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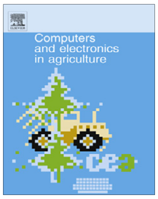

Wireless sensor network coverage measurement and planning in mixed crop farming

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ABSTRACT

Wireless sensor network technology holds great promise for application in agriculture to improve crop yield, improve quality, and reduce costs. This paper presents wireless sensor network coverage measurements in a mixed crop farmland. As one of its key contributions, this study shows that general vegetation attenuation models do not apply to low power wireless sensor networks. A log-linear model is proposed in this paper and validated for application in mixed crop environment. Unlike in mono-crop environment, this study shows that the network coverage is heterogeneous with asymmetric channel between communicating node pair. Crop specific parameters of the log-linear model are derived and used to simulate network coverage in a 7 acre test-bed farm. An adaptive energy consumption model for each sensor node is proposed and used to compute energy consumption in the network. A cluster head and two antenna heights deployment model is also proposed and simulated to alleviate short network lifetime due to vegetation attenuation of signals. The results show that this network deployment model extends the lifetime of the network by a factor of more than 20 compare to a deployment where cluster heads are not used.

1. Introduction

Advancements in electronics and communication have made possible the development of small sensors that can be integrated with miniature communication modules to make up wireless sensor nodes. Short range communication technologies include WIFI, Bluetooth, ultra-wideband and ZigBee. Amongst these technologies, ZigBee is more suitable for wireless sensor network because of its low energy requirements. Studies in (Petrova et al., 2006) show that the IEEE802.15.4 (ZigBee) modulation scheme enables a range extension of up to 8 times for the same amount of energy compared to IEEE802.15.1 (Bluetooth). Although a general purpose technology, one of the areas where wireless sensor network (WSN) is expected to make a global impact is in agriculture (López Riquelme et al., 2009). Food security, urbanization, population growth and climate change have attracted attention not just to food production, but also to food management, transportation, traceability and the need to reduce food wastage. These can be accomplished with the use of wireless systems provided appropriate sensors and controls are implemented.

In crop farming, WSN can be used to monitor and control factors that influence crop growing conditions and yields. They can also be used to determine the optimum time to harvest, which cultivar is more suitable for what condition, detect disease, control machinery, etc. (Camilli et al., 2007; López Riquelme et al., 2009; Abbasi et al., 2011; Díaz et al., 2011; Yu et al., 2013). In animal farming, wireless sensors can be used to monitor animal movement, activities, health condition, numbers, disease, interaction and diversity (Nadimi et al., 2008a,b; Huircán et al., 2010; Zerger et al., 2010; Nadimi et al., 2012). However the biggest impact of WSN in agriculture is expected to be the implementation of semi-autonomous and autonomous controls in farming. They can be used to optimize resources, mitigate the impact of climate change, and reduce cost, labor, and increase productivity.

A good number of studies have been carried out on WSN architecture in agriculture (Díaz et al., 2011). Limited studies have been reported on the models that could be used to deploy these

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networks (Mao et al., 2007; Ndzi et al., 2012a,b; Vougioukas et al., 2012). One of the reasons for the lack of appropriate models is because most crops and environments vary. In addition, the ad-hoc mode of operation of most of these nodes means that researchers have paid very little attention to individual nodes but mainly to the whole network. For precision farming in mixed crop agriculture the performance and reliability of each node is important. This is because different plants have different requirements, root zones/depths, and tolerant periods to adverse conditions before lasting damage occurs or yields are affected. To implement an autonomous system with context-aware sensor fusion and control, network reliability is required. Therefore this paper reports on measurements in a 12 acre farm used as a test-bed for WSN deployment.

Vegetation attenuation models (Qinetiq, 2002) reported in open literature make a number of assumptions. These include the assumptions that the communication system set-up uses the classical master–slave configuration and that one of the antennas is at a higher height or located outside the vegetation. In WSN where nodes operate in a peer-to-peer configuration and sometimes in an ad-hoc manner, very little studies have been carried out to develop appropriate models for network planning. Therefore, this paper evaluates a generic form of one of the vegetation attenuation models (Weissberger, 1982), validates path loss models and proposes appropriate parameters that could be used in the implementation of the models.

This paper is organized as follows; Section 2 describes the WSN device that was used, the measurement set-up and the layout of the agro–farm. Details of the various types of plant are also provided. Section 3 presents the measurement results of signal propagation in the different types of crops. Section 4 presents the path loss models that can be used for wireless network planning. Section 5 describes the node connectivity, network planning and possible performance indicators. It also presents energy consumption modeling in the network and the results from the proposed network deployment topology. Conclusions are drawn in Section 6.

2. System description and measurements

2.1. Measurement system

This study was conducted using wireless sensor devices (motes) from MEMSIC which are equipped with Atmel RF230 radio chip that implements the IEEE802.15.4 standard. In the 2.4–2.5 GHz band there are 16 channels with each channel having a bandwidth of 3 MHz separated by 5 MHz. It is designed to support an effective data rate of 256 kbps. The devices were configured to transmit a total power of 3.2 dBm. The receiver sensitivity is rated as −91 dBm. Omni-directional antennas with gains of 4.3 dBi were used to ensure greater coverage and each mote was powered by 2 AA size batteries (Huircán et al., 2010). Although other systems could have been used, the authors elected to use samples of commercially available WSN devices to ensure that a derived deployment plan is not only feasible but also implementable within a short timescale.

Link estimation is an essential part of network planning, prediction and network protocols development and evaluation. A number of quality measures were specified and are implemented in most of the devices that support the IEEE802.15.4 standard. These include Relative Signal Strength Indicator (RSSI) and Link Quality Indicator (LQI). RSSI gives an estimate of the signal power received and LQI is based on chip error. Studies based on devices that implemented the IEEE802.15.4 reported that RSSI was only reliable for detecting good links and is unreliable at signal values that are close to the limits of the receiver sensitivity (Atmel, 2003). However, Srinivasan and Levis (2006)), used 30 wireless sensor nodes to show that RSSI, for a given link, has very small variation over time and the packet reception rate is at least 85% for signals above the sensitivity threshold of −85 dBm. At smaller signal strengths no correlation between packet reception rate and RSSI which, may be more strongly influenced by system noise, was found. Comparison of LQI and RSSI showed that LQI only offers a better correlation with packet reception rate when averaged over a large number of packets. The study also showed that over a small number of packets, LQI varied over a wide range making it an unreliable parameter for short term measurements.

In general, for communication between two nodes there are three states in wireless links: connected, transitional and disconnected states (Zuniga and Krishnamachari, 2004). In the transitional state, communication links are unreliable and are characterized by large variations in the link quality parameters, such as RSSI.

Based on the studies into the reliability of RSSI and the need for measurements at many positions, measurements reported in this paper use RSSI as a measure of the link quality. The RSSI value of the Atmel RF230 radio device in the IRIS motes is saved as a 5-bit value indicating the receive power from −91 dBm to −10 dBm. RSSI computation in the device does not distinguish between IEEE 802.15.4 signal and other signal sources (Atmel-AT86RF230, 2011). Therefore it is critical to conduct the studies where there are no IEEE802.11 devices. Using the Basic Operating Mode, the relationship between RSSI values, which is updated every 2 μs, and the received signal is given by

$$P_{RF} = RSSI_{Base} + RSSI \qquad (1)$$

where $RSSI_{Base}$ is equal to −91 dBm.

2.2. Measurement environment and set-up

These studies were carried out to understand network coverage in areas cover by the following crops: corn, herbs (Misai Kuching), cashew nut, mango and guava trees. In addition, studies were conducted in open fields in areas with soil and grass covering to establish connection between sensor network cluster heads. Images of some of the areas where measurements were conducted are shown in Fig. 1. Also shown is the partitioning of the crops growing area. The whole 12 acres is not illustrated as part is covered by greenhouses and other buildings.

These areas were selected to provide the generic network coverage models and represent samples of the crops in the farm. Although the WSN deployment will focus on this part in the initial phase, network coverage is planned for the complete 250 acre site. The site includes rubber plantation and natural tropical forest. The study reported in this paper were conducted with the sensor nodes positioned closed to the ground, 15 cm above ground, and at 1 m heights. Whilst WSN coverage can benefit from the nodes being positioned at heights that are above the surrounding vegetation, this will either be cost inefficient or require constant repositioning due to the time variant nature of plant heights.

Different types of plants require different sets of growing conditions. This study is a small part of a bigger research program to better understand plant growth, impact of climate change, productivity and biodiversity. The conditions that will be monitored and controlled require some of the sensors to be placed in the soil. Others sensors will be placed at the base of the crops on the ground and also at trunk and branch heights. The distances between the sensor(s) and the wireless module, and the wireless module and the antenna need to be small to reduce signal losses in the units.

All trees or crops were planted in rows with regular spacing between plants and rows. The number of crop rows per bed