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On the design of beacon based wireless sensor network for agricultural emergency monitoring systems

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ABSTRACT

In this paper, we proposed new sensor network architecture with autonomous robots based on beacon mode for real time agriculture monitoring system. The proposed scheme also offers a reliable association with parent nodes and dynamically assigns network addresses. For the large scale multi-sensor processing, the proposed system accomplished the intelligent database, which generates alert messages to the handheld terminal by means of the fire and air-based sensor data. Thus farmers can easily check out the current conditions of crops and farms at anytime and anywhere. Moreover, we also developed a robot platform with network based mobility function for mobile surveillance.

1. Introduction

Recently, WSNs (Wireless Sensor Networks) [1] and mobile robot technology in agriculture have become one of the most popular technologies for agriculture monitoring systems. In general, WSNs can be widely-used such as agriculture, military, medical and industrial purposes. Among these various fields, agricultural application is considered one of the most promising services for WSN realizations to enhance the food-crop production and reduce burdens of farmers. However, for the deployment of WSN systems for monitoring purpose in agricultural environments, a number of open problems remain. The most representative examples of such problems are as follows.

1) In general, most crops are very vulnerable to weather conditions such as temperature, humidity, intensity of illumination and etc., which is a significant burden for farmers to observe weather conditions every hour and every day. Furthermore, in indoor environments (e.g. vinyl green houses), the occurrence of fire is one of most fatal agricultural disasters. These facts imply that the agricultural WSN system needs to provide real-time monitoring services of whole environmental conditions for improving crop production, plant growth and preventing serious disasters in farms.
2) Recently, due to increased industrial developments, air pollutions and biologically noxious elements (e.g. carcinogenic substance and influenza virus) are prevalent worldwide. Thus, the agricultural monitoring system should not only detect various air pollutions but also report to farmer and related agency from the remote sites for further investigations. Moreover, this critical information needs to be dealt with more emergence processing, which means that the WSN system should provide low latency transmissions with high reliability.
3) The agricultural monitoring system with various sensors should record and store whole measured information to establish an agricultural database system which may provide not only analysis of crop growth but also harvesting prediction by using analyzed patterns of changing conditions in farms.
4) The farmer may use unmanned vehicles or robot systems in order to monitor and patrol the wide farm areas due to manpower shortage. In this situation, the mobile platform needs to communicate with the deployed sensor network to transmit measured data, which means that it becomes a mobile node to join and disjoint the networks. Thus, the monitoring system should support the mobility service for smooth handover and seamless data networking.

Besides the aforementioned requirements, when we deploy WSNs in an agricultural multi-hop environment, several problems can be observed because of limited bandwidth and packet collision by channel interference, and so on. To improve these performance limitations, the authors in [5–7] have proposed an

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efficient beacon based WSN protocols with BOP (Beacon Only Period) and LAA (Last Address Assignment) schemes. However, there is no implementation in real test-bed systems with mobile robots in agriculture and neither do they consider real-time data processing nor the nodes mobility. In this paper, we designed and developed an efficient agricultural WSN monitoring system with an autonomous mobile robot for real-time agricultural emergency message processing applications which can be used to monitor indoor/outdoor disasters such as with fire detectors and atmosphere observation in farms. All sensor and sink nodes are implemented on the TinyOS [2] system which is based on NesC. In addition, we have also developed a new agricultural disaster database system which can process real-time data for emergency applications.

The rest of this paper is categorized into four sections. In Section 2, we review TinyOS architecture for our operating system platform and IEEE 802.15.4 MAC protocol as well as its improved versions with beacon scheduling. In Section 3, we illustrate the detailed design architecture and implementation issues of our agriculture monitoring system. Performance evaluation through operations in real test-bed and simulation is presented in Sections 4 and 5, respectively. Finally, concluding remarks are given in Section 6.

2. Related works

2.1. TinyOS

TinyOS is a free software and open BSD-licensed operating system which is well designed for tiny low-power wireless devices, such as those used in sensor networks, ubiquitous computing, personal area networks, smart buildings, and other smart industrial purposes. It is written in the nesC programming language [3] as a set of cooperating tasks and processes and its programs are built out of software components, some of which present hardware abstractions. Components are connected to each other using interfaces. TinyOS provides interfaces and components for common abstractions such as packet communication, routing, sensing, actuation and storage. TinyOS is completely non-blocking: it has one FIFO (First In First Out) stack. Therefore, all I/O operations that last longer than a few hundred microseconds are asynchronous and have a callback. To enable the native compiler to better optimize across call boundaries, TinyOS uses nesC's features to link these callbacks, called events, statically. While being non-blocking enables TinyOS to maintain high concurrency with one stack, it forces programmers to write complex logic by stitching together many small event handlers. In order to support larger computations, TinyOS provides tasks, which are similar to a Deferred Procedure Call and interrupt handler bottom halves. A TinyOS component can post a task, which the OS will schedule to run later. Tasks are non-preemptive and run in FIFO based scheduling. This simple concurrency model is typically sufficient for I/O centric applications, but its difficulty with CPU-heavy applications has led to the development of a thread library for the OS, named TOSThreads. Fig. 1 shows the overall scheduling policy in TinyOS.

2.2. IEEE 802.15.4 and beacon based protocols

IEEE 802.15.4 [4] intends to offer the fundamental lower network layers of a type of wireless personal area network (WPAN) which focuses on low-cost, low-speed ubiquitous communication between tiny sensor devices. The emphasis is on very low cost communication of nearby devices with little to no underlying infrastructure, intending to exploit this to lower power consumption even more. Networks of IEEE 802.15.4 can be built as either peer-to-peer or star networks. However, every network needs at least one FFD (Full Function Device) to work as the coordinator of the network. Networks are thus formed by groups of devices separated by suitable distances. Each device has a unique 64-bit identifier, and if some conditions are met short 16-bit identifiers can be used within a restricted environment. Namely, within each PAN domain, communications will probably use short identifiers. For the wireless medium access, the MAC layer function, it manages access to the physical channel and network beaconing. However, it has severe limitations by the fact that it supports only 1 hop distance nodes from the FFD, which is not a good solution for multi-hop communication and multi-beacon enabled large mesh networks like agricultural areas. Thus, if we use the original IEEE 802.15.4 in the wireless sensor network with large multiple paths and heavy data traffics, the network may suffer from significant performance degradation such as severe packet collisions, path losses in routing procedure etc.

In order to overcome these limitations of IEEE 802.15.4, the authors in [5–7] proposed the BOP (Beacon Only Period) and the LAA (Last Address Assignment) algorithm for dynamic mesh networks. However, these schemes were not implemented in real test-bed environments and sensor nodes did not support a stable operating system like TinyOS. Another limitation of [5–7] is that they show poor network performance because they do not solve packet collision problems between flooding packets for route discovery and beacon frames. Moreover, they do not suggest actual solution of node mobility support when the application requires seamless data services. Besides, in order to successfully install the wireless sensor network system in real-time monitoring applications such as fire and air pollution detection services, we need an efficient monitoring system which is enabled to process real-time data and communicate with the all sensor nodes in networks. Thus, throughout this paper, we propose a new network architecture for the real-time WSN monitoring system.

2.3. Wireless sensor networks for agricultural purposes

There are many wireless sensor network implementation works which have considered agricultural monitoring requirements in large rural areas. The authors in [8] presented agricultural a WSN application for wine production chain along the different non overlapping areas. They used simple commercial sensor motes and GPRS (General Packet Radio Services) gateways to forward measured data to the remote database server. The user who has a laptop or a PDA device can query the data at anywhere connected to Internet. In [9], an efficient fertigation system based on ZigBee network is developed with sensor motes, mobile terminal, and SQL server. The sensors of this system calls heuristic functions to determine the amount time to open the water value. Then, the remote server can take into account historical runoff water data. The authors in [10] developed an experimental distributed sensor network based on the European ISM band and measured temperature, humidity, solar radiation, rain gauge and etc. This system also has an Internet based remote database system for biological and ecological research analysis. Besides these contributions, a lot of agricultural applications have been proposed to tackle various goals such as climate

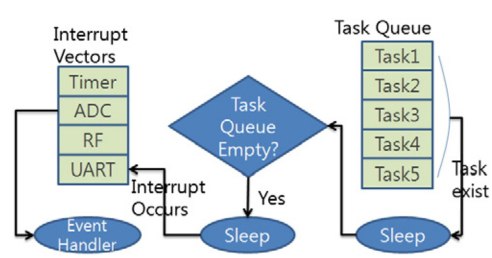

Fig. 1. The scheduling operation in TinyOS.