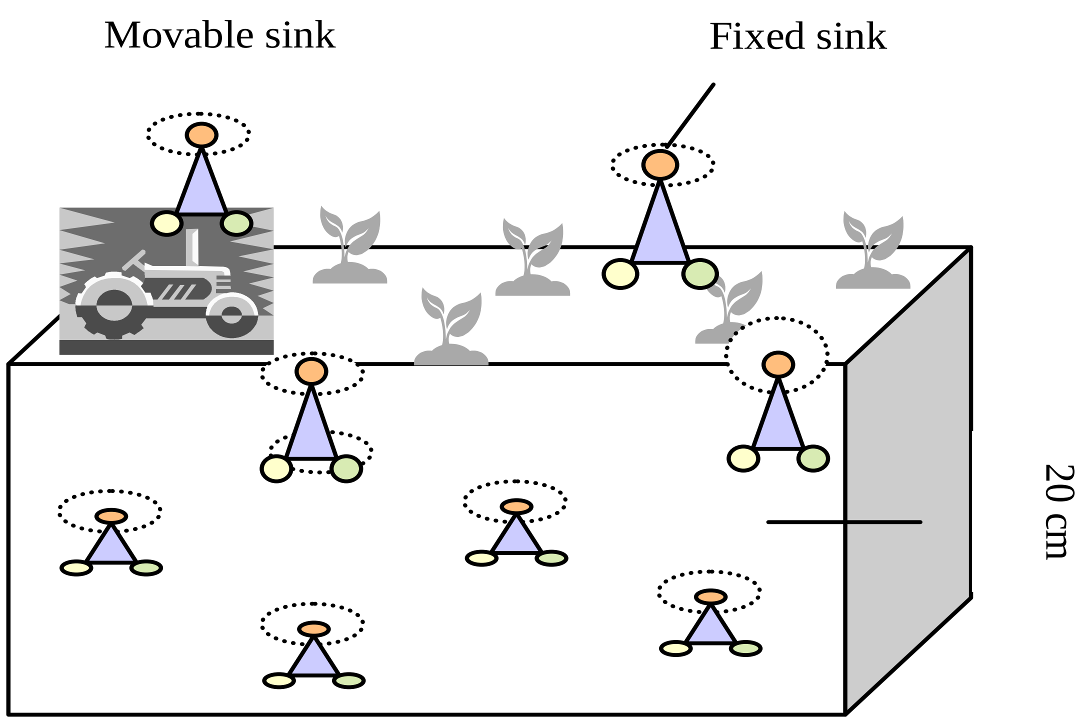

Figure 2. Topology structure of wireless sensor network.

consist of underground sensor nodes and aboveground data sinks, three different communication channels exist in WUSN based on the locations of the transmitter and the receiver, including: underground-to-underground channel, underground-to-aboveground channel, and aboveground-to-underground channel.

As shown in Figure 4, WUSN network consists of underground sensors deployed in the sensing field; fixed above-ground data sinks set around the sensing field, and mobile data sinks carried by people or machineries inside the sensing field.

EXPERIMENT RESULTS OF WUSN

Aiming at scattered regional, changeful terrain, different environment conditions features in agriculture, a long-term positioning monitoring, farmland homework should not be affected, good adaptability and conceal to the environment as a starting point, propagation characteristics of wireless underground sensor networks

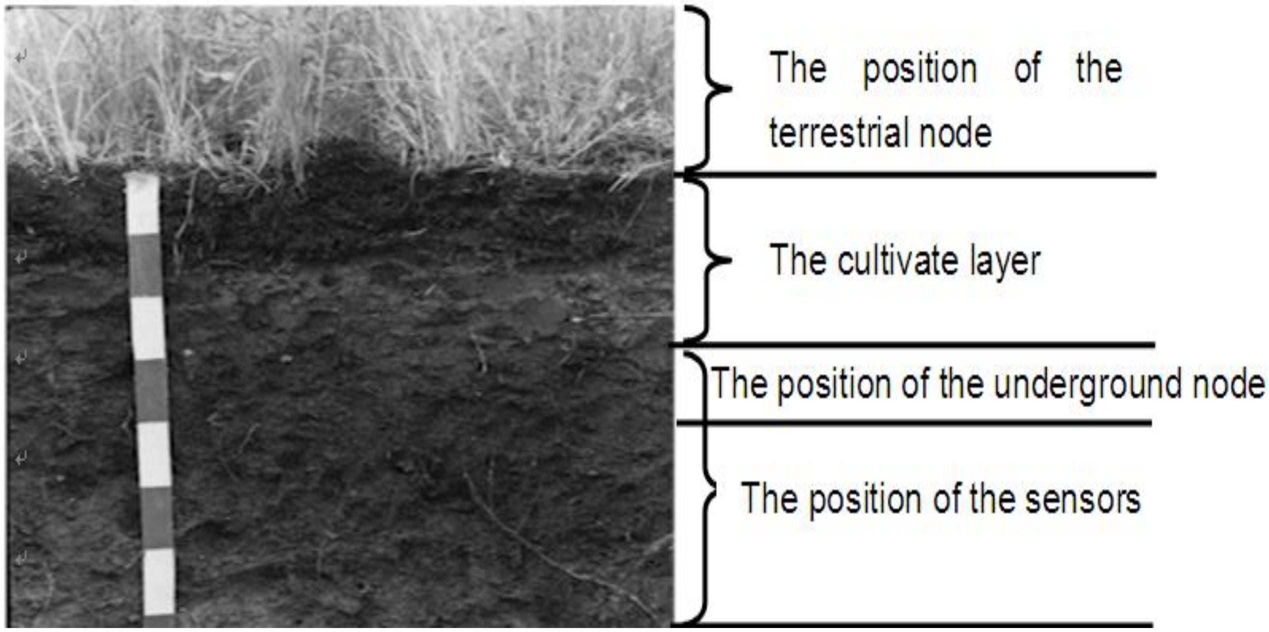

Figure 3. Schemes of WUSN nodes and sensor deployed.

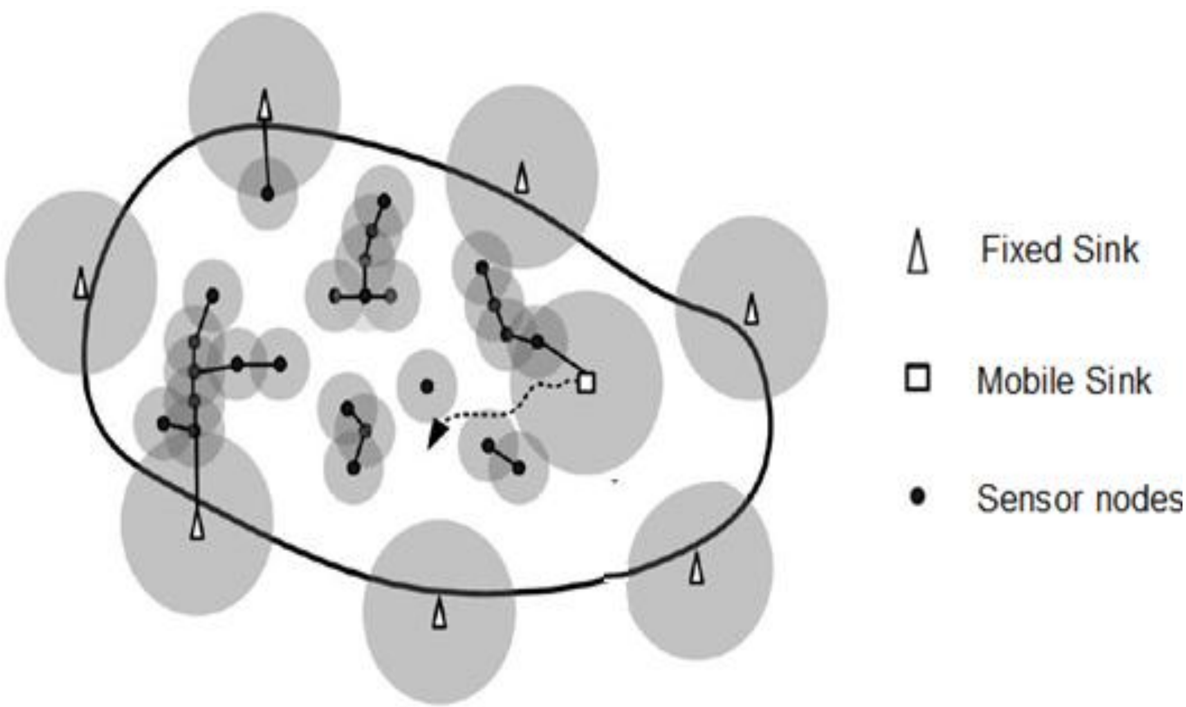

Figure 4. Connectivity in hybrid wireless sensor networks.

electromagnetic wave that monitor the multi-dimensional, networked, fast and accurately soil water content, temperature, and the salt parameters information of farmland and agricultural environment in the soil is

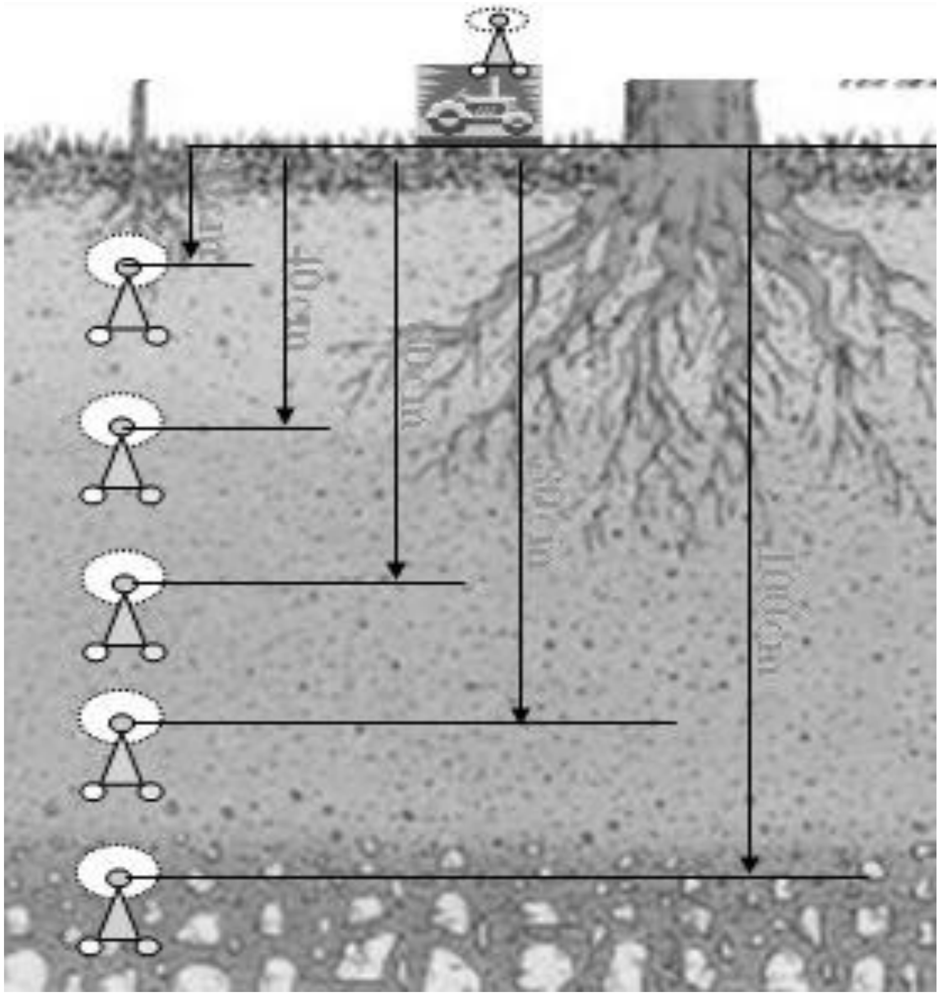

Figure 5. The main test model.

investigated, which provide technical means for the realization of the remote real-time monitor network of agriculture environment variable information.

WUSN nodes are buried in the certain depth of soil, propagation of wireless electromagnetic wave in the soil has two ways, one is penetrate directly soil to the ground, and the other is the transmission method of the communication between WUSN nodes. Through modeling, design and test of the WUSN node, this paper needs to study the relationship characteristics between soil parameters information, 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 main test model is shown in Figure 5.

Path loss is the difference in value between real received signal strength and source signal strength level, namely the signal attenuation extent, it reflects directly efficiency of wireless electromagnetic signal transmission. Figure 6 describes the path loss of the wireless signals caused by soil volumetric water content change in different frequencies. Figure 7 reflects the relationship between WUSN nodes deployed depth and the path loss under 433 MHz RF frequencies.

As shown in Figure 6, an increase in node frequency increases the path loss, as expected. The path loss is the least when frequency is 433 MHz. Moreover, the volumetric water content of soil is also an important factor to the effect of path loss. So the signal attenuation increases with the increase of water content. The Figure 6 also reveals that the path loss of 915 and 868 MHz RF frequency node is nearly the same when the volumetric water content is 15%.

It can be observed in Figure 7, that the loss path is change between 80 and 100 dB when node frequency using 433 MHz. Note that the path loss is the lowest 70 dB when the buried depth of node is 0.6 m. Accordingly,

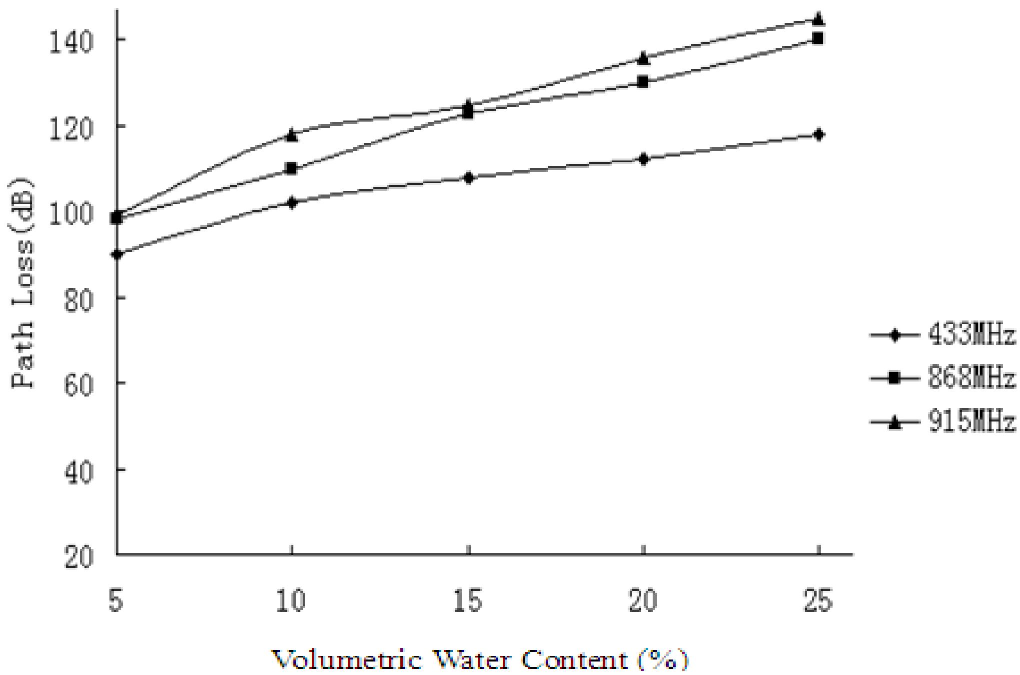

Figure 6. The relationship among path loss, operating frequency and volumetric water content.

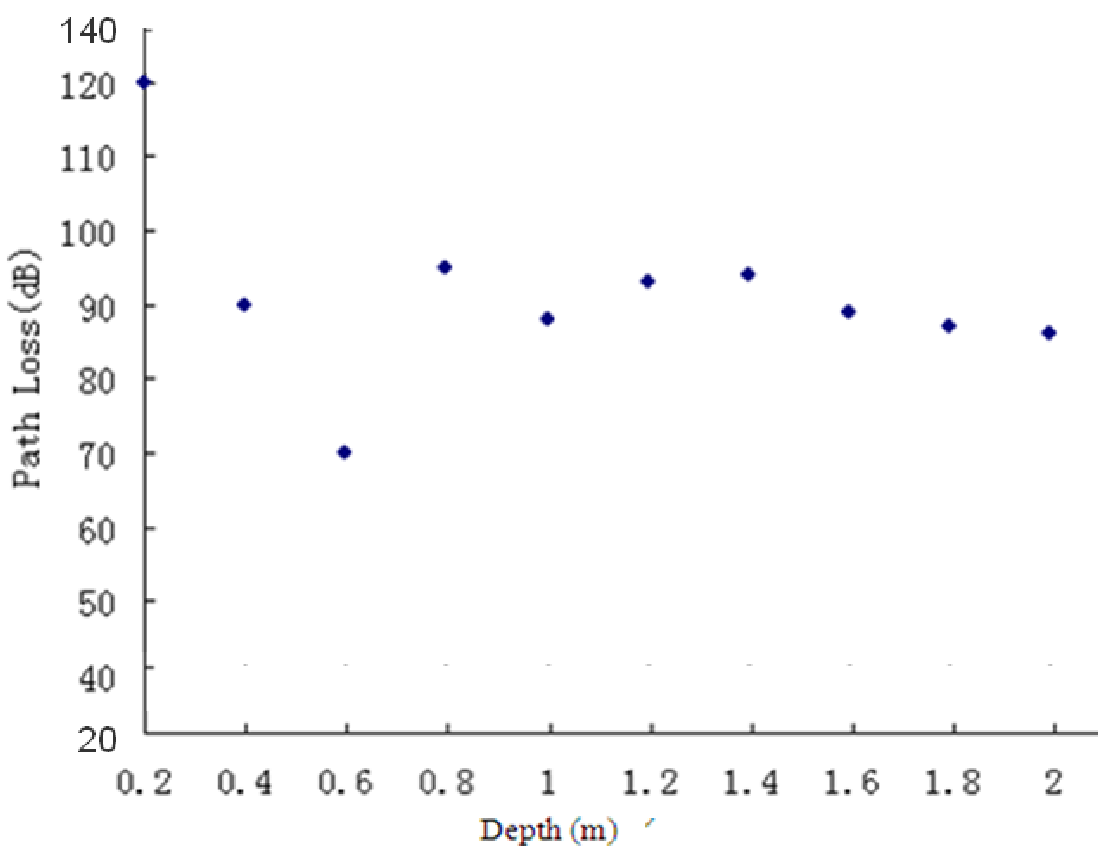

Figure 7. The relationship between path loss and depth.

for a given node deployment, there are the most suitable frequency and buried depth in the hybrid wireless sensor networks.

Conclusions

In this paper, we introduce an advanced network, a hybrid wireless sensor network architecture for agriculture to reduce the intensive human involvement and to improve the accuracy of current agricultural information collection system. An advanced sensor network includes the terrestrial wireless sensor networks and wireless underground sensor networks, which improve the real-time and accuracy of information acquisition. The hybrid WSN architecture combines the advantages of existing sensor techniques. It avoids inconvenient of WSN when WSN is only used and reduce cost of WUSN when WUSN is only used. In particular, the WUSN provides collection functionality when the monitoring area is not in the line-of-sight region of the terrestrial sensor networks; and the mobile sink nodes provide information acquisition capability after they have been collected. The network architecture of the hybrid wireless sensor networks is first described. Moreover, the deployment strategy of the hybrid sensors networks is discussed. Based on the network architecture and deployment strategies, tests of wireless underground sensor networks have been done. Finally, a test bed will be developed and field experiments will be conducted to test the performance of the hybrid wireless sensor networks system in the real agricultural applications.

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