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A survey for wireless sensor network applications

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Abstract

Wireless Sensor Networks (WSN) are an emerging technology for low-cost with vital applications such as unattended monitoring of a wide range of environmental parameters and target tracking. This has been enabled by the availability, particularly in recent years, of sensors that are smaller, cheaper, and intelligent. These sensors are equipped with wireless interfaces that they can communicate with one another to create a network. The design of a WSN depends significantly on the applications, and it must consider factors such as the environment, the application's design objectives, cost, hardware, and system constraints. This work not only discusses about their potential advantages and disadvantages but also gives an overview of several new applications and identifies the research challenges associated with such applications.

Key Words: Wireless sensor networks; Sensor network services; ZigBee; Sensor network deployment.

I. Introduction

A wireless sensor network (WSN) consists of hundreds to thousands of low-power multi-functional sensor nodes, operating in an unattended environment, and having sensing, computation and communication capabilities. The basic components of node are a sensor unit, a memory, an analog to digital converter (ADC), a central processing unit (CPU), a power unit, and a communication unit [1]. Sensor nodes are Micro-Electro-Mechanical Systems [2] (MEMS) that can sense, measure, and gather information from the environment such as temperature and pressure, and based on some local decision process, they can transmit the sensed data to the user. Since the sensor nodes have limited memory and are typically deployed in difficult-to-access locations, a communication is implemented for wireless communication to transfer the data to a base station (e.g., a personal computer, or an access point to a fixed infrastructure). Battery is the main power source in a sensor node. Secondary power supply that harvests power from the environment such as solar panels may be added to the node depending on the appropriateness of the environment where the sensor will be implemented.

A WSN typically has little or no infrastructure. There are two types of WSNs:

structured and unstructured. In a structured WSN, all or some of the sensor nodes are pre-determined to be placed at fixed locations. The advantage of this network is that fewer nodes can be implemented with lower network maintenance and management cost. An unstructured WSN is one that consist of a dense collection of sensor nodes. Sensor nodes may be randomly placed into the field. In an unstructured WSN, network maintenance such as managing connectivity and detecting failures is difficult since there are so many nodes. The advantages and disadvantages of wireless sensor networks can be summarized as follows:

Advantages:

- Network setups can be done without fixed infrastructure.
- Implementation cost is cheap.
- Ideal for the non-reachable places such as across the sea, mountains, rural areas or deep forests.

Disadvantages:

- More complex to configure than a wired network.
- Lower speed compared to a wired network.
- Easily affected by surroundings (walls, microwave, large distances due to signal attenuation, *etc.*).

The remainder of this work is organized as follows: Section 2 compares the different types of sensor networks. Section 3 surveys several applications of WSN. Section 4 summaries the field and identifies research challenges.

II. Types of wireless sensor networks

Current WSNs are implemented on land, underground, and underwater. Depending on the environment, a sensor network faces different challenges and constraints. There are five types of WSNs: terrestrial WSN, underwater WSN, underground WSN, multi-media WSN, and mobile WSN.

Terrestrial WSNs [3] typically consist of hundreds to thousands of inexpensive wireless sensor nodes deployed in a given area, either in an *ad-hoc* or in a pre-planned manner. In a terrestrial WSN, sensor nodes must be able to effectively communicate data back to the base station and be equipped with a secondary power source such as solar cells.

Underwater WSNs [4][5] contain a number of sensor nodes and vehicles deployed underwater. Autonomous underwater vehicles are used for exploration or gathering data from sensor nodes. As opposite to terrestrial WSNs, underwater sensor nodes are fewer sensor nodes and more expensive are implemented. Typical underwater wireless communications are established through transmission of acoustic waves. A challenge in this type is that sensor node failure due to environment mental conditions. Underwater sensor nodes must be able to self-configure and adapt to harsh ocean environment.

Underground WNSs [6][7] consist of a number of sensor nodes enshrouded underground or in a cave used to monitor underground conditions. Also, sink nodes are placed above ground to relay information from the sensor nodes to the base station. An underground WSN is more expensive than a terrestrial WSN in terms of equipment, maintenance, and deployment. Like terrestrial WSN, underground sensor nodes are equipped with a limited battery power and once deployed into the ground, it is difficult to recharge or replace a sensor node’s battery. Unlike terrestrial WSNs, the deployment of an underground WSN requires careful planning and energy and cost considerations.

Multi-media WSNs [8] consist of a number of number of low cost sensor nodes equipped with cameras and microphones to enable monitoring and tracking of events in the form of multi-media such as video, audio, and imaging. Multi-media sensor nodes are deployed in a pre-planned manner into the environment to guarantee coverage.

Challenges in multi-media WSN include high bandwidth demand, high energy consumption, quality of service provisioning, data processing and compressing techniques, and cross-layer design.

Mobile WSNs consist of sensor nodes that can move on their own and interact with the physical environment. Mobile nodes have the ability sense, compute, and communicate like static nodes. A main difference is mobile nodes have the ability to reposition and organize itself in the network. Information gathered by a mobile node can be transferred to another mobile node when they are within range of each other. Challenges in mobile WSN include deployment, localization, self-organization, navigation and control, energy, maintenance, and data process.

III. Applications of wireless sensor networks

WSN applications can be classified into categories: monitoring and tracing (see Figure 1). While there are many different applications, below we present a few example applications that have been deployed and tested in the real environment.

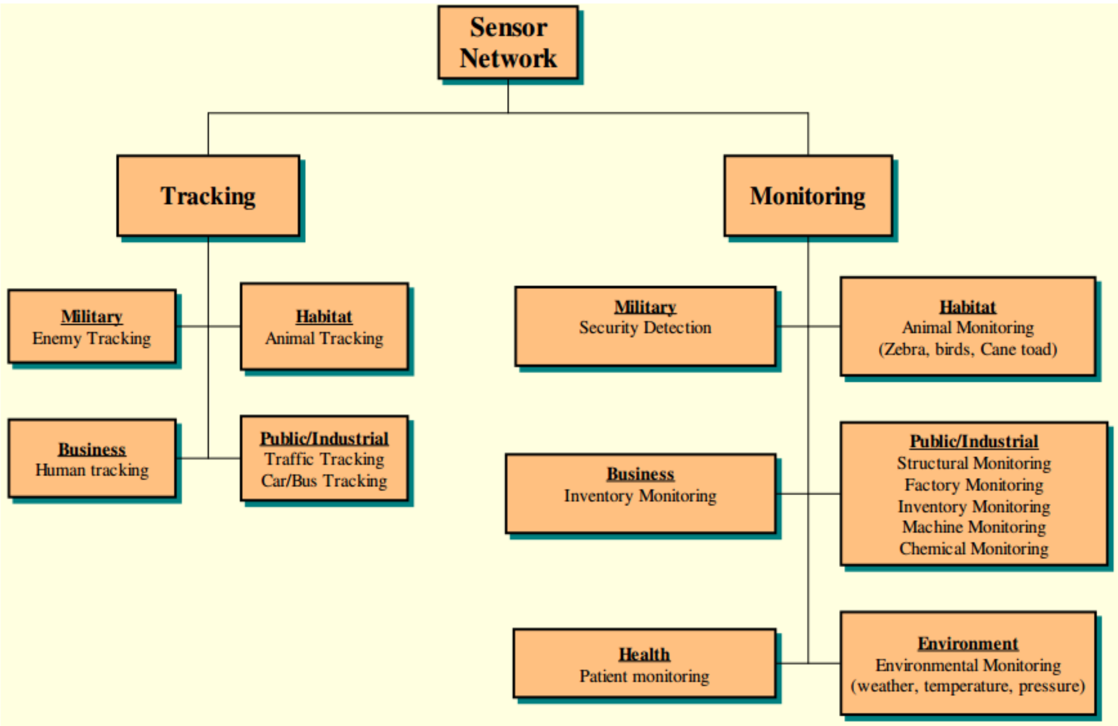

Figure 1. Overview of sensor applications

1. Sensor network based counter-sniper system

PinPtr [9] is an experimental counter-sniper system developed to detect and locate shooters. The system uses a dense deployment of sensors to detect and measure the time of arrival (TOA) of muzzle blasts and shock waves from a shot. Utilizing a message routing service, the TOA measurements are delivered to the base station, typically a laptop computer, where the sensor fusion algorithm calculates the shooter location estimate. The base station also acts as the primary user interface. The hardware of counter-sniper application is built upon the widely used Mica mote platform, developed by UC Berkeley [10]. The motes also have an extension interface that can be used to connect various sensor boards such as photo-, temperature-, humidity-, pressure sensors, accelerometers, magnetometers and microphones. Each multi-purpose acoustic sensor board is designed with three independent acoustic channels and a Xilinx Spartan II FPGA. The Mica motes run a small, embedded, open source operating system called TinyOS by UC Berkeley [11] that handles task scheduling, radio communication, time, I/O processing, etc. The PinPtr application uses several middleware services implemented on TinyOS; the most vital ones being time synchronization, message routing with data aggregation and self-localization.

2. Human-centric search of the physical world

MAX [12] is a system that facilitates human-centric search of the physical world. MAX allows people to search and locate physical objects when they are needed. It provides location information in a form natural to humans with reference to identifiable landmarks rather than precise coordinates. MAX was designed with the objectives of privacy, efficient search of any tagged object, and human-centric operation. To make search efficient, MAX utilizes a hierarchical architecture that requires objects to be tagged, sub-station as landmarks, and base station computers to locate the object. Tags on objects can be marked as private or public which is searchable by the owner only or public. To optimize system performance, MAX is designed for low energy and minimal-delay queries. The implementation of MAX was demonstrated using Crossbow motes where trials were conducted in a room of physical objects.

3. Animal migration tracking

ZebraNet [13] system is a mobile wireless sensor network used to track animal migrations. ZebraNet consists of sensor nodes built into collars on zebras which take positional readings using GPS unit and propagate multi-hop across zebras to the base station. The node is composed of a 16-bit TI microcontroller, 4 Mbits of off-chip flash memory, a 900 MHz radio, and a low power GPS chip. The primary global is to accurately log each zebra's position and use them for analysis. A total 6-10 zebra collars were deployed at the Sweetwaters game reserve in central Kenya to research on the effects and reliability of the collar and to collect some initial zebra movement data. After deployment, the biologists surveyed that the collared zebras were affected by the collars, with additional head shakes from those zebras in the first week. After the first week, the collared zebras showed little difference than the un-collared zebra in terms of behaviors like head shakes, eating, and social grouping. From a collected set of movement data, the biologists can better understand the zebra movements during the night and day.

4. Habitat monitoring applications

PODS [14] is a research project in University of Hawaii that built wireless network of environmental sensor to study why endangered species of plants will grow in one area but not in neighboring areas. Camouflaged sensor nodes, called Pods, are deployed, in Hawaii Volcanos National Park. The Pods consist of a computer, radio transceiver and environmental sensors sometimes including a high resolution digital camera, relay sensor data via wireless link back to the Internet. Energy efficiency is identified as one of the design goals, the lowest-power processors, radios, and an *ad-hoc* routing protocols called Multi-Path On-demand Routing (MOR) were used to computes multiple optimal routes to avoid depleting the energy at any given node. Two types of sensor data are that weather and image data were collected every ten minutes and once per hour, respectively. Bluetooth and 802.11 are chosen as MAC, and users can use Internet to access the data from a server in University of Hawaii at Manoa.

5. *Semiconductor plants and oil tanker application*

This application reported in [15] focus on preventive equipment maintenance using vibration signatures gathered by sensors to predict equipment failure. Based on application requirements and site surveys, an architecture of the network s was developed to meet the application data needs. Two experiments were performed: in a semiconductor fabrication plant and on a board oil tanker in the North Sea. The goal was to reliably validate the requirements for industrial environments and evaluate the effect of the deployment environment on sensor network architecture, including characteristics such as fault tolerance. Also, the work analyzed the impact of platform characteristics on the architecture and performance of real deployment.

6. *Health monitoring applications*

Heath monitoring applications [16] using WSN can improve the existing heath care and patient monitoring. Five prototypes have been designed for applications such as infant monitoring, blood pressure monitoring and tracking, alerting the deaf, and fire-fighter vital sign monitoring. These prototypes used two types of motes: T-mote sky device and SHIMMER (Intel Digital Health Group’s Sensing Health with Intelligence, Modularity, Mobility, and Experimental Re-usability).

Due to many infant die from Sudden Infant Death Syndrome (SIDS) each year, Sleep Safe is designed for monitoring an infant while they sleep. It detects the sleeping position of an infant and alerts parent when the infant is lying on its stomach. Sleep Safe consists of two sensor network motes. One sensor mote (SHIMMER) is attached to the infant’s clothing, while the other (T-mote) acts as a wireless base station to receive and process sensor readings. The SHUMMER mote has a three-axis accelerometer for sensing the infant’s position relative to gravity. The mote’s processor, running a small TinyOS program, periodically sends packets to the base station for processing.

Baby Glove prototype is designed to monitor an infant’s temperature, hydration, and pulse rate, three main health considerations important to development. The device consists of two sensor network motes, once connected to the swaddling wrap (SHUMER) and the other (T-mote) to a base station computer. SHUMMER monitors the vital information coming from the sensors via a ADC, organizes the measurements into packets and transmits them wirelessly to the T-mote for processing. Like Sleep Safe, an alert is sent to the parent if the analyzed data exceeds the health settings.

Heart@Home is a blood pressure monitor and tracking system with a wireless sensor network. It uses a SHIMMER mote located inside a wrist cuff which is connected to an electronic pressure sensor. A user’s blood pressure and heart rate is computed using the oscillometric method. SHIMMER mote records the readings and sends them to the T-mode connected to the user’s computer over the radio. The software application processes the data and provides a graph of the user’s blood pressure and pulse rate over time.

LISTENse is a prototype that enables the hearing impaired with the perception ability of critical audible information in their environment. A user carries the base station T-mote with him. The base station T-mote consists of a vibrator and LEDs. Transmitter motes are placed close to the sound source that can be “heard”. Transmitter motes consist of an omnidirectional condenser microphone. The microphone signal is periodically sampled at a rate of about 20 Hz and compared the sample with a reference value. If the signal is greater than the reference signal, an encrypted activation message is sent to the base station. The base station T-mote receiving and extracting message actives the vibrator and lights up the corresponding LEDs to warn the user. It will stop as soon as the user presses the acknowledge button.

FireLine is a wireless heart rate sensing system that can be used to decrease stress related fatalities and injuries through real-time firefighter health monitoring. FireLine consists of a wireless sensor device (T-mote), a custom-made heart rate sensor board, and three reusable electrodes. All these components are integrated into shirt that a fire fighter will wear underneath all his protective clothing and equipment. The readings are taken from the T-mote is then transferred to another T-mote connected to the base station. The firefighters beat per minute (bpm) are calculated from recorded and processed data by custom software. If the fire's heart rate is to increase or decrease past certain limits, an alert will appear on the laptop.

IV. Conclusion

Unlike other networks, WSN applications are not limited to, environmental monitoring, industrial machine monitoring, surveillance systems, and military target tracking. Each application differs in features and requirements. To support this variety of applications, the development of new communication protocols, algorithms, designs, and services are needed. The deployed applications to date share some common characteristics: raw sensor data transmission over wireless connection, centralized data processing, simple routing scheme, best-effort data transport design. Those applications serve as tested or prototype to identify research challenges, verify proposed methods.

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